

Ontology-based Decentralized Sharing of Industry Data in the European Circular Economy

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1. Introduction

Circular economy aims at reducing value loss and avoiding waste, by circulating material 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 attempting to create 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. Semantic interoperability of data is one of the biggest barriers towards data sharing in the Circular Economy.

A solution to these challenges needs to leverage open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, as well as create a decentralized digital platform that enables collaboration in a secure and confidentiality-preserving manner. This vocabulary can then be used to construct digital twins of circular value networks to further enable open collaboration. Once defined, the blueprints of these digital twins will be reusable as templates and can be reused with a different set of actors or used within a different industry domain. Established Semantic Web technologies and standards provide the technical foundations for information flows that will transform European Industry towards a CE, by means of digitalization and data sharing.

This vision includes several 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, and form their decentralized digital twins. The solutions will allow for automation of planning, management, and execution of circular value networks, at a European scale, and beyond. Thereby supporting the acceleration of the digital and green transitions, automating the discovery and formation of new collaborations in the circular economy.

2. The Onto-DESIDE vision

To address the above challenges, an EU-funded project, Onto-DESIDE, was started in 2022. Onto-DESIDE develops a standards-based web technology platform for allowing

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data sharing about materials, products and processes at a global scale. Since access to verifiable information is central, well-established open standards for secure and confidentiality-preserving information sharing are core components. Ownership and storage of data should remain with the data producer; hence a decentralized approach is necessary. Metadata and structures for transforming data into information (semantic descriptions, i.e. ontologies) are open, and comply with FAIR principles, to enable the highest possible degree of semantic interoperability and automation in data sharing. For sensitive data, methods allowing for proof of existence of the data can be used, where proofs can be shared while actual data is kept private.

Another aspect is to address the use of these technologies in a business context, and study the circular economy as a complex system to develop integrated tools and methods for further enhancing CE. Although the importance of various 'flows' - namely: resource flows, information flows, value flows, and energy flows - has been widely acknowledged within the transformation to CE, so far, they have not been integrated or linked into a single framework or approach. Without such integration or linking it is currently not possible to make robust designs of circular value networks, and to conduct value network coordination towards implementation and operation within industry. Moreover, this should result in robust value networks that are profitable, equitable, and invite long-term collaborations and partnerships. Therefore, apart from the solutions needing to be technically feasible, there is also a need to explore how such value networks can be designed and developed, using the ontologies for data documentation and data sharing, but considering the interplay of resource, information, value and energy flows, i.e. considering how the value network will behave as a system.

3. Onto-DESIDE core outcomes

Within the Onto-DESIDE project, four core components are envisioned:

- **A network of ontologies** for data documentation, that allows for semantic interoperability and supports flexible, automated, decentralized data sharing between industry actors.
- **An open circularity platform**, i.e. a secure and confidentiality-preserving decentralized data sharing platform allowing the creation of digital twins of circular value flows, by enabling FAIR sharing of data between industry actors, facilitating the initiation of new collaborations in the circular economy.
- **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 transitioning to a circular metabolism within industrial systems through co-design and co-creation.
- **Validation** - demonstrating and quantifying the potential for increased retainment of value when applying the above outcomes in cross-border and cross-industry sector circular value networks in Europe.

The overall project research methodology divides work into three iterations. In the first project iteration a first version of a Circular Economy Ontology Network was developed, short CEON³. This was then used as the backbone for semantic data interoperability, sharing, and querying in a data sharing platform for CE⁴, based on the Solid protocols,

³ <https://w3id.org/CEON/>

⁴ <https://github.com/KnowledgeOnWebScale/open-circularity-platform>

another emerging set of web standards. However, it is important to note that the prototype, including ontology modules, will certainly change in the current (second) and third iterations of the project.

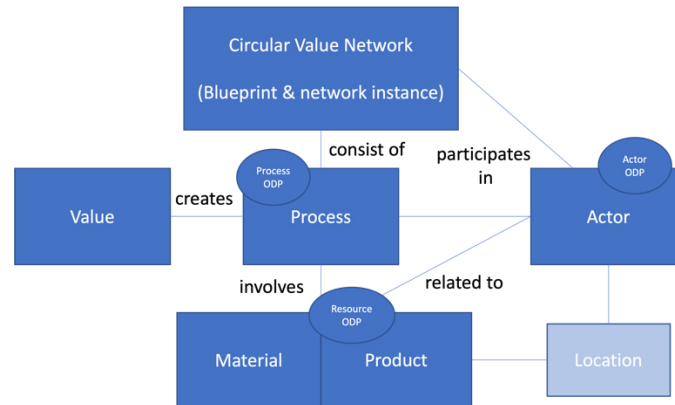


Figure 1: Informal conceptual overview of the topics covered by CEON modules.

The Digital Twin of circular value networks

While semantic interoperability, and ontology-based data documentation, are essential enablers for large scale CE, they are not enough in themselves. Semantically described data also need to be put into use, in automated processes. Today, there is limited data collaboration within industry domains and even less across domains, consequently new circular value networks are only created between known actors that have a certain degree of comfort working together – limiting the possibilities of more high value circulation scenarios, and novel innovative configurations being discovered. Open collaboration could remedy this, but data and ontologies cannot solve the problem alone. To facilitate open collaboration in a data driven circular economy a new entity is needed, the digital twin of circularity.

The concept of digital twins has been used for many use cases and in many industries and the fundamental theory behind the concept is not a new thing. But the idea of constructing digital twins of circular value networks, with the value network itself, and related ‘flows’, as the objects in focus, is a novel idea and has not been explored before. If digital twins are built upon shared ontologies, i.e. the ontology network, once defined, their blueprints are also reusable as templates for a certain circular value network. These blueprints could be shared with a different set of actors or used within a different industry domain to instantiate new value networks.

4. Validation through industry use cases

The core project outcomes are tested and evaluated in the three project use cases, i.e. in the textiles, electronics and construction domains respectively. In the project a research dataset, incorporating data structures and attributes relevant for CE decisions and value network execution in one example circular flow in each of these industry domains have been developed. Together with scenarios, representing information needs of actors in the value network, this sets the ground for establishing feasibility and evaluating the efficacy and quality of the project outcomes. So far the first platform and ontology

network release have been evaluated, rendering a basic confirmation of feasibility and a set of necessary points of further work and improvements have been noted.

Regarding the ontology network, the validation more concretely meant to test the ability for the core ontology modules to be extended into more (industry) domain specific ontologies and concepts. Hence, as a test case, three industry specific ontologies were created, by specialising the core modules and patterns, and thus assessing their ability to document the data needed in those three use cases.

5. Conclusions and outlook

When analysing existing ontologies, we note gaps in coverage of central CE concepts, such as the Circular Value Network itself. In other domains on the other hand, e.g. materials and manufacturing, there are instead many overlapping ontologies and/or partly competing conceptualizations. Our proposed solution is to create a set of Ontology Design Patterns, i.e. a “pattern language”, and ontology modules that represent core concepts related to CE, to provide a core to which existing ontologies can be aligned, and in addition complement missing CE concepts. Alignments to existing ontologies are still part of future work, and validation of the core CE concepts against emerging standards such as the CE terminology and definitions by ISO/TC 323. However, we can still conclude that the approach has proven feasible and useful, in initial modelling exercises of the project, c.f. the use case validation described above. Together with the extended methodology, FAIR publishing, and the high degree of modularisation we see this as a step towards true ontology reusability, even in cross-domain scenarios such as CE.

Ongoing and future work includes the creation of alignment modules, to connect our network to other ontologies, and to perform a more extensive evaluation, involving actual data exchange through the Solid-based Onto-DESIDE data exchange platform, and to extend the evaluation to encompass cross-sectorial data exchange.

6. References

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