Towards Connecting General DPP Ontology Frameworks with Domain-specific Information Sources*

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Abstract

As sustainability, resource efficiency, and traceability gain increasing importance, concepts such as the Circular Economy (CE) and the Digital Product Passport (DPP) are becoming central to regulatory and industrial efforts. While sector-specific DPPs are being developed, their integration with existing standards and ontologies remains a key challenge. This paper examines how domain-specific ontologies and standards can be leveraged to enhance the semantic annotation of DPP data. We systematically compare existing Core DPP ontologies (C-DPPOs) and assess their adaptability to specific use cases. To illustrate the approach, we analyze two case studies: the car battery and the timber wall. These use cases represent different levels of regulatory and industry preparedness for DPP implementation. We identify relevant information sources (IS), including ontologies and standards, and evaluate their applicability for extending a Core DPP ontology. Our findings reveal substantial differences in IS coverage depending on the maturity of EU-mandated DPP initiatives. Based on this analysis, we propose an initial selection of ISs that can effectively provide the required information. This study lays the foundation for linking C-DPPOs with domain-specific extensions, ensuring interoperability and facilitating the practical implementation of DPPs across industries.

Keywords

Circular Economy, Digital Product Passport, Ontology, Standard, Semantic Technologies

1. Introduction

The transition from a linear to a data-driven circular economy (CE) is one of the most pressing challenges modern societies face. Especially in regions like the European Union (EU), where economic stability relies on the import of finite resources, ensuring sustainable resource use has become a strategic priority. However, the successful implementation of CE principles depends heavily on the collection, storage, and exchange of comprehensive product data to enable informed decision-making by various CE actors. In recent years, data spaces have emerged as decentralized infrastructures designed to facilitate secure and sovereign data sharing by CE actors [1]. One initiative leading this effort is the Catena-X initiative (https://catena-x.net/en, accessed February 18, 2025), which is developing a data space for the automotive industry and setting a precedent for other sectors. Thereby, its open-source component, Tractus-X, fosters collaboration and facilitates the integration of new use cases.

While data spaces provide a foundation for secure data exchange, they do not address the challenge of data acquisition and standardization. To address part of this gap, the EU has introduced the Digital Product Passport (DPP) as part of the Ecodesign for Sustainable Products Regulation (ESPR) [2]. The DPP mandates the structured collection and storage of product-related data with four primary objectives: (1) enhancing product circularity, (2) creating new business opportunities, (3) empowering consumers to make sustainable choices, and (4) supporting regulatory compliance. The first mandated application of the DPP is the Battery Passport (BPP), which will become legally required by 2027 under the EU Battery Regulation [3]. Additional DPP implementations are planned for textiles, electronics and construction materials. To ensure the semantic consistency and interoperability of DPP data, the Battery Passport Technical Guidance [4] has been introduced. This document highlights the necessity of a structured and

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machine-readable description of battery-related data and provides recommendations for ontology-based modeling. It identifies key domain-specific ontologies, such as the Battery Interface Ontology (BattInfo) and the Battery Value Chain (BVC) Ontology, which can be leveraged to annotate battery-related data in a standardized manner. These ontologies play a crucial role in aligning BPPs with existing regulatory and industry frameworks, ensuring seamless data integration across manufacturers, supply chain actors, and regulatory bodies.

However, while these recommendations represent a significant step toward a structured DPP implementation for battery data, they also highlight the broader challenge of semantic interoperability, enabling seamless data reusability and integration. The DPP and its DPP system [5] is intended to cover a wide range of sectors - which is also needed for a CE - each with distinct data requirements, industry standards, and regulatory frameworks. A key challenge is therefore the development of a common semantic foundation that remains adaptable to sector-specific extensions.

Ontologies provide a structured way to address this challenge by defining a machine-readable vocabulary that can be used to standardizes how product data is represented and exchanged. Thus, there is a need for a Core DPP Ontology (C-DPPO) that acts as this common semantic foundation.

This is particularly valuable for the semantic description of data, as ontologies can serve as a common ground for the semantic description of different data sets, enabling interoperable data exchange. This eliminates misunderstandings caused by ambiguities inherent in raw data and provides clarity and structure that facilitates the interpretation and analysis of newly acquired information. By leveraging semantic modeling in combination with public ontologies and data spaces, we can ensure that DPP data is structured in a way that aligns with the FAIR principles—making it findable, accessible, interoperable, and reusable [6], as defined by Wilkinson et al. [7].

However, modeling a C-DPPO requires careful consideration of several key aspects. First, future DPPs will be mandated across highly diverse industries, including textiles, electronics, and construction. Hence, as highlighted by Jansen et al. [8], a unifying C-DPPO is essential to ensure interoperability between these sector-specific DPPs. Second, this C-DPPO must be extensible, allowing for the integration of use case-specific ontologies that capture the domain knowledge required for the semantic annotation of industry-specific data. Finally, as with all ontologies, broad standardization and industry-wide acceptance are crucial. A well-standardized ontology ensures that its vocabulary aligns with existing structures, terminologies, and processes across different sectors, facilitating seamless data integration and exchange.

In this work, we address two pressing key research questions, resulting from these considerations: (1) What is the current state of C-DPPOs? (2) Which ontologies and standards can already be used for modeling sector-specific DPP extensions? So far, DPP ontologies have primarily been designed as modular core ontologies, but their applicability across multiple use cases remains largely untested. To bridge this research gap, we analyze two distinct use cases that represent different stages of DPP standardization and development. This comparison highlights the varying challenges and starting points for DPP implementation across industries. The first use case focuses on car batteries and the aforementioned upcoming BPP. We choose this use case because it represents the most advanced stage of DPP development. With the introduction of the BPP, this sector is, as previously stated, subject to regulatory mandates, detailed industry standards, and ontology recommendations. Examining this case allows us to explore how existing frameworks can be leveraged to extend a C-DPPO. In contrast, the second use case, a timber wall, represents an industry without predefined DPP requirements from the EU. This sector features complex supply chains but offers significant potential for improving data exchange and interoperability between stakeholders. Analyzing this case highlights the challenges industries face when no established ontological frameworks exist, emphasizing the need for structured sector-specific extensions.

To address these aspects, the paper is structured as follows: Section 2 provides an overview of existing DPP research and the state of C-DPPOs. Section 3 compares the available C-DPPOs. In Section 4, we present an analysis and classification of potential Information Sources (ISs) that can be used to extend a C-DPPO, while Section 5 applies these insights to the two selected use cases. Finally, we discuss our findings in Section 6 and conclude with key takeaways and future research directions in Section 7.

2. Related work

This section provides an overview of prior research on DPPs, focusing on regulatory developments, industry initiatives, and ontology-based modeling efforts. We start with an overview of general DPP research and end with our findings on available C-DPP ontologies. For this search, Google Scholar and ResearchGate were used to identify relevant academic papers.

Research on DPPs has gained momentum since the introduction of the concept in the ESPR [2]. Various EU-funded projects and research institutes have explored the implementation and impact of DPPs across different sectors. Notably, the battery and automotive industries, being the first to face mandatory DPP requirements, have led the way in defining data models and standards for DPP integration. A significant milestone in this domain is the DIN DKE SPEC 99100 standard [3], which specifies essential data attributes for the BPP and provides a structured framework for product information exchange. Building on these foundational efforts, the EU-funded CIRPASS project has extended the scope of DPP research to additional industries, including textiles, electrical and electronic equipment, tires, and construction materials. In its D5.1-DPP-Prototypes report [9], CIRPASS presents a non-exhaustive catalog of ontologies and data models that could support the semantic representation of DPP data. These ontologies address both system-level requirements—defining the infrastructure for data accessibility—and content-level requirements, which focus on product-specific data annotation.

To support the integration of DPPs into semantic data infrastructures, researchers have proposed ontology-based approaches as a foundational element. Among the notable efforts is the modular ontology network by Jansen et al. [8]. Their approach introduces a C-DPPO designed to function as a cross-sector product ontology while enabling alignment with domain-specific ontologies. However, it remains at a conceptual level, with limited validation across multiple use cases. Additionally, it does not explicitly incorporate pre-existing ontologies, despite being influenced by them, and should therefore be regarded as a proof of concept.

A more structured approach is presented by Kebede et al. [10]. They propose a modular ontology modeling framework for DPPs. Their work is grounded in a comprehensive literature review of DPP information requirements (IRs) and supplemented by expert interviews. The resulting ontology framework systematically captures lifecycle information from product creation to end-of-life using Semantic Web technologies. Its modular architecture consists of multiple aligned ontology modules, allowing for flexible extensions and domain-specific adaptations. In contrast to Jansen et al., their approach incorporates pre-existing domain-specific ontologies and follows the modular ontology modeling approach [11], demonstrating how DPP ontologies can be structured, extended, and standardized if the IRs are clearly defined.

3. Comparison of Existing DPP Ontologies

Both Jansen et al. [8] and Kebede et al. [10] propose a modular approach to a unifying C-DPPO. To further assess how useful for application as C-DPPO they are, we compare them based on the general DPP IRs defined by CIRPASS [9]. The results are summarized in Table 1, where ✓ (checkmark) indicates that the IR is fully addressed, ✘ (cross) signifies that the IR is not covered, and (✓) (bracketed checkmark) denotes partial coverage or an inconclusive implementation. This comparison makes it evident that the ontology proposed by Jansen et al. [8] does not cover all DPP IRs, as the authors themselves acknowledge. However, it demonstrates potential for future use.

In contrast, Kebede et al. [10] come significantly closer to fulfilling the CIRPASS-defined IRs. The IRs that are partially or completely missing in their ontology were active choices in the ontology modeling, as their own literature review included all of these IRs, but they were later discarded for various reasons. This raises the question of whether these IRs should be general DPP IRs at all, or whether they could be sector-specific. Since the Kebede et al. ontology currently represents the most advanced DPP modeling approach, we use it as a reference framework to assess the need for additional sector-specific extensions.

Kebede et al. [10] identify ten independent modules that include the Product, Material, Certification,

General DPP Information Requirements	Kebede et al.	Jansen et al.
Product Identification	✓	✘
Manufacturer Identification	✓	(✓)
Material and Composition Information	✓	✓
Product Design and Service-Related Information	✓	✓
Product Use and Lifecycle Information	(✓)	✘
Compliance, Certification and Circularity	(✓)	(✓)
Access, Rights and Permission	✘	✘

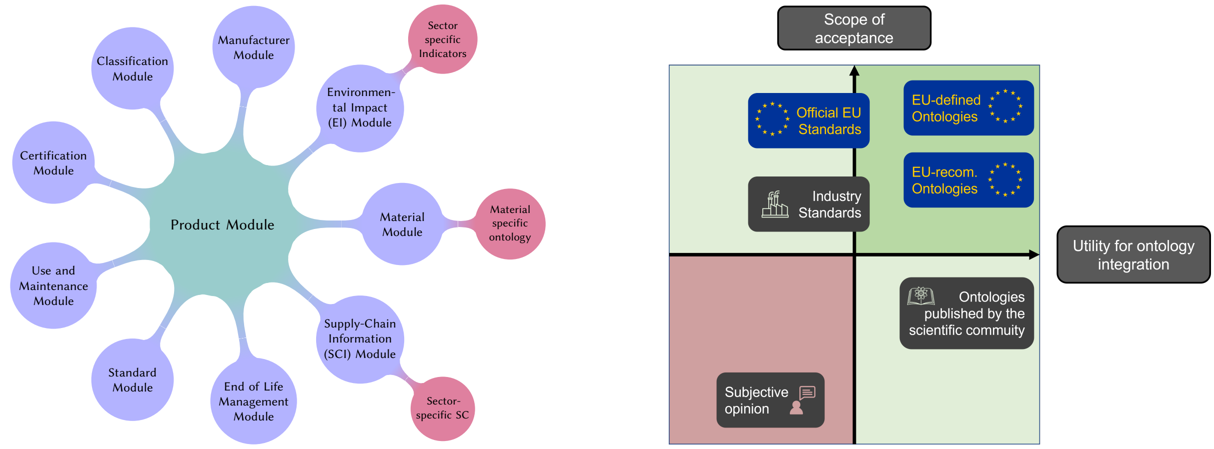
Table 1
Comparison of the two C-DPPO versions and their addressed IRs

Classification, End of Life Management, Standard, Environmental Impact, Manufacturer, Supply-Chain Information Management and Use and Maintenance Modules. These modules are documented and marked as a work in progress in the GitHub repository [12]
Each of these modules can stand alone and be added or removed based on the use case at hand, as the author of the ontology emphasizes. Of particular interest for this work is how these modules can be extended to describe different use cases.
For this work, we focus on three key modules that require adaptation for sector-specific DPP extensions:
(1) Material Module: While it defines a core ontology, each use case must extend it to capture domain-specific materials used in a product and throughout its lifecycle. A clear nomenclature is essential for precise semantic annotation.
(2) Environmental Impact Module: Although it already defines several key environmental indicators, it is not exhaustive. Each use case must determine additional relevant indicators to assess environmental impact, circularity, and social sustainability.
(3) Supply Chain Information Management Module: Each use case features a distinct supply chain with different manufacturers, suppliers, and logistics processes. Therefore, nomenclature and supply chain-specific metadata must be added.
These relationships are visually summarized in Figure 1a.

4. Use case specific DPP ontology extension

In the following, we examine how these three modules can be extended to fit specific use cases while maintaining standardization and interoperability. We focus on the documents published by the EU DPP initiatives and extend our search by searching Google Scholar, ResearchGate and Google.
Extending a C-DPPO involves a twofold challenge. The first step, as in standard ontology modeling, is to define the IRs for a given use case and translate them into Competency Questions (CQs). As defined by Grüninger et al. [13], CQs express IRs as queries, ensuring that the ontology can provide the necessary information.
Once the CQs are defined, the second step is to structure the ontology extension in a way that maximizes standardization and interoperability. This can be achieved by using either widely used ontologies or open standards as ISs. In evaluating different IS candidates, suitable as extension, two key characteristics must be balanced to determine their suitability: the utility for ontology integration, i.e. how much further work someone has to do to integrate this IS into the ontology, and the level of acceptance of the IS, i.e. how many people have agreed on it. Figure 1b visualizes these characteristics. The closer an IS is to the top-right corner, the more suitable and relevant it is for integration into the DPP ontology network.

Ontologies and standards each offer distinct advantages for extending a C-DPPO. Ontologies are inherently structured and machine-readable, making them the easiest to integrate. In contrast, standards are typically provided in written form, requiring manual translation into an ontology format. However, standards contain agreed-upon nomenclature, which, when correctly utilized, ensures terminological consistency and industry-wide acceptance [14].



(a) Own visualisation of the modules of the C-DPPO presented by Kebede et al. [10] with the necessary extensions.

(b) Illustration of possible ISs in a coordinate system that denotes the utility for ontology integration and the scope of the acceptance of the IS.

Figure 1: Side-by-side visualization of the DPP ontology modules and the coordinate system illustrating ISs.

Since DPP relevant ontologies and standards must ultimately be accepted and implemented, their development is shaped by three key actors:
(1) The European Union (governments): The main regulatory driver, ensuring that DPPs align with sustainability policies and legal requirements. The EU provides open-access information and actively funds research initiatives to define DPP frameworks. However, official EU-published DPP ontologies do not yet exist, although recommendations for some use cases have been issued through EU-funded projects.
(2) Industry: The primary stakeholder in the real-world application of DPPs. Industry plays a critical role in shaping standards and ontologies, but industrial ontologies are often proprietary and not publicly available, limiting their use in open DPP frameworks.
(3) The Scientific Community: The main source of open-source ontologies, typically developed according to FAIR principles. These ontologies are widely available but must align with regulatory and industry needs to be effectively adopted.
This consideration leaves us with six potential sources of information that can be used to extend the C-DPPO (see Figure 1b (b)): The first source that should be preferred are EU defined and published ontologies, followed by EU recommended ontologies. The next three ISs are official EU standards (e.g. with the prefix EN, industry standards such as ISO, or DIN, and ontologies published by the scientific community. The choice of which IS to prioritize depends on the specific use case and the trade-off between ease of integration and level of acceptance (see Figure 1b (a)).
The last IS is the subjective opinion based on experience that should be used as a last resort if none of the previous sources are available.

5. Use Cases

In this section, we identify available ontologies that could be used to extend the C-DPPO for two selected use cases. We follow the approach outlined in Section 4, which includes defining CQs derived from use case-specific IRs and mapping relevant ISs to assess their suitability for answering these CQs.

5.1. Car Battery

Car batteries contain critical raw materials, such as lithium and cobalt, which are not mined domestically in Europe. Given the high dependency on imports, the EU has prioritized sustainable and circular strategies to secure supply chains and reduce environmental impact. This rationale led to the BPP.

Since the introduction of the Battery Regulation [3], the topic has gained significant attention, resulting in a wide range of publicly available ISs (see Table 2).
The Battery Regulation defines key IRs for the BPP. We focus on three representative ones—battery materials, carbon footprint, and manufacturing activities—which require extending three C-DPPO modules introduced in Section 4. These IRs are translated into the following competency questions (CQs), with the relevant module that needs to be extended to answer this CQ noted in parentheses:

CQ1 What materials are used in the battery? (Material Module)
CQ2 What is the total battery carbon footprint of the battery throughout its lifetime? (EI Module)
CQ3 What are the manufacturers of the battery and what activities did they perform? (SCI Module)

In table 2, we present a non-exhaustive list of available ontologies and standards that can be used to extend the C-DPPO for the Car Battery use case. It provides an overview whether they qualify as ontologies, and whether they have been officially published or recommended by the EU. Additionally, the Module column maps the identified information sources (ISs) to the corresponding modules proposed by Kebede et al. [10], which, based on our findings in Section 4, require extension. The CQ column denotes if this IS was used to answer any of the CQs. An analysis of these two columns shows that there are ISs available for each Module that needs extending and each CQ.
Before evaluating how these ISs can be used to answer competency questions one to three, it is

Information source	Ontology	Module	CQ	EU(-rec.)	Source
Automotive Ontology (AUTO)	✓	Material		(✓)	[15]
Battery Value Chain Ontology	✓	Supply-Chain Information	CQ3	✓	[16]
Battery Interface Ontology	✓	Material	CQ1	✓	[17]
Battalogy	✓	Material			[18]
BPC Ontology	✓	Material			[19]
Battery Domain Ontology	✓	Material			[20]
Li-Ion Battery Ontology	✓	Material			[21]
Battery Regulation	✘	Environment	CQ2	✓	[3]
FEDeRATED semantic model	(✓)	Supply-Chain Information		(✓)	[22]

Table 2
A non-exhaustive list of ISs in connection to the Car battery use case.

important to first examine the EU(-recommended) column. This column indicates which sources have been published or recommended by the EU or EU-funded projects, helping to prioritize which ISs to favor. AUTO has a check in parentheses because it was used and therefore recommended indirectly by the EU-funded project called DATAPIPE at TU Delft, which developed a car BPP demo with an ontology and incorporated AUTO [9].
The most important ontologies here are the previously mentioned BVC and BattInfo Ontology, as both are recommended for the BPP application in the Battery Passport Technical Guidance [4]. BattInfo has also been recommended in the cross-sector and sector-specific DPP roadmaps of CIRPASS [23]. It is well-suited for extending the Materials Module as it describes the internal components and chemical processes of batteries. Furthermore, it is perfectly aligned with the BVC ontology, which describes the process chains for material processing and manufacturing for batteries.
Figure 2 visualizes an extension of the C-DPPO designed to address the three CQs. As outlined in Section 4, a key limitation of the Material Module in the existing C-DPPO is the lack of a detailed nomenclature for battery materials. BattInfo fills this gap by providing a structured classification of chemical substances. Specifically, it defines **skos:prefLabel "ChemicalSubstance"**, with subclasses such as **ChemicalCompound** (e.g., lithium salts, cobalt oxides) and **ElementalSubstance** (e.g., lithium, graphite). These BattInfo classes can be mapped to the C-DPPO's existing structure, aligning with the **ChemicalEntity** or **MaterialComponent** classes.
A similar gap exists in the SCI Module, particularly concerning battery manufacturing terminology (CQ3). BattInfo introduces **skos:prefLabel "Manufacturing"** which includes subclasses such as

LiquidElectrolyteCellManufacturing or **BatteryModuleManufacturing**. These classes can be mapped to the **ProvenanceActivity** class that is part of the Material Module and connects to the SCI Module from the C-DPPO to specify the type of manufacturing or activity that was performed. This extends the SCI Module and contributes to answering CQ3.
Unlike CQ1 and CQ3, CQ2 cannot be fully addressed by any of the listed ontologies. However, the Battery Regulation provides a detailed definition of the required nomenclature and outlines the necessary data and IRs for measuring this indicator. This information can be used to manually extend the C-DPPO to incorporate a structured representation of carbon footprint data.
While the C-DPPO already provides a general framework for carbon footprint assessment, it currently lacks a precise unit definition. This gap can be addressed by extending the Unit class within the EI Module to incorporate standardized measurement units. By defining carbon footprint values in "kg of carbon dioxide equivalent" for individual lifecycle stages and specifying the total footprint as "kg of carbon dioxide equivalent per kWh of total energy provided over the battery's expected service life" [3], the ontology can ensure a more accurate and consistent representation of environmental impact data.

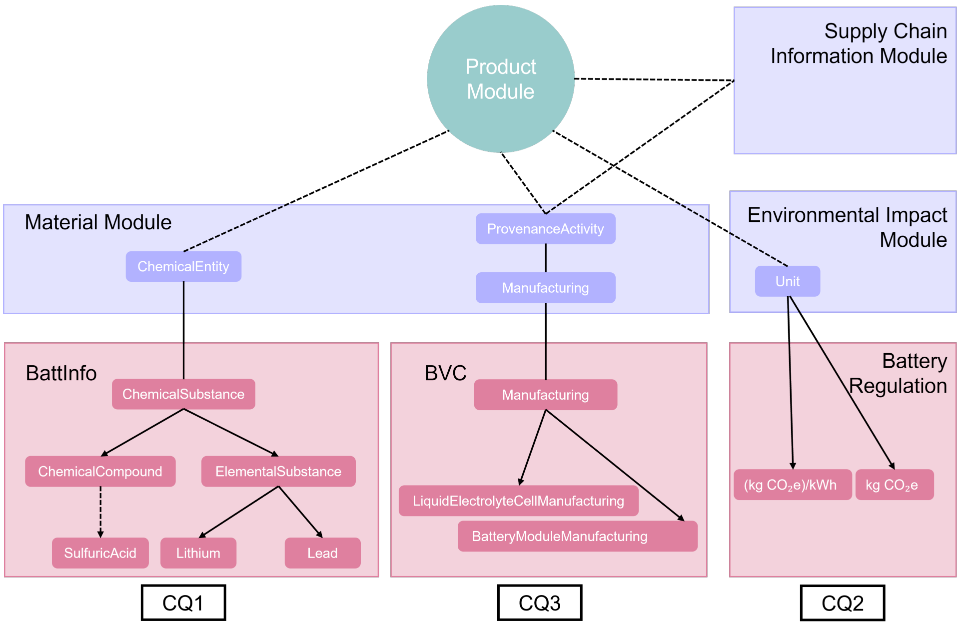


Figure 2: Own Illustration of a possible car battery extension of the C-DPPO to answer CQ 1-3.

5.2. Timber wall

A timber wall begins its lifecycle in forests and forestry operations, undergoing multiple stages of processing and transformation before it becomes part of a building. Unlike the car battery use case, which involves a complex combination of materials, a timber wall consists predominantly of wood, with adhesives as the only significant additional component. Despite its seemingly simple composition, defining a DPP ontology for this product presents several challenges. Key IRs include identifying all manufacturers and suppliers, mapping the processing stages the timber undergoes, specifying wood characteristics (species, density, strength class), and quantifying the global warming potential of both production and transportation [24]. These IRs translate into the following CQs with their corresponding C-DPPO Module that needs extending:

- CQ1 Which manufacturers and suppliers were involved in the production of the timber wall? (SCI Module)
- CQ2 What are the different processing stages the timber has undergone? (SCI Module)
- CQ3 What type of wood (species, density, strength class) is used in the timber wall? (Material Module)

CQ4 What is the global warming potential measured in CO_2 equivalent (kg CO_2 eq./m^2 during the life-stages of the timber wall? (EI Module)

To determine whether these CQs can be answered using existing ISs, we again compiled a non-exhaustive list of available ontologies and standards (see Table 3). An important asset for describing data related

Information source	Ontology	Module	CQ	EU(-rec.)	Source
Australian Timber Sector Ontology (ATSO)	✓	Material			[25]
EPCIS Ontology	✓	SCI/ Environmental	CQ4		[26]
CBV Ontology	✓	SCI/ Environmental		✓	[27]
IFC for BIM	✘	Material			[28]
StanForD 2010	✘	Material/ SCI	CQ1/2/3		[29]
ELDAT	✘	Material	CQ1/2/3		[30]

Table 3
A non-exhaustive list of ISs in connection to the timber wall use case.

to the supply chain of timber are the CBV and EPCIS Ontology, that define event data. However, despite their usefulness in structuring supply chain data, neither EPCIS nor CBV provide timber-specific nomenclature

Relevant standards that could help bridge this semantic gap are the StanForD 2010 standard or the ELDAT standard. StanForD 2010 standardizes data communication during timber harvesting. Therefore, StanForD 2010 includes nomenclature about tree species such as oak, pine, birch, and spruce, which can be used to extend the material module and contribute in answering CQ3. However, because ELDAT also defines tree species, an alignment of both standards is necessary to avoid redundancy in the ontology. While StanForD 2010 primarily deals with harvesting data, ELDAT governs post-harvest data exchange across market actors — including forest owners, timber industries, and logistics providers. It provides a structured representation of processing stages, such as wood measurement, wood intake, and wood allocation. Hence, it can be incorporated into the C-DPPO as subclasses of the **ProvenanceActivity** class, similar to the car battery use case, thereby contributing to CQ2 and the SCI Module.

CQ1 can also be at least partially answered by StanForD 2010 and ELDAT, as both define the nomenclature of key supply chain actors. StanForD 2010 introduces roles such as timber harvesting organizations, while ELDAT expands on the logistics chain, specifying actors like shippers and wood dealers. These classifications can be mapped to the C-DPPO's **Agent** class that ic connected to class **Provenance Activity**.

However, StanForD 2010 and ELDAT only cover the logistics chain up to the first buyer, leaving gaps in the representation of downstream processes, such as manufacturing and integration into construction projects. A potential candidate to extend the C-DPPO beyond this initial scope is the Industry Foundation Classes (IFC) standard, widely used in Building Information Modeling (BIM) [31]. IFC enables the classification of timber walls under the **IfcWall** class, which represents generic wall structures. A more detailed description can be achieved using the **IfcMaterialLayerSetUsage** class, which allows for the decomposition of a wall into distinct material layers. These IFC concepts provide a strong foundation, though further adaptation is needed to align with timber wall-specific materials and processing steps.

For CQ4 (global warming potential measurement), no existing standard or ontology explicitly defines a methodology for assessing carbon footprint at different lifecycle stages. To bridge this gap, insights from academic research, such as Sultana et al. [24], can be leveraged to inform necessary extensions to the C-DPPO.

The release of EPCIS 2.0 introduced the "how" dimension, which enables the integration of sensor metadata—such as temperature, humidity, and other environmental indicators—through the **SensorMetadata** class. This structure can be leveraged to incorporate lifecycle-based emissions data by aligning the C-DPPO's **Event** class with EPCIS's **EPCISevent** class. Furthermore, **SensorMetadata** and **SensorElement** can be utilized to capture carbon footprint data at various lifecycle stages.

To fully support CQ4, an additional subclass under the **Quantity** class in the C-DPPO is required to represent carbon footprint values. A standardized unit definition, such as kg CO_2-equivalent per square

meter (kg CO_2-eq./m^2), must also be introduced — following the same approach as in the car battery use case.
Another potential information source, the ATSO [25], appears to be a strong candidate for extending the C-DPPO. However, since this ontology is not publicly available, its direct integration remains uncertain. Figure 3 illustrates an extension of the C-DPPO for the timber wall use case, integrating the available IS where applicable.

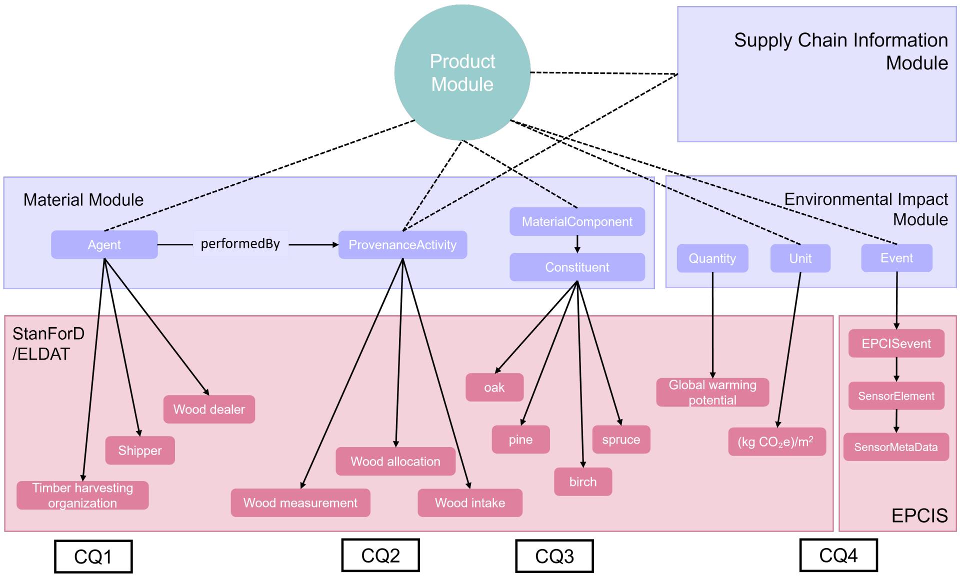


Figure 3: Own Illustration of a possible timber wall extension of the C-DPPO to answer CQ 1-4.

6. Discussion

This study examined early efforts toward developing a general and modular DPP ontology, designed as a top-level framework to serve as the foundation for future sector-specific DPP implementations. We identified the most advanced C-DPPO to date and analyzed which modules require further adaptation for different industry applications. To assess the feasibility of such extensions, we investigated existing ISs, including ontologies and standards, both EU-recommended and non-recommended.
By selecting car batteries and timber walls as contrasting use cases, we demonstrated how the availability of standardization resources significantly impacts ontology development efforts. In doing so, our findings reveal a stark contrast between the two selected domains.
For car batteries, while no publicly available DPP ontology currently exists, the BPP initiative is already in an advanced phase, supported by EU recommendations, regulatory frameworks, and sector-specific ISs. The challenge in this case is not the lack of data standards, but rather ensuring their semantic alignment and integration into a coherent ontology before the 2027 mandate takes effect. However, the tight implementation timeline raises concerns about whether the necessary DPP infrastructure and interoperability mechanisms will be fully established in time.
In contrast, the timber wall use case presents a different set of challenges. Here, the absence of a standardized DPP framework translates into significant gaps in available ontologies. Although certain industry standards (e.g., StanForD 2010, ELDAT, IFC for BIM) provide valuable data models, they lack a unified semantic structure that would enable direct DPP integration. While this sector does not yet face an immediate regulatory deadline, the lack of a comprehensive ontology underscores the need for proactive standardization efforts before future DPP requirements emerge.
This work establishes an initial foundation for further refinement and development of sector-specific DPP ontologies, but several key challenges remain:
(1) Systematic Collection of IRs: To ensure completeness and consistency, structured surveys and consul-

tations with industry stakeholders, policymakers, and researchers are needed. A deeper understanding of sector-specific data needs will provide a clearer roadmap for ontology extensions.
(2) Comprehensive Literature Review of ISs: A more exhaustive review of existing standards, ontologies, and regulatory guidelines will help identify additional resources that could support DPP ontology development. Crucially, inconsistencies between different ISs must be resolved to ensure semantic alignment.
(3) Evaluation of Modular DPP Ontologies in Practice: The general DPP ontology framework, as discussed in Section 4, should be tested with real-world sector-specific data to assess its adaptability. This involves examining how well existing modular DPP structures (e.g., those proposed by Kebede et al.) align with practical use cases.
(4) Practical Implementation and FAIR Data Integration: Beyond theoretical development, the practical applicability of the DPP ontology must be demonstrated. This can be achieved by integrating real-world data into distributed data spaces, ensuring compliance with FAIR principles. Such implementations would highlight the benefits of standardized ontologies, facilitating seamless data exchange across industries.

7. Conclusion

This study has demonstrated that the challenges in developing DPP ontologies vary significantly across industries and depend on the availability of standardized information sources. By analyzing two contrasting use cases — car batteries and timber walls — we outlined a path to addressing these challenges. A key takeaway is the necessity of establishing a unified framework that connects sector-specific DPP ontologies within a coherent top-level ontology. To assess the feasibility of such an approach, we evaluated the two most advanced DPP ontologies currently available, comparing their completeness and applicability. Additionally, we examined information sources—including standards and ontologies—to determine how they could be used to extend a general Core DPP ontology in a standardized and interoperable manner.
The current state of Core DPP Ontologies is preliminary, with the modular framework by Kebede et al. offering the most comprehensive foundation to date. Broader validation and sector-specific extensions remain necessary.
Our findings highlight a clear disparity in standardization readiness between different industries. Products that are already subject to future DPP regulations, such as car batteries, benefit from well-developed standards and structured data models. In contrast, industries without an EU-mandated DPP, such as the timber sector, lack an established framework, requiring significant effort to align existing standards, define IRs, and develop sector-specific ontologies.
Addressing these gaps will be essential for ensuring that DPP adoption expands beyond early regulatory mandates, ultimately supporting a broader transition toward structured, interoperable product data across industries.

Declaration on Generative AI

During the preparation of this work, the author(s) used GPT-4o and DeepL Write in order to: Grammar and spelling check. After using these tool(s)/service(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication’s content.

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