Research on a SaaS (Software as a Service)-based Digital Product Passport System Model for the EV Battery Industry Value Chain

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Abstract: - A notion for a policy tool that is particularly supported in policy circles to support the circular economy is the digital product passport (DPP). To lay the groundwork for more circular products, the basic design of a DPP should primarily comprise product-related data gathered by manufacturers. This study aimed to look into the design options for a DPP system and how these options for a DPP system and how these options could help players in the EV battery market given the absence of scientific debate surrounding DPP. With a focus on the role of stakeholders, it does so while introducing the idea of DPP and outlining the current system of legal and voluntary product information instruments. These preliminary results are incorporated into an examination of the possible advantages of DPPs that is actor centered. Through desk research and stakeholder workshops, data is produced. We discovered a significant need for more research, in particular, by examining the function of the DPP system for various actors. These issues include how to reduce red tape and increase incentives for manufacturers to provide specific information, how pertinent data can be compiled, what data collection tools (such as databases), and to which stakeholder groups these data are made available. To give DPPs better policy direction, other researchers might be able to fill the research gaps identified in this work.

Key-Words: - Digital product passport; Digital product passport system; Asset Administration Shell; Plug Play Link Socket; Data sovereignty

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1 Introduction

1.1 Background

The Digital Product Passport (DPP) is a policy tool concept that is being proposed in policy circles as a way to contribute to the circular economy. A DPP's preliminary design should largely comprise product-related information gathered by manufacturers, serving as the foundation for more circular products. Given the scarcity of scientific discourse on DPP, this study attempted to evaluate design choices for DPP systems and how these options could benefit stakeholders in the EV battery industry's product value chain.

The 2021 Circularity Gap Report indicates that both material consumption and carbon emissions are on the rise. Notably, Digital Product Passports

(DPP) are emerging as solutions to enhance transparency, data sharing, and standardization within the Circular Economy. There is an urgent need to develop services that digitize both product and process information throughout the product lifecycle, bridging the gap between conceptualization and real-world implementation.

To elucidate the concepts presented in Section 2, we detail the theoretical underpinnings of a SaaS-based DPP system. This entails a summarization of the DPP system's structure, an overview of the present state of the secondary battery industry, and an update on the current advancements in SaaS-based architectural development. Currently, data collected at the production site is stored on the DAQ server at the production site in real-time. In order to study a system that utilizes the DPP system, regardless of place or time, we propose a design and implementation plan for a DPP system that is flexible in terms of data sovereignty and security, which requires detailed research on data sovereignty and security in order to be configured as a system that utilizes a cloud platform. Within the proposed DPP system, essential components include information regarding product composition and origin, coupled with insights on the environmental and social impact assessments of the product throughout its production, utilization, and modification phases. The Digital Product Passport (DPP) concept has been introduced as a pivotal mechanism for gathering and disseminating information pertinent to a product's entire life cycle. It represents a compilation of data/information contributed by stakeholders engaged in the product's value chain. The primary objective is to foster a resource-efficient Circular Economy by consolidating data from the product life cycle, facilitating its sharing and analysis among key players in the value chain. This approach aids in conserving resources, making informed decisions, enhancing product circularity through R-strategies (including reuse, repair, refurbishment, remanufacturing, and recycling), and bolstering the transparency and traceability of products, materials, and components. A fundamental tenet of the DPP System is the imperative to institute a unified approach to DPP across diverse sectors. Concurrently, there's a necessity to devise strategies that guarantee the currency of product passports throughout their life cycle, emphasizing the reincorporation of recyclable waste into the economy as secondary raw materials. Figure 1 elucidates the foundational elements of the DPP system.

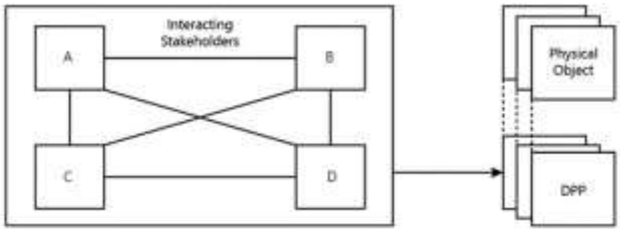

Fig. 1: Basic components of a DPP system

This paper is organized as follows. The concept of DPP and the method of collecting field data are studied, and a review of DPP currently used in the construction industry is presented in section 2. The DPP system architecture and studies the database operation structure that ensures data sovereignty by the supply chain, including data collection and storage methods based on international standards and connecting modules to enhance interoperability of data and programs by service provided in section 3. Section 4 provides a detailed account of the DPP system deployed, while Section 5 offers our conclusions and delineates forthcoming challenges [1], [2], [3].

2 Related Work

2.1 DPP (Digital Product Passport)

With the endorsement of the European Green Deal (European Commission 2019a) and the Circular Economy Action Plan (European Commission 2020a), the EU has ushered in a groundbreaking phase in its product policy. The concept of a 'electronic' or 'digital' product passport (PP) is expressly discussed in both strategy documents as a crucial tool for more product-focused policy. As a result, the terms "electronic" and "digital" are frequently used interchangeably in EU literature, indicating that the PP must include computer-readable data that has been stored on a server or in the cloud, such as details about a product's composition, its ability to be repaired and disassembled, and how to handle it at the end of (its) life (EOL). In order to recycle materials from items that are no longer in use, the European Resource Efficiency Platform, among others, started the present demand for a pan-European PP in 2014 (European Commission (COM) 2014). Subsequent to that, the discourse on the circular economy has seen significant evolution, particularly within the European context [4], [5]. According to the Wuppertal Institute, a broad definition that defines it as a data set that summarizes information about a product’s components, materials, and chemicals, as well as its repairability, spare parts, and proper disposal [1], [2], [3]. Depicted in Figure 2 is Configure DPP System Services.

Fig. 2: Configure DPP System Services

- The materials used for each component, information about the manufacturing procedure (such as joining techniques, binders), and details about the physical and chemical characteristics of the materials used, as well as their effects on human health and the environment, are all included in manufacturing data.
- Usage data consists of data such as documentation of replaced or repaired product parts.
- End-of-life data consists of end-of-life data, such as documentation of the “collection, sorting, and processing” of a product during its “end-of-life” (EoL) phase.
- Life cycle data includes information on product sales that can be used to estimate how much waste will be generated at any particular time and how many resources can be recycled.

2.2 Collecting Field Data: IIoT (Industrial Internet of Things)

Industrial IoT is part of the smart factory area and is the step from JIT (Just in Time) to FIT (Fit in Time) by integrating all the information. RFID technology is being considered as a way to verify the identity of objects, and IPv6 needs to be applied to give each object an identity. The MQTT protocol is posited as a replacement for HTTP, with the Organization for the Advancement of Structured Information Standards (OASIS) adopting MQTT as the standardized protocol for the Internet of Things. In factory automation, data is collected via OPC-UA and uploaded to the upper cloud via MQTT [6]. By replacing human senses, datafication is not only used in daily life, but also in factories, collecting data and implementing it into actual IoT service interfaces, rather than traditional, independent, and individual sensors. By using multi-disciplinary sensor technology, more intelligent and high-level information can be extracted. In addition, through arbitrary manipulation, users can instruct objects to act. IoT is a convergence technology, a combination of various technologies, and builds a system based on IoT and big data. Figure 3 depicts Ecosystem model directly related to industrial applications. IoT is more adaptable in terms of connectivity and criticality, allowing for ad hoc and mobile network structures as well as having fewer strict requirements for timing and reliability (with the exception of medical applications). IIoT, on the other hand, typically utilizes fixed and infrastructure-based network solutions that are well designed to meet communication and coexistence requirements, [7].

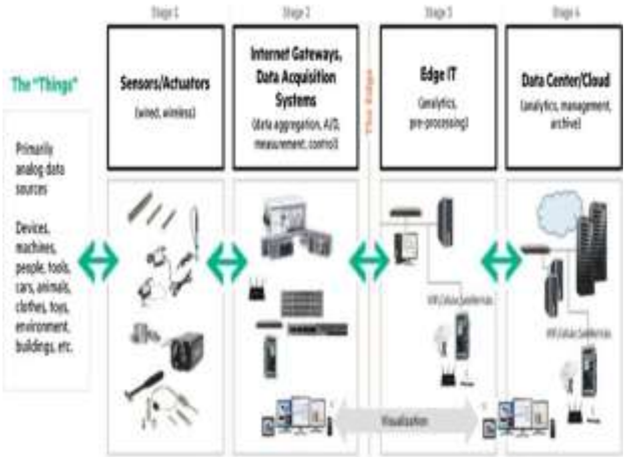

Fig. 3: Ecosystem model directly related to industrial applications

2.3 Create a Data Standard: AAS (Asset Administration Shell) Collecting

The "AAS networked" project should be used to ensure the interoperability of various VWS implementations from various companies and institutions, which will be based on the technology of AAS and proven by virtual testbeds and demonstrations, and evidence of the functional and general validity of the AAS concept and specifications should be used as the first goal, which is currently the implementation of an Industrie4.0 platform with globally connectable AAS models by 2030. In addition, several requirements must be specifically fulfilled on the basis of the AAS model [8], [9].

- Connectivity: Assets should connect the same analog and digital worlds via standard communication methods. Data integrity and cyber security: Appropriate integration and protection mechanisms ensure that processed data is kept accurate and is not damaged or unexpectedly changed.
- Clear semantics: Ensure that assets consistently use the same vocabulary for meaning and content and that messages are clearly understandable. Be able to communicate by exchanging and

interacting digitally. Complete tasks autonomously.

- Include AI: All stakeholders should be able to collaboratively use and interconnect machine and user data. Artificial intelligence can also be used to arrive at new solutions and business models.
- Guidelines for governance, along with data security and sovereignty: It mandates that stakeholders across national, European, and global spectrums operate equitably within an open ecosystem. The structure of the AAS data is illustrated in Figure 4.

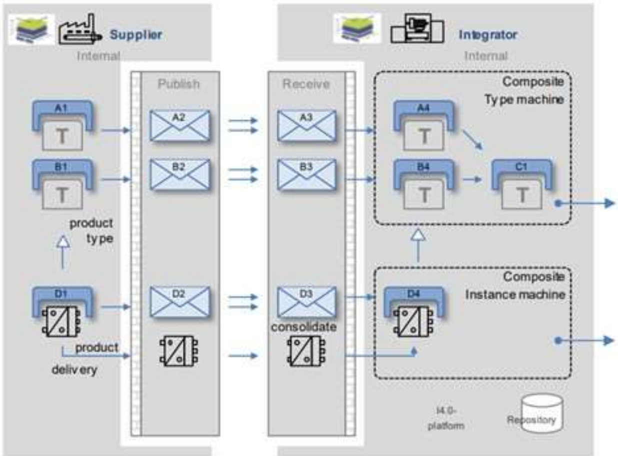

Fig. 4: AAS data structure

There are two types of assets set up using AAS. One is the type of product and the other is the actual data of the product. At this time, the data is delivered to the client or cloud AAS database using the OPC-UA protocol server.

2.4 AAS Data Interface: Leveraging OPC-UA (Open Platform Communications Unified Architecture)

OPC stands for OLE for Process Control. It is a standardized communication protocol. It is maintained by the OPC Foundation. Originally, the communication that followed the abbreviation was called OPCDA, OPC Classic, and then it evolved into OPCUA, which stands for Open Platform Communications Unified Architecture.

You may have a headache, but the version that runs only in the Windows environment because the concept of OPC Classic came out first is OPCDA. So, because it communicates with DCOM, the port is also specified, and it is difficult to set up for external access.

If you say that the PLC has OPC function in your environment, it means that UA has been introduced. Figure 5 depicts OPCUA application.

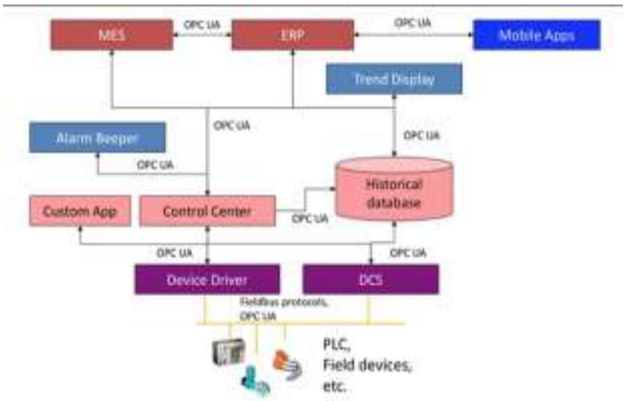

Fig. 5: OPCUA application

The reason to adopt OPC is that the same communication method can be used to communicate from the bottom to the top using the same protocol. If the communication protocols of each driver were divided into Chinese, Korean, and English, it would be difficult to communicate with each other.

So, it's easier to understand that OPC is organized to communicate in one language. This is called interoperability. But to make this communication more efficient, OPC servers provide many features, [10].

The Classic OPC standard provides three server services: Data Access (DA), Alarm AND Events (AE), and Historical Data Access (HDA). DA is exactly what it sounds like: Data Access. You can check and get the current value of the PLC. This is the most useful feature in the industrial field.

You can't get historical data. This is where it is compared to HDA. HDA can get historical data. The OPC HDA server stores the current data in a local historian and accesses it from the client. AE is a function that registers an alarm tag as an event on an alarm and notifies the client as an event when the alarm changes to True. In this way, Classic OPC has three types of servers.

3 DPP System Model

3.1 System Architecture

The DPP system serves as an IT/software infrastructure that associates physical products with DPPs, assimilates requisite data for DPPs, and fosters collaboration among diverse stakeholders within a product's value chain. At its core, the DPP system must establish an integrated approach to DPP across industries, ensure that recyclable waste is injected back into the economy as secondary raw materials, and develop mechanisms to ensure that product passports are kept up to date throughout the product lifecycle.

In addition, confidential business information and IP security issues need to be addressed to enable enterprise adoption. Figure 6 depicts DPP System Model for EV batteries.

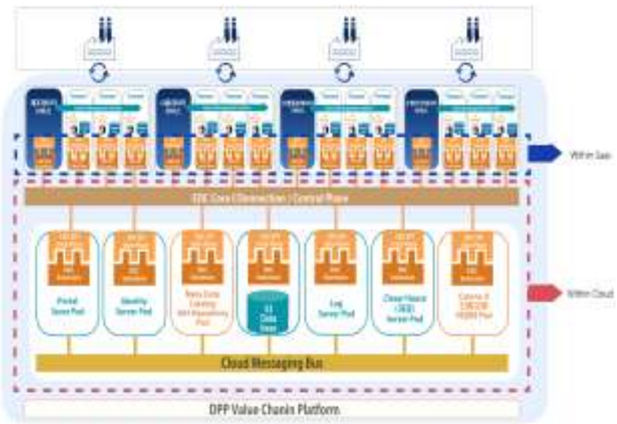

Fig. 6: DPP System Model for EV batteries

The Wuppertal institute has created a dataset that compiles information on a product's parts, materials, chemistry, repairability, spare parts, and directions for its disposal.

It has a broad definition and is gathered over the course of a product's life cycle. It is then utilized to optimize the design, production, usage, and disposal of the product. The following service modules make up the DPP system model.

- Manufacturing data service: The product encompasses components, the materials designated for each, a comprehensive overview of the manufacturing process (including joining techniques and binders), along with the physical and chemical properties of the materials in use. Additionally, details pertaining to substances detrimental to the environment or potentially hazardous to human health are incorporated.
- Usage data service: a service that provides information like records of product parts that have been replaced or repaired.
- End-of-life data service: a service that contains end-of-life information, like records of the gathering, sorting, and processing of a product during its "end-of-life" (EoL) phase.
- Lifecycle data service: Includes data such as product sales that can be used to predict the amount of waste expected at a given time and the number of resources that can be recycled

3.2 Trust Framework Architecture

It is a data-neutral platform that supports EV battery value chain Scope 1 to 3, providing suppliers with real-time measured data-based LCA calculation and PCF data exchange solutions. Figure 7 depicts the Trust Framework Architecture.

Fig. 7: Trust Framework Architecture

Implement a trust ecosystem with a governance framework that organizes and describes an ecosystem of issuers, holders, and validators.

- Issuers: Issue verifiable credentials to holders based on specific use cases. Typically refers to a trusted party in the ecosystem that claims compliance for an organization or product.
- Holder: Holds and controls verifiable credentials and shows them upon request. Typically refers to a party that is bound to an enterprise, entity, or individual.
- Validator: Requests the presentation of a verifiable credential and cryptographically verifies it to ensure that the data has not been tampered with. Uses data to support business processes and is typically bound to an organization or individual.
- Trust framework: defines the basic principles and governance that apply to the ecosystem, sets the rules that must be met to participate in the ecosystem (e.g., to become an issuer) and sets the technical standards to be followed.

4 Discussion and Challenge Issues

4.1 European Green Deal

The European Commission (EC) released the underlying presumptions of the European Green Deal, a new growth plan for the European Union (EU) and its citizens, in December 2019. The European Green Deal's primary goal is to make the EU into a just and affluent society with a cutting-edge, resource-effective, and competitive economy.

The European Commission (EC) aims to achieve net-zero greenhouse gas emissions across the Union by 2050. Emphasis is placed on mineral resources management, as the European Green Deal underscores economic growth that is independent of resource consumption, [11]. A paramount objective in actualizing this new European strategy is galvanizing the industry towards a clean and circular economy (CE), [12].

The EC emphasizes that transforming an industrial sector and all value chains will take the next 25 years. As a result, during the course of the next five years, significant decisions and actions will be taken. In March 2020, the EC released a new CE Action Plan, emphasizing a cleaner and more competitive Europe, [13]. Currently, the EU is transitioning towards a Circular Economy (CE), a shift that began with the initial communication on the CE from the European Commission (EC) in 2014, [14]. In the years that followed, the EC has diligently published subsequent CE communications: the CE Action Plan in 2015, [15], the CE Monitoring Framework in 2018, [16], and a report on the implementation of the initial CE Action Plan in 2019, [17].

The Circular Economy (CE) advocates for a shift from the linear "take-make-dispose" model to a circular approach where waste, when generated, is regarded as a valuable resource, [18]. In addition, it is advised to recycle and recover raw materials (RMs) from all waste streams in order to make better use of mineral resources. The European Commission emphasizes the need to keep an eye on changes to how mineral resources are managed throughout each of its member states.

Consequently, in 2018, the EC highlighted the management of Raw Materials (RMs) as a crucial component within the monitoring framework for the transition towards a Circular Economy (CE), [16]. In summary, the management of raw materials within the EU presents several challenges in executing the directives stipulated in the Green Deal strategy and the Circular Economy (CE) model. These challenges predominantly center around augmenting the recycling rates of critical raw materials, bolstering stakeholder participation, and elevating awareness regarding Sustainable Development (SD) and CE among enterprises active in the Raw Material (RM) sector.

To speed up the transformation process toward the circular economy and the Green Deal, all Member States are currently cooperating, for instance by putting national CE initiatives into place. The revised financial perspective for projects focusing on the balanced and circular management of Raw Materials (RM) under Horizon 2020 and other supporting mechanisms offers an exceptional opportunity to accelerate the transformation process.

4.2 Decarbonizing Transport in the European Union

The relationship between society and nature is currently under danger. This is the general scientific consensus, which is expressed, for instance, in the Anthropocene idea. The discourse surrounding the Anthropocene posits that from the onset of industrialization, human activity has had a profound impact on the Earth's system. Concurrently, several planetary boundaries have been surpassed, [19].

Amidst this discourse, various scholars critique the term "Anthropocene" and suggest the alternative "Capitalocene." This terminology posits that the disruption in the relationship between society and nature isn't a consequence of humanity as a whole, but rather a specific trajectory of social evolution, especially within capitalist production relations. Given the inherent disparities in development within capitalism, the accountability for and susceptibilities to events like climate change are disproportionately allocated, [20]. However, recent decades have seen a significant politicization of various issues, including climate change. The EU is often cited as a forerunner in environmental and climate policy. This leadership role in environmental stewardship forms a cornerstone of the European integration process. However, this perception has been contested and sometimes labeled as "the myth of a Green Europe, [21]."

In a recent development, Ursula von der Leyen, the President of the EU Commission, reaffirmed these aspirations at the close of 2019 by introducing the Green Deal, which sets the goal of decarbonizing the EU by 2050, [22]. The EU's balance sheet, however, shows a strong ambivalence when it comes to climate policy, with a picture that is heterogeneous both in terms of member states and from a sectoral viewpoint. emissions decreased 21.6 across the EU. We contend that the emission performance criteria put some emphasis on the environmental upgrading of the EU transportation sector in 2019.

Unlike the 2009 discussions, the German Government refrained from firmly advocating for the interests of the German automobile sector during negotiations on fleet limitations. This, in part, enabled the EU Directive to adopt a notably ambitious stance.

However, the political dynamics and institutional structures of the EU prevent a more comprehensive and effective response to the ecological crisis in the transportation industry. In studies on European environmental policy, this aspect is frequently not given enough weight. As we will demonstrate, this is especially true in discussions about environmental leadership.

4.3 ESPR (Eco-design for Sustainable Products Regulation)

Echo design for Sustainable Products Regulation establishes EU DPP and is key link between policies, [23]. Lately, there's been a growing demand for the integration of a DPP within the EU framework. In response, the DPP was initially presented in 2020 within the proposal for a new Batteries Regulation (European Commission 2020c). It also forms a core component of the EU's 2022 ESPR proposal. This proposal further seeks to broaden the ambit of the Echo Design Directive on energy-related products to encompass the broadest possible product range, establishing suitable minimum sustainability standards and information requisites for specific product categories (European Commission 2022), [24], [25].

The proposed DPP can be characterized as an organized compilation of product-associated datasets with a predetermined scope, established data ownership, and specific access privileges tailored for distinct target groups. These groups include consumers, policymakers, recyclers, and market surveillance authorities. This data is accessible via a unique identifier (either a number or code) that is also displayed on the product itself, [26]. Within the EU, the approach will likely involve a decentralized data storage system paired with a streamlined central registry managed by the EU, focused on select key parameters, [27].

4.4 The DPP in the new Batteries Regulation

A model for other policy topics The product group "battery," specifically portable, industrial, automotive, and light means of transportation batteries, serves as one illustration of the growing complexity of product assessment and legislation as well as the tremendous potential that a DPP can bring. The EU Batteries Directive (2006/66/EC) has governed the manufacture and disposal of batteries in the EU since 2008. The primary objective of the directive at that juncture was to curb the usage of cadmium and mercury, as well as to standardize and oversee the waste management of used batteries (European Commission 2020d), [24], [25].

The demand for batteries has significantly increased over the past several years as a result of its role as a fundamental element of e-mobility and the gradual electrification of power tools. The Batteries Directive 2006/66/EC no longer does them justice because not only the quantity of batteries has changed, but also their size, composition, and intended application. In addition, the battery's value addition and environmental impact have grown in importance at the same time. In order to support further battery research and industrialization in the EU, the European Commission established the European Battery Alliance in October 2017. The following year, the European Commission laid down the groundwork for a competitive and sustainable battery value chain in Europe with the "Strategic Action Plan for Batteries" (European Commission 2018). Given these circumstances, and as an element of the European Green Deal, the Commission unveiled a draft for a novel Batteries Regulation in December 2020, which was subsequently endorsed by the EU parliament in March 2022 (European Commission 2022), [25], [26].

The proposed Batteries Regulation encompasses rigorous standards to enhance sustainability, traceability, and social norms throughout the entire battery product lifecycle. It covers specifications for the effectiveness and longevity of batteries, as well as their carbon impact, usage of recycled materials, and rate of collection and recycling. The statute also mandates a label denoting the carbon footprint performance grade of the batteries, in addition to the ethically sourced origins of its components. Labeling batteries, for instance through QR codes, is pertinent for various stakeholders: it aids end-users in decision-making during purchase or disposal, whereas service providers, middlemen, or recyclers can access in-depth details about the battery's status and makeup (European Commission 2020c), [26].

The Batteries Regulation is set to roll out an electronic battery information exchange system by 2026. Here, data concerning every battery model introduced to the EU market would be cataloged and disclosed to the public. Each regulated battery that is transacted (or undergoes a status alteration, like repair or repurposing, and so on) in 2026 will also be accompanied by an electronic document, termed the "battery passport," serving as a DPP for batteries. The systems and policies that catalyze DPP include, [27]:

- The European Commission’s updated Circular Economy Action Plan.
- The EU’s Strategy for Sustainable Chemicals.
- The European Commission’s Refreshed Consumer Agenda.
- U.S.: An extract from the White House's 100-Day Reviews pursuant to Executive Order 14017.
- Japan’s 2020 Vision for a Circular Economy.

- China's 14th Five-Year Development Blueprint for Circular Economy.
- The Australian Parliament's investigation and report titled "From Waste to Worth: Pioneering a Circular Economy."
- The Federal Consortium for Advanced Batteries (FCAB).

5 Conclusions

Although the analysis, demand, and partial implementation of the collection and publication of product-specific data using IT-based systems have been ongoing for many years in various contexts, the concrete discussion of the so-called "electronic" or "digital" PP is still in its infancy, and many aspects and details are still being worked out. It must be remembered that the concept of PPs as a whole has historically been debated using a variety of terms and methodologies, including "digital twins," resource or material passports, environmental product declarations, life cycle files, cycle/recycling passports, etc.

The central concepts behind these terminologies often remain in nascent stages and are yet to evolve into universally comparable standards. Hence, while these terminologies may often converge on a foundational principle, nuances in their application and objectives can differ. It remains an open question as to which existing informational tools will either be phased out in favor of a standardized EU-wide DPP or will form the foundation for its evolution. Regardless of the specific format of future Product Passports (PPs), it's vital that data is systematically collected, updated, and rendered accessible to relevant user groups, possibly even at a product-specific level—e.g., for high-value items.

While certain data can be gathered that is generally applicable to a product group or model (for example, generic repair data), product-specific data that has to be even more precisely defined would necessitate integrating all pertinent stakeholders across the whole product life cycle. It would be necessary to update product-specific information if, for instance, the qualities or components of a certain product changed as a result of a repair procedure in order for, say, waste management businesses, to dispose of the product in the best possible way. Product-specific information would be required when mass production becomes more and more customized and incorporates design preferences. Although there is currently not enough information regarding the precise specifications of the future DPP, some factors must unquestionably be thoroughly compared in terms of advantages and disadvantages as part of anticipated additional stakeholder conversations.

For effective execution, the roles and standards pertinent to various stakeholders must be explicitly articulated, especially in contexts like transparency, verifiability, long-term data availability, data disclosure, and security stipulations. Based on the assessment, decisions need to be made concerning where, by whom, and for what duration data will be stored—be it with manufacturers, importers, or other "distributors" (Figure 2). The consideration shouldn't just be about where the data resides but also about the entities responsible for feeding the data into the system during the DPP's implementation. This could range from producers and suppliers to importers, ensuring that proprietary and trade secrets remain confidential.

Critical to note is that the system must not only facilitate data input (write access) from distributors in the long run but also from other entities, such as repair services. This allows for the possibility to update product-specific data over its lifecycle. Moreover, the data and insights collected won't hold uniform relevance across all user demographics in line with their market functions. Hence, to achieve focused data management (often termed the "need to know" principle), the system must ensure that designated user groups have access only to pertinent, curated information, emphasizing the protection of sensitive business intelligence (as noted by the European Policy Centre 2020). This brings up the question: Should such data be exclusive for market surveillance purposes, or should it be extended to other agencies to promote equitable global supply and value chains, especially if there's a need to trace the origins of raw materials used in products or components?

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