DELIVERABLE

D2.8 Standardisation plan - v.2

Deliverable number	D2.8
Deliverable name	Standardisation plan - v.2
Work package	2
Lead partner	+ImpaKT Luxembourg
Contributing partners	Linköping University Interuniversitair Micro-Electronica Centrum
Deadline	31st January 2025
Dissemination level	Public
Date	31.01.2025

Funded by the European Union

Project information

Project summary

Circular economy aims at reducing value loss and avoiding waste, by circulating materials or product parts before they become waste. Today, lack of support for sharing data in a secure, quality assured, and automated way is one of the main obstacles that industry actors point to when creating new circular value networks. Together with using different terminologies and not having explicit definitions of the concepts that appear in data, this makes it very difficult to create new ecosystems of actors in Europe today. This project will address the core challenges of making decentralized data and information understandable and usable for humans as well as machines. The project will leverage open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, as well as a decentralized digital platform that enables collaboration in a secure and privacy-preserving manner.

The project addresses a number of open research problems, including the development of ontologies that need to model a wide range of different materials and products, not only providing vertical interoperability but also horizontal interoperability, for cross-industry value networks. As well as transdisciplinary research on methods to find, analyse and assess new circular value chain configurations opened up by considering resource, information, value and energy flows as an integral part of the same complex system. Three industry use cases, from radically different industry domains, act as drivers for the research and development activities, as well as test beds and demonstrators for the cross-industry applicability of the results. The developed solutions will allow for automation of planning, management, and execution of circular value networks, at a European scale, and beyond. The project thereby supports acceleration of the digital and green transitions, automating the discovery and formation of new collaborations in the circular economy.

Project start date and duration

1st of June 2022, 36 months

Project consortium

No	Partner	Abbreviation	Country
1	Linköping University	LiU	Sweden
2	Interuniversitair Micro-Electronica Centrum	IMEC	Belgium
3	Concular Ug Haftungsbeschrankt	CON	Germany
4	+Impakt Luxembourg Sarl	POS	Luxembourg
5	Circularise Bv	CIRC	The Netherlands
6	Universitaet Hamburg	UHAM	Germany
7	Circular.Fashion Ug (Haftungsbeschrankt)	FAS	Germany
8	Lindner Group Kg	LIN	Germany
9	Ragn-Sells Recycling Ab	RS	Sweden
10	Texon Italia Srl	TEXON	Italy
11	Rare Earths Industry Association	REIA	Belgium

Document reference

Project acronym	Onto-DESIDE			
Programme	Horizon Europe			
Grant agreement number	101058682			
Project URL	https://ontodeside.eu/			
EU Project Officer	Giuseppina LAURITANO			
Project Coordinator	Name	Eva Blomqvist	Phone	+46 13 28 27 72
	E-mail	eva.blomqvist@liu.se	Phone	
Project Manager	Name	Svjetlana Stekovic	Phone	+46 13 28 69 55
	E-mail	svjetlana.stekovic@liu.se	Phone	+46 701 91 66 76
Deputy PC	Name	Olaf Hartig	Phone	+46 13 28 56 39
	E-mail	olaf.hartig@liu.se	Phone	
Deliverable name	Standardisation plan – v.2			
Deliverable number	D2.8			
Deliverable version	2			
Deliverable nature	Report			
Dissemination level	Public			
Due data	31.01.2025			
Delivery date				
Keywords	ontology, decentralized data sharing, circular economy, standards review, standard alignment, interoperability			

Document change log

Version	Date	Description	Authors	Checked by
0.1		Draft to be reviewed	Daryna Panasiuk, Eva Blomqvist, Huanyu Li, Ben De Meester	Caroline Braus, Dominik Campanella, Thibaut Wautelet
0.2		Revision after internal review	Daryna Panasiuk, Eva Blomqvist, Huanyu Li, Ben De Meester	

Document approval

Version	Date	Name	Role in the project	Beneficiary
0.2	28.01.2025	Caroline Braus, Dominik Campanella	Internal reviewer	Concular
1.0	31.01.2025	Eva Blomqvist	Project coordinator	LiU

Table of Content

Acronyms

AMO	Additive Manufacturing Ontology
BCAO	Building Circularity Assessment Ontology
BFO	Basic Formal Ontology
BiOnto	Sustainable Bioeconomy and Bioproducts Ontology
CAMO	Circular Materials and Activities Ontology
CE	Circular Economy
CEON	Circular Economy Ontology Network
CEO	Circular Exchange Ontology
DID	Decentralized Identifier
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik (German Commission for Electrical, Electronic & Information Technologies)
DPP	Digital Product Passport
EMMO	Elementary Multiperspective Material Ontology
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
ISO	International Organization for Standardisation
JSON-LD	JavaScript Object Notation for Linked Data
MDO	Materials Design Ontology
MATONTO	Materials Ontology
MPO	Material Properties Ontology
OWL	Web Ontology Language
PCDS	Product Circularity Data Sheet
PROV-O	Provenance Ontology
RDF	Resource Description Framework
RML	RDF Mapping Language
SPARQL	SPARQL Protocol and RDF Query Language
URI	Uniform Resource Identifier
VC	Verifiable Credentials
W3C	World Wide Web Consortium
WP	Work Package

Summary

Onto-DESIDE focuses on semantic data interoperability for circular economy, integrating ontologies and decentralized data-sharing solutions. The report D2.8 Standardisation Plan (v.2) presents the second iteration of Task 2.4, which aims to map and align project outcomes with existing and emerging technical and circular economy standards. This report aims to:

- **Review standards** that have been published since the previous iteration or are under development in order to complete the review of relevant standards listed in the first report D2.7.
- **analyse the alignment** of the project outcomes with existing and emerging standards
- **outline the contribution** of Onto-DESIDE to standardisation**.**

In the domain of technical standards, no major changes have been observed in core representation languages such as RDF/RDFS and OWL. The ongoing development of RDF 1.2 introduces RDF-star syntax and semantics, which is a non-conflicting extension compared to the current planform set-up. This could also simplify the representation of metadata, including provenance information in ontologies such as CEON. The extension is not integrated in the project due to its ongoing standardisation but its potential impact on future ontology maintenance is recognized. Onto-DESIDE continues to align with W3C best practices for ontology publication and linked data standards, to monitor advancements in decentralized identifiers and Verifiable Credentials.

In the domain of circular economy, the alignment of Onto-DESIDE with ISO 59000 family of standards was analysed. In general, the project is aligned with principles of circular economy provided in ISO 59004:2024. Moreover, the terminology outlined in this standard was partially integrated into ontologies. The Circularity Thinking method developed in WP 5 aligns with ISO 59010:2024, which provides guidance on transitioning to circular business models. The Circular Tracker tool partially aligns with ISO 59020:2024, defining methods for measuring and assessing circularity performance. Onto-DESIDE also uses the Product Circularity Data Sheet (PCDS in its use cases) in WP6, currently under standardisation in ISO 59040, into, reinforcing its commitment to structured and interoperable circularity data sharing.

Beyond aligning with standards, Onto-DESIDE contributes to standardisation. This includes the creation of an ontology for the Product Circularity Data Sheet (PCDS), participation in ISO/TC 323 (Circular Economy) and W3C community groups, and the creation of a W3C community group focused on Circular Economy and Digital Product Passport (DPP).

Some challenges were identified. First one is the misalignment between digital and physical interpretations of concepts in different standards. For example, ISO defines "resource" as a physical asset, whereas RDF employs a broader concept that includes digital entities. Onto-DESIDE addresses this challenge by aligning with ISO definitions where possible while accommodating digital representations to bridge the gap. Second challenge is related to evolving regulatory landscape, particularly the Ecodesign for Sustainable Products Regulation (ESPR) and the forthcoming JTC 24 harmonized standards for Digital Product Passports. The challenge consists in ensuring that project outcomes remain adaptable and compliant with emerging regulations and standards. The project addresses this by prioritizing modularity, scalability, and flexibility in ontology and platform development.

In addition, the document discusses future actions of project members to ensure long-term impact, including continued participation in standardisation efforts, the development of complementary tools for PCDS.

1 Introduction

The Work Package (WP) 2 of the Onto-DESIDE project aims to achieve generalization across three project domains (ontology, decentralized data sharing, and the principles of a circular economy) and three use case domains (construction, electric and electronic equipment, and textile). It ensures that the project addresses a comprehensive set of requirements that not only meet the specific needs of all these use cases but are also sufficiently versatile to be applicable in other industries.

One of the tasks of the WP2 is to formulate a standardisation plan and to identify the standardisation needs. The review of standardisation and legislative context is pivotal in addressing the multiple topics addressed in Onto-DESIDE: development of ontologies and data-sharing platform in the context of circular economy. The development of ontologies requires modelling a diverse array of topics, e.g. materials and products as well as actors and processes, ensuring both vertical interoperability within industries and horizontal interoperability across different industry networks. This requires compliance with established standards in modelling and data sharing.

The review of legislation and standards is crucial for the development of a data sharing platform as it ensures legal compliance, data security, and interoperability. It helps create a framework that promotes trust among users, facilitates cross-industry data exchange, and supports the platform's alignment with industry best practices and regulatory requirements.

In the context of circular economy, the review of the legislation is necessary for guiding and enforcing sustainable practices, while standards offer guidelines and benchmarks for implementing effective and consistent methodologies. The utilization of three industry use cases also necessitates a comprehensive understanding of industry-specific standards and regulations.

1.1 Objectives of task 2.4

The objective of the Task T2.4, Standardisation, is to 1) map the existing standards landscape, both for the overall project domain, as well as the specific use case domains (construction, electronics and textile), and 2) develop a standardisation plan for the project outcomes.

The task consists of two iterations, each serving a distinct purpose.

1) **The first iteration** aims to provide a comprehensive overview of existing standards that the project will align with and leverage. This includes standards within the project domain, such as ontology, decentralized data sharing, and circular economy. Additionally, the first iteration covers specific use cases related to construction, electronics, and textiles. Furthermore, an introduction to the legislative context is also provided to ensure a comprehensive understanding of the legal framework within which these standards operate. The identified standards are analysed for their alignment with relevant EU regulations and policies.
2) **The second iteration** of the task expands the initial overview of standards by incorporating emerging ones and developing a standardisation plan for the project ontologies and protocols. The inclusion of emerging standards aims to facilitate the adoption and utilization of the project outcomes in various industry domains. Furthermore, the second iteration will analyse future standardisation needs and outline a roadmap for achieving standardisation beyond the project timeline.

1.2 Introduction to deliverable

This report presents the outcomes of the second iteration of T2.4, Standardisation. The objective of this deliverable is threefold:

- Review standards that have been published since the previous iteration or are under development in order to complete the review of relevant standards listed in the first report D2.7.
- analyse the alignment of the project outcomes with existing and developing standards.
- outline the contribution of the Onto-DESIDE project to standardisation.

2 Update of Standards review

This section provides an updated review of standards relevant to the scope of Onto-DESIDE project. It includes standards that either were published after the completion of the D2.7 report or were previously not identified. This updated review focuses on identifying newly emerged standards that could influence or be integrated with the Onto-DESIDE activities to ensure that the standardisation alignment (section 4) considers the latest developments.

2.1 Ontologies

Regarding technical standards, there are no significant updates since the first version of this deliverable, i.e. the representation languages (RDF/RDFS, OWL) are the same, and no new guidelines or best practices have emerged. There is however, an ongoing standardisation process aiming towards a new version of the RDF standard, which will include the recently proposed RDF-start extension (c.f. https://w3c.github.io/rdf-star/cg-spec/editors_draft.html). RDF-star introduces the notion of nested triples into RDF, allowing to annotate single triples with metadata, similar to what is possible with other graph formats, such as labelled property graphs. This introduction could in the future mean an easier way to annotate single triples with for instance an issuing date, an author, and similar metadata. This might reduce the need for using the PROV-O for provenance metadata of RDF datasets and could impact the way that CEON (the ontology network developed in Onto-DESIDE) should model such metadata. However, since this standard is not yet in place, we have chosen not to apply the RDF-star extension in the project. It could however impact the CEON maintenance in the future and will be discussed more in-dept in the ontology maintenance plan, delivered in WP3.

Regarding related ontologies, which are commonly not standards per-se but important related work, WP3 has conducted a survey of related ontologies. The list of such ontologies is being regularly updated, and is maintained in our GitHub repository (c.f. https://github.com/LiUSemWeb/Circular-Economy-Ontology-Catalogue). In section 4.1 of this deliverable, we describe the work of analysing these ontologies, and their relations to CEON, in terms of alignments and gaps that CEON is filling. While there are also several other standards that relate to ontologies, such as the IoT and digital twin standards of ISO/IEC JTC 1/SC 41, these mainly specify terminology and abstract guidelines of creating and using ontologies, rather than providing specific ontologies. In addition, for this specific example of ISO/IEC JTC 1/SC 41, digital twins are assumed to use sensors and IoT technology. For the purpose of this project, we are not studying IoT-based digital twins, but rather digital twins of a value network, and thus those standards are not directly applicable.

2.2 Platform

Concerning **Identifiers**, we continuously monitored emerging standards, or standard updates. Notably, we reviewed the W3C DID Working Group to make sure our work remains aligned with emerging actor identification standards. Notably, we reviewed following new standards and identified no conflicts with our current solution

- Sporny, M., & Sabadello, M. (2024). DID Document Property Extensions [W3C Note]. W3C. https://www.w3.org/TR/2024/NOTE-did-extensions-properties-20241119/

- Sporny, M., & Sabadello, M. (2024). DID Methods [Techreport]. W3C. https://www.w3.org/TR/2024/NOTE-did-extensions-methods-20241119/
- Sporny, M., & Sabadello, M. (2024). DID Resolution Extensions [Techreport]. W3C. https://www.w3.org/TR/2024/NOTE-did-extensions-resolution-20241119/

Concerning **Data Carrier**, our active participation in the W3C RDF-Star Working Group ensures that the evolution of RDF (v1.2) is closely monitored and up to now, no conflicts with our current Platform's technical set-up have been identified. The minor version change mostly involves the addition of RDF-Star syntax and semantics, which is a non-conflicting extension compared to our current set-up

- Seaborne, A., Champin, P.-A., Hartig, O., & Kellogg, G. (2024). RDF 1.2 Concepts and Abstract Syntax [W3C Working Draft]. W3C. https://www.w3.org/TR/2024/WD-rdf12-concepts-20241121/ . See https://www.w3.org/groups/wg/rdf-star/publications/ for a more detailed publications list.

Concerning **Data quality**, an extension to the Verifiable Credentials standard was introduced, which, after review, showed no conflicts with our current set-up

- Sporny, M. (2024). Verifiable Credential Extensions [Techreport]. W3C. https://www.w3.org/TR/2024/NOTE-vc-extensions-20240930/

Concerning **Protocol**, our active participation in the W3C Knowledge Graph Construction Community Group makes sure our platform's technical solution remains aligned with ongoing advancements. Onto-DESIDE-specific challenges have been proposed as extensions to the RML community group standard.

- https://rml.io/specs/target/dynamictarget/20241212/
- https://rml.io/specs/access/httprequest/20241212/

The Solid protocol community efforts have materialized in a W3C Working Group named Linked Web Storage. We actively participate in that working group to make sure Onto-DESIDE-specific challenges are considered during standardisation.

- https://www.w3.org/groups/wg/lws/

Finally, our active participation in the W3C RDF-Star Working Group ensures that the evolution of SPARQL (v1.2) is closely monitored and up to now, no conflicts with our current Platform's technical set-up have been identified. The minor version change mostly involves addition of RDF-Star syntax and semantics, which is a non-conflicting extension compared to our current set-up

- Tanon, T. P., Seaborne, A., & Taelman, R. (2024). SPARQL 1.2 Update [W3C Working Draft]. W3C. https://www.w3.org/TR/2024/WD-sparql12-update-20241113/. See https://www.w3.org/groups/wg/rdf-star/publications/ for a more detailed publications list.

Concerning **Cybersecurity**, the Solid protocol community efforts have materialized in a W3C Working Group named Linked Web Storage. We actively participate in that working group to make sure Onto-DESIDE-specific cybersecurity challenges are considered during standardisation.

2.3 Circular economy

Since the first version of this deliverable, the International Organization for Standardisation (ISO) Technical Committee (TC) 323 has published ISO 59000 family of standards, designed to ensure the transition to a circular economy:

- ISO 59004:2024 Circular economy — Vocabulary, principles and guidance for implementation.
- ISO 59010:2024 Circular economy — Guidance on the transition of business models and value networks and associated technical document ISO/TR 59032:2024 - Circular economy. Review of existing value chain networks
- ISO 59020:2024 Circular economy - Measuring and assessing circularity performance.

Two ISO standards are in the draft stage:

- ISO 59040 Product Circularity Data Sheet

- ISO 59014:2024 Environmental management and circular economy — Sustainability and traceability of the recovery of secondary materials — Principles, requirements and guidance

ISO 59004:2024 defines terms and concepts, a vision for a circular economy, and its core principles. The vocabulary is particularly relevant for Onto-DESIDE as a source of unified definitions for ontologies. Core principles of circular economy are relevant for the method and associated tools developed in WP5 and applied to use cases in WP6.

ISO 59010:2024 focuses on business-oriented strategies to implement circular economy practices at both organisational and inter-organisational levels. It provides guidance on setting goals and boundaries, developing circularity strategies, transitioning to value creation model or value network, reviewing and monitoring for continuous improvement. The objective of the standard is to provide a structured approach to shift from linear to circular value creation models, which is similar with the method developed in WP5 and thus will be addressed in the section 4 “Alignment with Standards”.

ISO 59020:2024 "Circular economy - Measuring and assessing circularity performance," provides a framework for the evaluation of circularity performance at different levels of economic systems, e.g. regional, inter-organizational, organizational, and product. It standardises the process of the definition of system boundary, choice of indicators and associated data collection, circularity assessment and reporting. For the Onto-DESIDE project, the content of this standard is relevant due to its focus on structured data collection. Additionally, it focuses on the circularity performance evaluation, which aligns with one of objectives of the deliverable D6.9.

A forthcoming ISO 59040 provides a standardised framework for documentation and sharing data related to circularity of products. PCDS outlines a structured way to collect, organize and share data on the lifecycle of a product. It covers data attributes related to material composition, resource recovery potential, recyclability, durability and lifetime extension aspects (repairability, disassembly potential, etc.), hazardous substances, renewable energy and water recirculation in production and intended end-of-life management. It is designed to enable transparency and interoperability across value chains. Documenting and sharing circularity data is addressed in Onto-DESIDE; moreover, PCDS is incorporated into use cases (D6.6), underlining the relevance of this standard.

Thus, ISO 59000 family is used to analyse alignment of OntoDeside project in the section 4 of the report.

In January 2025 German Institute for Standardisation (DIN and the German Commission for Electrical, Electronic & Information Technologies (DKE) released a specification DIN DKE SPEC 99100 “Requirements for data attributes of the battery passport”. It was developed by the Battery Pass consortium in cooperation with public industry consultation. The specification builds on the “Content Guidance for the EU Battery Passport” and defines data requirements for the battery passport, a digital tool imposed by the EU Battery Regulation. The specific focus on battery data limits direct applicability for Onto-DESIDE, which addresses construction, electronics, and textiles. However, EU is planning to the define the information requirements of DPP in these three industries by 2026, thus the principles employed in DIN DKE SPEC 99100 for defining data attributes and aligning with standards potentially valuable as a reference.

In this context, the categories of data proposed for product passports are interesting as they provide context and might influence the development of DPPs in textiles, electronics, and construction. It is reasonable to expect similar categories will be applied across these industries in the future. The specification also highlights standards to be applied for data attributes, including identifiers for products, operators, and manufacturers, as well as standards for date format. While these insights provide useful background, they do not directly affect the outcomes of the Onto-DESIDE project. Since Onto-DESIDE is not a DPP project, selecting specific data attributes and performing alignment analyses with this specification fall outside the project’s scope.

In the domain of construction, the work of CEN/TC 350/SC must be closely monitored. CEN/TC 350/SC refers to a subcommittee (SC) under Technical Committee 350 (TC 350) of the European Committee for Standardization (CEN). It focuses on the standardization of circular economy

principles, guidelines, and requirements for the built environment, covering the entire lifecycle from design to deconstruction and end-of-life. CEN/TC 350 is responsible for developing standards that assess the sustainability of buildings and infrastructure, including life cycle assessment (LCA), circularity, and environmental performance metrics. The subcommittee has not yet published a standard. Monitoring the upcoming standards developed under CEN/TC 350/SC would allow to assess the interoperability between Onto-DESIDE and construction industry circularity standards.

3 Alignment with Standards

In this section we present the various alignments that have been made in order to make sure the project outcomes are in line with, and explicitly refer to, existing relevant standards.

3.1 Ontologies

In this section we describe how the standards mentioned inn D2.7 have been implemented, used, or aligned with, in the ontologies developed by the project (the Circular Economy Ontology Network - CEON). Overall, the ontologies use established W3C standards for their representation, including some standards or de-facto standards for representing certain aspects, such as ontology metadata. In addition, we describe how other existing ontologies are related to our ontology network.

3.1.1 Standard Representation Languages and General Ontologies/Vocabularies

The project uses the widely recognised W3C standards RDF (Resource Description Framework) and OWL (Web Ontology Language) for representing the ontology network. This is in line both with how Web-based data sharing is intended to be set up in general, i.e. according to W3C best practices for the web, as well as in line with European efforts such as the EOSC, recent advances on infrastructure for data spaces, as well as FAIR principles.

RDF is a framework for representing data and information on the Web using a graph-based data model where data is represented as a set of triples in terms of subject, predicate and object. The main RDF standard is "*RDF 1.1 Concepts and Abstract Syntax"* [Beckett et al., 2014] that introduce the basics of RDF, with additional standards on data serialization formats such as the turtle format, which is used in our project.

OWL provides a formal way to define semantics (meaning), for instance describing classes of data entities and relationships between data elements. OWL 2 ontologies can be used along with information represented in RDF by reusing some RDF vocabularies and OWL 2 ontologies are primarily exchanged as RDF documents [W3C, 2012]. The main OWL standard is "OWL 2 Web Ontology Language Structural Specification and Functional-Style Syntax (Second Edition)" that defines the OWL 2 language.

In addition to the RDF and OWL related standards, we use the Dublin Core (ISO 15836-1:2017) to define the metadata for our ontology network. Dublin Core includes a vocabulary for defining basic metadata and has been published as an RDF vocabulary. Each ontology module in our ontology network is annotated with these metadata elements, for describing things such as the authors and contributors of the module, its creation date, license etc.

Moreover, we reuse or align with other W3C recommended general ontologies or ontologies that have gained well development though community-based efforts. These ontologies include for instance, the PROV-O ontology standardised by W3C for representing provenance information that we aligned with our ontology network. The Time ontology as a candidate standard of W3C where we plan to reuse relevant concepts and relationships in our ontology network. The GeoSPARQL ontology which is a standard to represent geospatial information proposed by the Open Geospatial Consortium. We reuse some relevant concepts and relationships from the GeoSPARQL ontology.

In addition to follow standards for developing ontologies or representing data, or community-efforts on developing ontologies, we follow closely the W3C working group in which good practices can be noted. For instance, working group summarised the best practice recipes for publishing RDF vocabularies which are aligned with our process for ontology publishing.

3.1.2 Related domain ontologies

In the first iteration of the project, we conducted a comprehensive survey of related ontologies for the circular economy domain [Li et al., 2023] identifying 37 ontologies totally across 6 topics (4 for circular economy, 6 for sustainability 9 for materials, 15 for manufacturing, 10 for products, 8 for logistics and EMMO as a general upper-level ontology). Detailed survey result has been presented in Deliverable 3.2.

We noted that not many core ontologies for CE can be found when we conducted the ontology survey. Most target very specific use cases in specific industry domains. The 5 CE related ontologies are Circular Materials and Activities Ontology (CAMO), Circular Exchange Ontology (CEO), Building Circularity Assessment Ontology (BCAO), Sustainable Bioeconomy and Bioproducts Ontology (BiOnto), and DPP Ontology (DPPO).

The Materials module in CEON reuses material-related concepts from the top-level ontology EMMO (Elementary Multiperspective Material Ontology). This allows for modelling of materials at various levels of granularity. Our ontology survey includes 9 materials related ontologies. In the initial alignment work in [Li et al., 2024], aligning CEON and materials ontologies is one sub-task of task b. These 9 ontologies are AMO (Additive Manufacturing Ontology), BUILDMAT, BWMD-Domain, CAMO, IOF-core, MATONTO (MatOnto Ontology), MDO (Materials Design Ontology), MPO (Material Properties Ontology), and NMRVOCAB.

AMO models materials with respect to manufacturing processes and physics-based models. BWMD-Domain shares a similar focus, modeling materials in manufacturing contexts. BUILDMAT models materials and related concepts within the building domain. IOF-core defines general materials which can be inputs of manufacturing processes. MATONTO and MPO both focus on modeling materials properties. In addition, MPO also includes a modeling of building components (e.g., layer and layer set). MDO also reuses the material concept from EMMO, focusing on representing structures and properties information that can be inputs or outputs of material calculations.

3.1.3 Alignment to related domain ontologies

In addition to this survey, we aligned CEON v1.0 with the aforementioned 37 ontologies. The initial alignment outcomes, based on our research detailed in [Li et al., 2024], are also documented in Deliverable 3.4. In [Li et al., 2024], we introduced a pipeline for producing ontology alignments (Figure 1). The alignment process was divided into three tasks:

1. Aligning circular economy-related ontologies (Task A).
2. Aligning CEON with industry-specific domain ontologies (Task B).
3. Aligning CEON with top-level ontologies, such as EMMO (Task C).

This section highlights results specific to circular economy (CE) and materials ontologies.

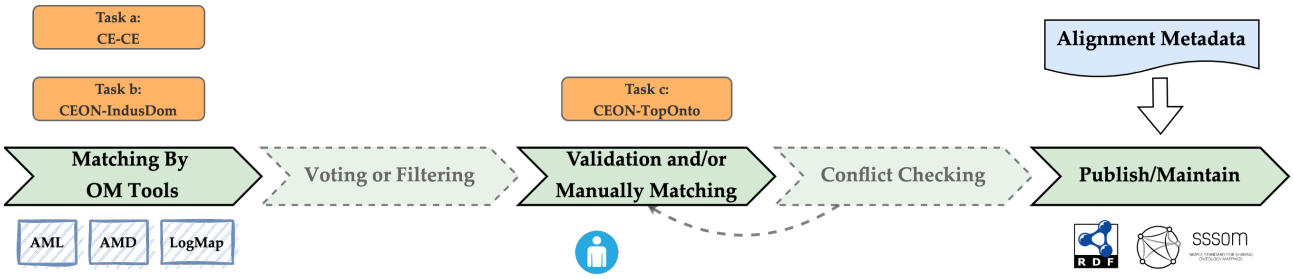

FIGURE 1 ONTOLOGY ALIGNMENT PIPELINE IN WP3

3.1.3.1 Relation to CE and materials ontologies

Alignment results between CEON v1.0 and CE related ontologies (5 CE related ontologies):

The initial alignment results are available at https://github.com/LiUSemWeb/Circular-Economy-Ontology-Catalogue/tree/main/alignments/task_a. Both CAMO and CEO define core concepts such as "Resource," "Product," and "Activity," which are commonly used in CE. However, both ontologies have a specific focus on the construction domain. CEO reuses existing ontologies, such as GeoSPARQL, while CAMO categorizes materials, products, and activities specific to CE. Following the pipeline (Figure *), 10 common mappings between CEON and CEO were generated. After user validation, 4 equivalence mappings were confirmed: "Product," "Resource," "Activity," and "Location." Similarly, 9 common mappings were identified between CEON and CAMO, with 4 validated as true. These involve concepts like "Material," "Actor," "Activity," and "Agent."

Nevertheless, there are a few more ontologies that deal with CE, targeting more specific use cases. BCAO targets the construction industry by linking data from different manufacturers to support circularity-focused decision-making. For example, BCAO models a product as being made of materials produced by an organization, a representation versatile enough to be applied to other industries. The alignment process generated 4 common equivalence mappings between CEON and BCAO. Two mappings related to "Product" and "Material" concepts, while the other two described relationships associated with products. However, since BCAO focuses on building-related products and materials, these mappings were deemed subsumption mappings rather than equivalence mappings, as CEON's concepts are more generic.

Further, BiOnto from the BIOVOICES project, aims to build a shared and common terminology in the bioeconomy domain so that multiple different stakeholders can provide information according to the ontology. There are 37 common equivalence mappings generated by the three matching systems between CEON and BiOnto of which 18 are validated as true by. user validation. These mappings covered concepts such as "Material," "Chemical Substance," "Process," "Product," and "Resource." Additionally, both ontologies reuse the Provenance Ontology, which contributed to several equivalence mappings due to their similar modelling approaches.

The last relevant CE ontology is DPPO (Digital Product Passport Ontology) which focuses on representing product lifecycle information. There are 14 common equivalence mappings generated by the three matching systems in which 6 are validated as true. These mappings are about "Actor", "Product" concepts and their related relationships.

Based on the abovementioned alignment results among CE ontologies at the concept and relationships level, we can summarise that most CE-related ontologies (including CEON) are developed with focuses on use cases while CEON intends to model general domain knowledge in CE, particularly for CVNs where CE requirements are derived not only from the CE perspective but also the perspectives of three use cases: textiles, electronics, and construction. This positioning makes CEON a more general ontology than the other CE-related ontologies, given its potential for reuse across different scenarios. This is due to the fact that our project research methodology is built

upon both CE and use cases perspectives, and our ontology engineering methodology is grounded in modular modelling and agile development. In our modular organized ontologies, CE-related domain knowledge is represented in several topics with their own modules (such as process, materials, resource and value). The three use cases have specific own domain ontologies which reuse CEON for their own CE purposes. In such a way, other domains, for instance biomaterials and plastics, can have their own ontologies representing domain knowledge and connect/reuse CEON for CE purposes

Alignment results between CEON v1.0 and materials related ontologies:

Equivalence mappings for the "Material" concept were identified in alignments between CEON and eight of the nine ontologies (excluding NMRVOCAB). However, broader overlaps in the materials domain were limited. For instance, AMO and CAMO (equivalence mappings on Material concept only), BUILDMAT (equivalence mappings on Material and Constituent concepts, respectively), MDO and MPO (equivalence mappings on Material and Composition concepts, respectively), MATONTO (equivalence mappings on Material and ChemicalSubstance concepts, respectively). These variations are understandable, as most ontologies focus on specific domains where material-related concepts play roles in particular processes or contexts. In addition, given that quite a number of top-level ontologies such as EMMO and Basic Formal Ontology (BFO) have detailed modeling of materials, many ontologies reuse or connect to such top-level ontologies for using materials related concepts. For instance, CEON reuses the Material and Matter related concepts from EMMO, BWMD-Domain, IOF-core reuse BFO. MDO, MPO and MATONTO are those ontologies have more focus on modeling materials structures or properties. Another observation is that several ontologies, such as IOF-core, MATONTO, and BWMD-Domain, model materials from the perspective of entities, actors, and roles rather than focusing solely on physical or philosophical attributes.

We emphasise that, despite the existence of numerous materials-related ontologies, there is no consensus on a standardised approach to representing materials domain knowledge. For instance, on one hand, people may prefer to develop specific domain ontologies tailored to their use cases (such as MPO and MDO). On the other hand, others may particularly focus on foundational and philosophical models aiming for broad coverage (such as BFO), or like EMMO from the applied sciences point of view. Consequently, in our work, for the materials related domain knowledge, we decided to follow EMMO and reuse relevant concepts and relationships. This approach provides us with the flexibility to model knowledge that directly reflects application scenarios while also allowing us to use materials-related knowledge as much as represented in EMMO. This enhances the interoperability of our ontologies.

3.2 Decentralized data-sharing platform

The platform currently makes use of the following standards.

For **Identification**, we use the Uniform Resource Identifiers (URI) standard as identifiers, and the Solid WebIDstandard – aligned with the Decentralized Identifiers (DID) standard – as identity document.

For **Data Structure**, we use the Resource Description Framework (RDF) standard which has multiple serializations standardized (e.g. RDF/XML, JSON-LD, Turtle).

For **Data quality**, we provide verification mechanisms using the Verifiable Credentials (VCs) standards.

For **Exchange protocol**, we provide data conversion using the W3C Community standardized RDF Mapping Langugage (RML), data exchange using the Solid Protocol and Linked Data Platform standards, and data querying using the SPARQL Query Language standard

For **Cybersecurity / governance**, we provide authentication using the (Solid-)OIDC OAuth 2.0 standard, and authorization according to W3C Community standardized Web Access Control.

Being part of imec, we follow a large set of quality and integrity policies (https://www.imec-int.com/en/about-imec/quality-and-integrity-policies-imec), based on ISO 27000 series and NIST 800-53. This includes the protection of personal data in cloud computing services. As the Onto-DESIDE set-up are demonstrated using either dummy or public data, no additional protection is currently needed.

3.3 Circular Economy

The following methodology is applied to analyse the alignment of project's outcomes with identified relevant standards:

- Outline clauses, criteria and/or requirements within each standard that apply to the project's scope.
- Determine which parts of the project activities and elements each standard affects. Different elements of the project are considered, such as ontologies, data collection, Circular Value Network Design & Development, evaluation activities, etc.
- Maps each project element or deliverable to the relevant specific sections or clauses of the standards.
- Identify areas where the project aligns, partially aligns, or does not align with the standards.
- Define the significance of each identified gap for the project's objectives.

In the Onto-DESIDE project, circular economy is a foundation that is integrated in different aspects of the project. It guides the work in multiple project domains, including the development of ontologies, data collection, tools supporting decision-making and evaluation of use cases outcomes. Thus, it is important to analyse the alignment with the ISO 59000 family. As for other identified standards within the circular economy domain and listed in the D2.7, they are related to data attributes listed in the user stories and are not impacting project outcomes. The summary of the alignment between project elements and relevant clauses of standards is provided in Table 1.

Circular economy principles outlined in ***ISO 59004:2024*: *Circular Economy — Vocabulary, Principles, and Guidance for Implementation*** are integral part of the project, since they are fully in line with the objectives of Onto-DESIDE to develop ontology and Open Circularity Platform for decentralized data sharing.

Circularity Thinking method (WP5) is a structured method that is looking into opportunities for a systemic shift, in how resources are managed, products designed, and the value is created (e.g. reverse logistics, ecodesign) and retained (e.g. reuse, repair). Circularity Thinking draws on the experience of numerous businesses and addresses circular economy by "following the flows" of materials and resources. It focuses on uncovering waste within systems and identifying opportunities to create value for companies and their stakeholders. This method and associated tools emphasize the importance of systems thinking to address the complexity of circular economy, considering the interactions across value chains. This is aligned with circular economy principles outlined in ISO 59004. Moreover, the use WP5 tools (Circularity Compass, Value Chain Activity Cycle, Multi Flow method) by members of WP6 use case is in line with principles of system thinking, value creation, value sharing and resource stewardship. Resource traceability principle is reflected in structured data collection and project objective for decentralized data sharing.

The project's ontology incorporates key definitions from ISO 59004:2024 using semantic constructs to ensure interoperability and consistency of the vocabulary. However, the ontology integrates only the most relevant definitions from the standard. It prioritized terms relevant to project's objectives and applicable across its multidisciplinary scope. In accordance with the categories defined in the standard, the ontology includes the following definitions:

- Terms related to a circular economy: resource, value;

- Terms related to solutions: solution, product;
- Terms related to organizations and other interested parties: organization, stakeholder
- Terms related to value creation models and design and development: value network, process.

TABLE 1 - SUMMARY OF THE ALIGNMENT STATE BETWEEN RELEVANT CLAUSES OF THE STANDARDS AND PROJECT ELEMENTS

Standard	Title	Relevant content	Concerned project output	Alignment status
ISO 59004:2024	Circular economy — Vocabulary, principles and guidance for implementation.	Terms related to circular economy	WP3 Ontology: Resource ODP (Concept “Resource”), Value module (Concept: “Value”)	Aligned
		Terms related to solutions	WP3 Ontology: Product module (Concepts “Solution” and “Product”)	Aligned
		Terms related to resources	WP3 Ontology:	Aligned
		Terms related to organizations and other interested parties	WP3 Ontology: Actor module (Concept “Organisation”, “Stakeholder”	Aligned
		Terms related to value creation models and design and development	WP3 Ontology: Circular Value Network module (Concept “value network”), Process ODP (Concept “Process”)	Aligned
		Circular economy principles: - system thinking, - value creation - value sharing, - resource stewardship - resource traceability	- objectives of the Onto-DESIDE (ontology, decentralized data sharing platform) - WP5 (Circularity Thinking method and its tools) - WP6 - implementation of Circularity Thinking tools (D6.1 – D.6.3): Circularity Compass, Value Chain Activity Cycle, Multi Flow method; - structured data collection (D6.4-D6.6) - Circular Tracker tool (D6.9)	Aligned
		Actions that contribute to a circular economy	WP5 (Circularity Thinking method)	Aligned
ISO 59010:2024	Circular economy — Guidance on the transition of business models and value networks and associated technical document	Setting goals for the transition to a circular economy (Clause 4): goal definition	WP5 (Circularity Thinking method)	Aligned
		Clause 4: Mapping the value chain and networks of flows	WP5 (Circularity Thinking method)	Aligned
		Clause 4: Setting the boundary for addressing circularity	WP5 (Circularity Thinking method)	Aligned
		Clause 4: Considering actions that contribute to a circular economy	WP5 (Circularity Thinking method)	Aligned
		Determining a circular economy strategy (Clause 5): Identifying gaps and opportunities	WP5 (Circularity Thinking method)	Partially
ISO 59020:2024	Circular economy — Measuring and assessing circularity performance	Circularity measurement and assessment principles - Ensure relevant boundaries - Ensure meaningful outcome	Circular Tracker tool	Aligned
		Circularity indicators	Circular Tracker tool	Not aligned
ISO 59040	Product Circularity Data Sheet	documentation and share of circularity data	WP6: data collection	

ISO 59010:2024 Circular economy — Guidance on the transition of business models and value networks provides a framework for implementing circular economy principles at both organizational and inter-organizational levels. It outlines the following key steps (Figure 2):

- Setting Goals and Boundaries (Clause 4)
- Determining a Circular Economy Strategy (Clause 5)
- Transitioning Toward Circularity (at the organizational level (Clause 6) and the network level (Clause 7))
- Reviewing and Monitoring (Clause 8)

The Circularity Thinking method used in WP5 and ISO 59010:2024 share the same objective of identifying and implementing strategies that enable circularity within organisations and systems, but they differ in their application. The alignment analysis is limited only to efforts and tasks performed in the context of the Onto-DESIDE project, since the Circularity Thinking method has a broader scope than applied in the project. WP5 contribution can be positioned as a bridge between exploratory stage (Clause 4) and implementation phases (Clauses 6 and 7). Below is the analysis of alignment to Clauses 4 and 5.

Circularity Thinking and ISO 59010 both underline the importance of clearly defined goals and system boundaries for implementing circular strategies, but starting point differs:

- ISO 59010 starts with goal setting, definition of boundaries and understanding the current state of value network (Clause 4), before addressing any circularity aspects.
- Circularity Thinking starts with a material flow perspective (e.g. waste flows), exploring multiple strategies.

Circularity Thinking and ISO 59010 both support the development of circular strategies. However, ISO 59010 assumes a linear progression from goal definition and aligning all actions, while Circularity Thinking employs iterative approach. It aims to ensure a more effective transition by addressing system dynamics and complexities, both required for operationalizing circular economy strategies.

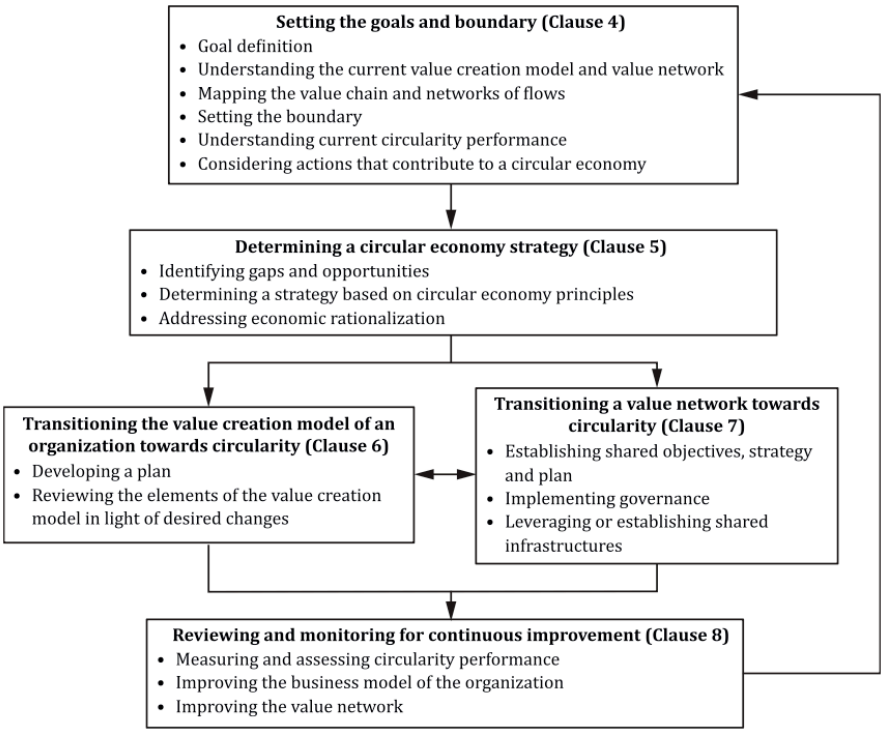

FIGURE 2 STRUCTURE OF ISO 59010

The standard ***ISO 59020:2024 Circular Economy - Measuring and Assessing Circularity Performance*** focuses on measuring and evaluating circularity performance. It focuses on defining system boundaries, selecting indicators, data collection, assessment, and reporting. The principles of measuring and assessing circularity include ensuring relevant spatial and temporal boundaries and meaningful outcome, additionally to CE principles.

Circular Tracker tool evaluates circular performance of products and components derived from PCDS statements (based on ISO 59040). It evaluates circularity based on specific indexes that are estimated by the aggregation of relevant statement:

- Transparency
- Environmental safety
- Use of recycled, reused, or renewable materials in the product
- Product's capacity to extend its lifetime through reparability, upgradability
- Separability
- Product's potential for reuse, refurbishment, or remanufacturing
- ability to cycle through technical and biological cycles without exiting the circular loop

By linking PCDS data to a dedicated evaluation, stakeholders get insights into circularity performance of their product and areas for improvement. It can also be used for multi-criteria comparison or circularity monitoring.

The methodology of Circular Tracker aligns with ISO59040 and with other standards of ISO59000 family. Circular Tracker explicitly incorporates the system boundary defined in the PCDS, so the evaluation contain a clearly defined system boundary, as requested by to ISO 59020's principle. The second principle of "meaningful outcome" ensures that circularity assessments are transparent, traceable, relevant for significant aspects and comparable. The Circular Tracker aligns with this principle through its foundation in ISO 59040 and its use of a multicriteria evaluation approach.

In terms of indicators to measure circularity performance, ISO 59020 provides a list of normative indicators that shall be considered and a standardized method to measure them. These indicators encompass various aspects, including:

- Resource Inflows: Metrics such as the average reused, recycled, and renewable content of inputs.
- Resource Outflows: Indicators like the average product or material lifespan relative to industry standards, and the percentages of products or components that are reused or recycled.
- Energy: The proportion of consumed energy derived from renewable sources.
- Water: Metrics assessing the percentage of water sourced from circular processes, the quality of discharged water, and the rate of on-site water reuse or recirculation.
- Economic Factors: Indicators such as material productivity and resource intensity indices.

While the Circular Tracker incorporates some of these indicators through PCDS data, it is not aligned with the full set of ISO 59020 indicators. The objective of the Circular Tracker is to provide a cost-effective and qualitative assessment of PCDS statements and to allow the comparison of different datasets of different products. This gap is intentional and aligned with scope and purpose of the tool.

Additionally, the documentation process described in ISO 59020 is outside the scope of the Circular Tracker, as the tool focuses on assessment and visualization. The establishment of the PCDS itself already covers the comprehensive documentation.

ISO 59040 focuses on the ***Product Circularity Data Sheet (PCDS)*** as a tool to standardise and facilitate data exchange regarding circularity across product life cycles. The Onto-DESIDE project integrates the use of PCDS in its use cases, which aligns directly with the purpose of the standard, of standardisation, interoperability and transparency.

4 Standardisation plan

This section outlines the contributions of Onto-DESIDE to the development of standards in the context of circular economy, ontology, and digital data sharing. The contributions listed here reflect short-term and long-term actions, supporting data interoperability and transition to circular value chains. During the project duration, an ontology for PCDS is being developed and W3C community group is created. In a long term, the community group discussions could lead to standardisation of both ontologies and other technologies, as well as contributions to the non-technical CE standards developed by ISO.

Creation of a PCDS ontology

PCDS is a digital document that provides detailed information about a product's circularity characteristics, which is being standardised under the umbrella of ISO/TC 323. It is designed to facilitate transparency and data sharing regarding product's ability to be reused, recycled, or repurposed at the end of its life. While the ontology network published by WP3 (i.e. CEON) only partially covers the PCDS concepts and data entries, in the core ontology modules, the use case demonstrator ontology for the textile use case has represented PCDS elements almost entirely. After the second iteration, the project therefore identified the opportunity to lift this part of the demonstrator to a specific ontology, reflecting the PCDS emerging standard. The benefit of a digital semantic representation of the PCDS will be that it can be used to map data from sources that are used to generate a PCDS or simply link to origins of data elements in a PCDS document. It allows to view a PCDS not only as a filled-in document, but also as a data set, underlying that document, including provenance and metadata. This can increase the automation in generating PCDSs from a company's data sources, especially when data needs to be integrated from different sources, but it can also increase the usability and utility of a PCDS for other applications.

Onto-DESIDE thereby develops a specialized ontology for the PCDS. This effort aims to create a consistent data model that can be adopted across various industries, contributing to data exchange and comparability across domains. The PCDS ontology will be reusing concepts and properties from CEON, i.e. be fully aligned with the core network, but it will be a stand-alone module for usability reasons. This increases the opportunity for using the PCDS ontology in various use cases, without the need to understand and reuse the entire CEON.

The ontology is still being developed and will be released by the end of the project. The maintenance and ownership of the ontology is still being discussed, but the aim is to include the ontology as a part of the maintenance process of PCDS templates and other tools related to the PCDS standard.

Contributions to other standardisation committees

POS actively contributed to the development ISO 59040, as a part of the ISO/TC 323 Technical Committee on Circular Economy, specifically within Working Group 5. Three experts of +ImpaKT have been contributing to the standard definition since the beginning of the ISO process, by participating at the ISO/TC 323 - WG5 experts meetings and by providing comments on the draft standard document via the Luxembourgish committee.

W3C activities – technical standardisation

W3C Community Groups are informal open forums within the World Wide Web Consortium (W3C) where participants share and discuss ideas related to web technologies. These groups allow to build consensus around different questions, that can be further subjected to a formal standardisation process within W3C. In this way a community group is the first step towards technical (web) standards specifically related to CE data.

Onto-DESIDE created a W3C community group that focuses on Circular Economy and DPP) (acronym ce-dpp). The starting point for discussion in the group will be based on the ontology for the circular economy, aligned with W3C standards, developed within Onto-DESIDE. The full description of the community group is:

> "*The mission of this group is to support the technical implementation of infrastructure and applications for the Circular Economy (CE), and one of its cornerstones — Digital Product Passports (DPPs). This community group will complement the work of the ISO/TC 323 on CE standardisation, with discussions from a technical web perspective.*
>
> *The group will primarily be a discussion group, but may in the future decide to produce reports or other deliverables. This group will not publish Specifications. Starting out, the group will discuss the requirements set by the CE and DPPs on web technologies and standards, to identify standardisation challenges that are not yet met. Group members will share ideas, experiences and thoughts on usage of web technologies in these areas, their strengths and weaknesses, and open challenges — for instance in the form of use cases.*
>
> *For this community group we welcome all parties interested in the technical aspects of CE, and DPP implementation. We envision that participants either have knowledge and expertise on CE and DPPs, e.g. material flows, manufacturing, modelling, or business aspects, so they are able to, for instance, contribute use cases, needs, and test scenarios. Additionally, we welcome participants with knowledge and expertise on web infrastructure, technologies, and standards who are interested in applying their expertise to address CE-related challenges.*"

The W3C community group has already been validated, and upcoming activities include inviting industry experts, researchers and digital solution providers to participate in discussions that will continue after the project's end. These discussions will focus on:

- practical applications of the developed ontologies and need for their standardisation
- gathering feedback on potential challenges in implementation, and challenges in using existing we standards in CE and DPP
- data models specific for CE and DPP, including the effects of new versions of W3C standards
- best practices in data sharing,
- ontology integration across platforms and domains.

Ultimately, it could lead to formal standardisation of one or more ontologies or other CE or DPP technologies by W3C, contributing to the digitalisation within circular economy value chains.

In addition to the newly proposed group, IMEC actively participated in the W3C Knowledge Graph Construction Community Group to make sure the platform's technical solution remains aligned with ongoing advancements. IMEC also actively participated in the W3C Solid Community Group and Linked Web Storage Working Group to make sure the platform's technical solution remains aligned with ongoing advancements.

5 Future mapping

Following the completion of the Onto-DESIDE project, POS will continue the implementation of the PCDS. The next steps will focus on expanding PCDS adoption, supporting industry engagement, and enhancing IT tools to simplify the process of creating and sharing data. Further steps include:

- Registration as a PCDS Issuer on the Terra Matters Platform

Terra Matters is a company supported by the Luxembourg Ministry of the Economy whose mission is to promote, democratise the use and achieve mass adoption of the PCDS at international level. POS will register as a PCDS issuer on the Terra Matters platform. With the

increasing maturity of PCDS, POS will work with companies on its implementation. This engagement will include support in scope definition, support in data collection and interpreting PCDS results, providing trainings and guidance.

- Collaboration with Terra Matters on the Development of IT-Based Application

POS will support Terra Matters in developing an IT-based application for PCDS intended to facilitate the creation, management, and sharing of PCDS documents. The IT tool will enable partial automation of the data input process, verification of information, and simplification of document generation. As part of this collaboration, POS will propose the integration of ontologies developed by LIU to facilitate machine-to-machine data exchange. These ontologies can enhance the interoperability of circularity data across various platforms.

- Development of tools complementary to PCDS

To promote and facilitate the adoption of the standard 59040, 2 tools are under development: PCDS Assembly and Circular Tracker.

PCDS Assembly refers to the ongoing process of developing a adds-on for automated consolidation of several PCDS documents into one, imitating the process of mounting several components into a product. The challenge of the PCDS assembly lies in the consideration of manufacturing processes, that may lead to physical or chemical modifications and thus modify statements related to components. After the project, efforts will focus on refining the “building blocks” related to processes and their impact on statements, as well as on ensuring that resulting PCDS accurately represents the circularity information.

Circular Tracker is another complementary tool that evaluates circular performance of products and components based on the PCDS statements, according to the following indexes:

- Transparency
- Environmental safety
- Use of recycled, reused, or renewable materials in the product
- Product's capacity to extend its lifetime through reparability, upgradability
- Separability
- Product's potential for reuse, refurbishment, or remanufacturing
- ability to cycle through technical and biological cycles without exiting the circular loop

By linking PCDS data to a dedicated evaluation, stakeholders get insights into circularity performance of their product and areas for improvement. It can also be used for multi-criteria comparison or circularity monitoring.

Imec will continue to participate in the **W3C RDF-Star Working Group**, however, we foresee no future conflicts with the current platform setup.

Imec will continue to participate in the **W3C Knowledge Graph Construction Community Group** to make sure the platform's use cases and requirements keep being represented in future standardisation efforts.

Imec will continue to participate in the **W3C Linked Web Storage Working Group** to make sure the platform's use cases and requirements keep being represented in future standardisation efforts.

Regarding the ontology perspective, in this deliverable, we have briefly presented the current alignment results between CEON with other CE-related ontologies and domain ontologies especially for the materials domain. The alignment results have shown the difference between CEON and other CE ontologies where CEON has a specific goal from the beginning which is to represent CE domain with a focus on CVNs for cover more usage scenarios for different domains. Based on our alignment work, we also contribute to the broad ontology matching community by proposing a new CE track in

the yearly organized OAEI (Ontology Alignment Evaluation Initiative) which aims to evaluate ontology matching systems. In this track, we evaluate ontology matching systems over one of the ontology alignment tasks in our project to investigate challenges in terms of finding alignments among CE ontologies. We will continue this work within OAEI. Since CEON is still in the development for final release, we will follow the alignment framework as shown in Figure 1 to update alignments between CEON and other relevant ontologies. Moreover, these alignments will be published following the overall ontology publishing workflow used in Onto-DESIDE as a separated module of CEON. We will also keep track of recent research to include any new developed CE ontologies or other relevant domain ontologies and include them in our ontology survey.

6 Gaps and challenges

During the work on aligning the ontologies with the ISO 59004:2024 vocabulary a number of implicit assumptions and potential mismatches were uncovered. An example of such a challenge was the definition of a "resource", which in the ISO standard is described as:

"*asset from which a solution (3.2.1) is created or implemented*

[...] Note 2 to entry: For the purpose of this document, asset refers to physical resources"

While in technical standards, such as RDF, a resource is a broader notion, c.f. the RDF 1.1 standard:

"*Anything can be a resource, including physical things, documents, abstract concepts, numbers and strings*"

In the ontologies produced in this project, we have restricted the resource notion slightly, to mean a resource useful for or involved in some CE process, but still allowing also non-physical resources. This mismatch originates in the underlying assumption and scope of the respective standards, i.e. ISO 59004 being about circular economy and mainly considering the physical side of materials, products and components, while RDF focuses data and information in general, regardless of what the data represent. In Onto-DESIDE we are attempting to connect the digital and the physical worlds, hence, such mismatches are bound to arise. For the moment, the CEON is aligned to ISO 59004 where possible, and where we are able to interpret the definitions in the standard in a way that may encompass also digital representations. For instance, in the example above, we have chosen to interpret the ISO 59004 standard as not excluding other types of resources, but interpreting the note as a clarification to understand the specification document, and hence did not include the note itself in our ontology documentation.

However, while such design decisions have been made, for the moment, in our current CEON version, these are still up for future consideration. This is also to be considered only an example of such mismatches, and this will continue to be a challenge when integrating and connecting data and information relating to different sets of standards.

The EU legislative context is rapidly evolving. For example, Ecodesign for Sustainable Products Regulation entered into force on July 2024, mandatory product-specific ecodesign requirements will be specified in delegated acts. The legislation put forward DPP as a central tool to ensure product information transparency and traceability across value chains. To support DPP implementation, European Commission mandated the creation of JTC 24 "Digital Product Passport – Framework and System" under the European Standardization Organizations (CEN and CENELEC). JTS 24 aim to create harmonised standards for the technical framework of DPP system, excluding the content of passport data. Its modules include topics like unique identifiers, data carriers, access rights management, interoperability, data storage, processing, authentication, and APIs. The goal is to deliver harmonised standards by the end of 2025.

For Onto-DESIDE this evolving context means the need to ensure that project outcomes are relevant to mandatory requirements and remain adaptable to incorporate results of JTC 24 on data exchange protocols and interoperability. During project duration, it is necessary to prioritize modularity,

scalability and flexibility during development of ontologies and data-sharing platform. Beyond project timeline, Onto-DESIDE members must monitor updates to harmonised standards in order to remain aligned with regulatory and standardisation context.

7 Conclusion

The Onto-DESIDE project has demonstrated its alignment with established and emerging international standards in circular economy, ontology development, and decentralized data sharing.

From a technical perspective, Onto-DESIDE monitored standards evolutions (e.g. by actively participating in relevant working groups) and applied them to the Open Circularity Platform where relevant. Current choice of standards aligns with complementary projects such as Cirpass. It is demonstrated how the use of Linked Data standards provides for added functionality such as federated querying. As future work, alignment with the upcoming European Dataspaces pilots is foreseen, to ensure findings are not limited to the set of standards we focused on, but can be further applied in other data sharing networks.

In ontology development, to comprehend the state-of-the-art of the intersection of CE and Semantic Web, Onto-DESIDE studied existing CE-related ontologies to better understand the commonalities and differences between usages scenarios and content of these ontologies compared to those developed in the project. The project scope is on covering different domains where CE implementations are needed, i.e. being independent of industry domain. To satisfy such a requirement, CEON has been developed with a focus on representing generic CE domain knowledge in a modular and general way, applicable for various domains and being able to act as a bridge between other ontologies. To this end, the project provides the alignments between CEON and other CE ontologies to improve the interoperability. Furthermore, we investigate other domain ontologies where the domains could be interesting for a CE context, such as materials, manufacturing and products. Therefore, Onto-DESIDE align CEON also with these domain ontologies. For the materials domain, we align with a top-level ontology EMMO, and reuse relevant concepts and relationships for modelling materials related domain knowledge. This approach provides enhanced interoperability and reusability for using CEON in different scenarios.

The project demonstrates alignment with existing and emerging international standards in circular economy, ontology development, and decentralized data sharing. The project shares principles of circular economy outlined in ISO 59000 family. Important achievement includes the alignment of ontologies with ISO 59004:2024 vocabulary, and integration of PCDS (ISO 59040) into project use cases.

Beyond alignment, Onto-DESIDE contributes to the evolution of standards. Its contributions include the development of an ontology for PCDS, which facilitates data sharing, automation, and interoperability across industries. Another contribution is engagement in standardisation committees, and community groups. The proposal for a W3C Community Group focusing on circular economy and digital product passports enables a dialogue among stakeholders and could lead to formal standardisation of ontologies. By participating in ISO/TC 323 and W3C standardisation committees, Onto-DESIDE contributes to future standards. These efforts will support broader adoption and evolution of standards that are critical for achieving digital transitions in the circular economy.

The alignment of ontologies with ISO 59004:2024 revealed challenges to align physical and digital systems. The integration of the definitions of “resource” illustrates this challenge. ISO focuses on physical assets, while RDF uses broad meaning of data and information. Onto-DESIDE addresses this gap by aligning with ISO where possible and accommodating digital representations.

The evolving legislative context, particularly ESPR and the development of harmonized standards under JTC 24 for DPP, represents additional challenge. Project outcomes must remain up-to-date and able to integrate mandatory requirements and standards developments even beyond the project timeline. Onto-DESIDE ensures its outcomes are modular, scalable, and adaptable to align with

evolving standards. Continuous monitoring after the project is important to maintain relevance and compliance.

References

Beckett, D., Berners-Lee, T., Prud'hommeaux, E., & Carothers, G. (2014). RDF 1.1 Turtle – Terse RDF Triple Language. World Wide Web Consortium (W3C). Available at: http://www.w3.org/TR/turtle/

International Organization for Standardization (ISO). (2024). ISO 59004:2024 Circular Economy — Vocabulary, Principles and Guidance for Implementation.

International Organization for Standardization (ISO). (2024). ISO 59010:2024 Circular Economy — Guidance on the Transition of Business Models and Value Networks.

International Organization for Standardization (ISO). (2024). ISO 59020:2024 Circular Economy - Measuring and Assessing Circularity Performance.

International Organization for Standardization (ISO). (2024). ISO 59040:2025 Product Circularity Data Sheet.

Li, Huanyu, Eva Blomqvist, and Patrick Lambrix. "Initial and Experimental Ontology Alignment Results in the Circular Economy Domain." *KG4S 2024: The 2nd International Workshop on Knowledge Graphs for Sustainability co-located with the 21st Extended Semantic Web Conference (ESWC), May 27th, 2024, Hersonissos, Greece.* 2024.

Li, H., et al. (2023). A survey of general ontologies for the cross-industry domain of circular economy. *Companion Proceedings of the ACM Web Conference 2023*.

Seaborne, A., Champin, P.-A., Hartig, O., & Kellogg, G. (2024). RDF 1.2 Concepts and Abstract Syntax [W3C Working Draft]. W3C. Available at: https://www.w3.org/TR/2024/WD-rdf12-concepts-20241121/

Sporny, M. (2024). Verifiable Credential Extensions [Techreport]. W3C. Available at: https://www.w3.org/TR/2024/NOTE-vc-extensions-20240930/

Sporny, M., & Sabadello, M. (2024). DID Document Property Extensions [W3C Note]. W3C. Available at: https://www.w3.org/TR/2024/NOTE-did-extensions-properties-20241119/

Sporny, M., & Sabadello, M. (2024). DID Methods [Techreport]. W3C. Available at: https://www.w3.org/TR/2024/NOTE-did-extensions-methods-20241119/

Tanon, T. P., Seaborne, A., & Taelman, R. (2024). SPARQL 1.2 Update [W3C Working Draft]. W3C. Available at: https://www.w3.org/TR/2024/WD-sparql12-update-20241113/

W3C. (2012). OWL 2 Web Ontology Language Primer (Second Edition). W3C Recommendation, 11 December 2012. Available at: http://www.w3.org/TR/owl2-primer/