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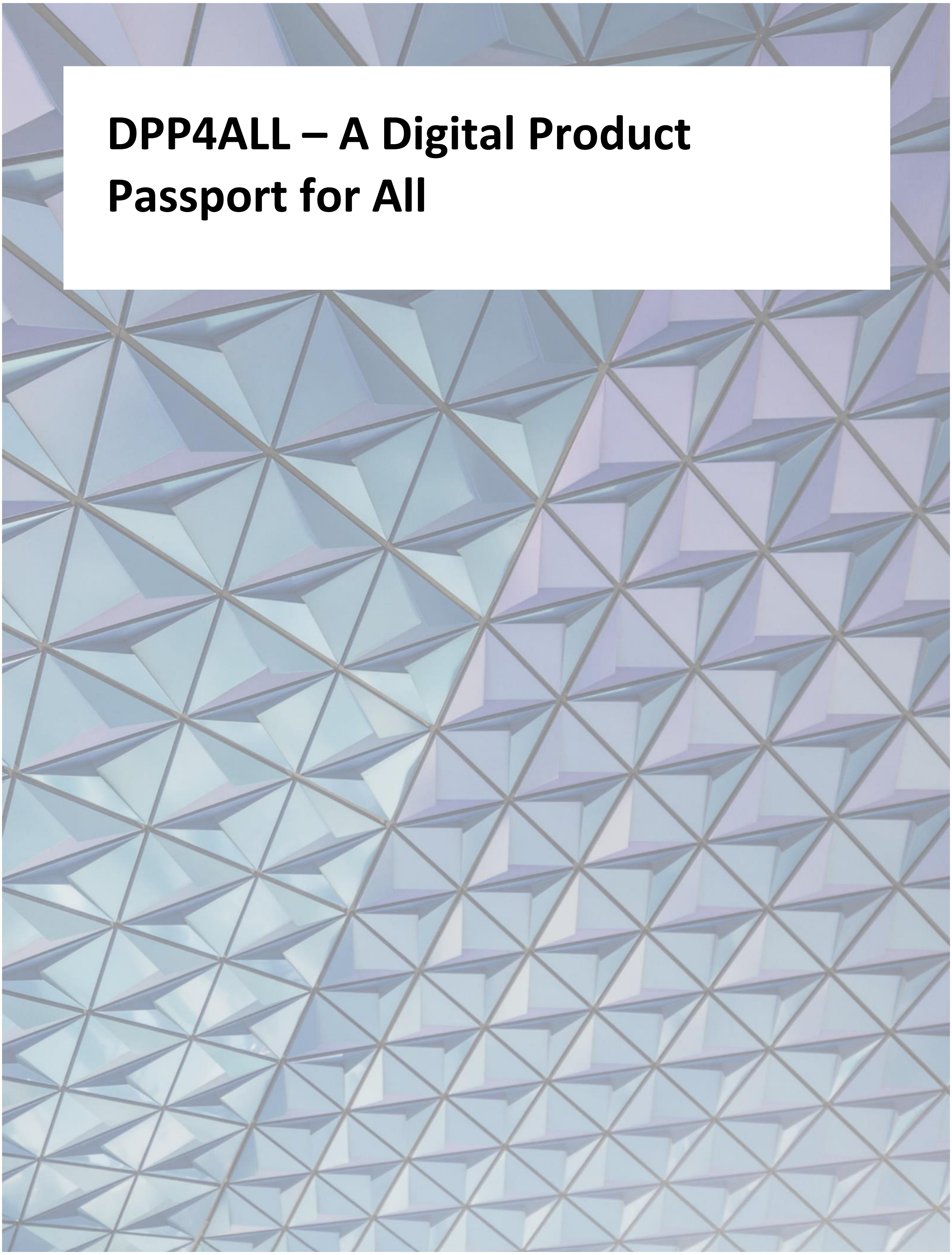
DPP4ALL – A Digital Product Passport for All



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Foreword

This report was commissioned by the Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK).

The contract was publicly tendered in the form of an R&D service on the topic of "Data service ecosystems for the digital product passport" by the Austrian Research Promotion Agency between 03.10.2022 and 14.12.2022 and awarded in a competitive, jury-based application process, from which the bidder consortium consisting of St. Pölten University of Applied Sciences and Brainbows GmbH emerged as the winner.

According to the tender text, the aim of this R&D service was "to investigate the data-related prerequisites for digital product passports based on the Sustainable Products Initiative in the Circular Economy Action Plan. During the project, key questions are to be elaborated and R&D needs are to be identified. The results will flow into the lead project (Leitprojekt) call planned for 2023."

Specifically, stakeholders of the priorities named in the Circular Economy Action Plan (including textiles, energy storage, electronics) were to be identified for the implementation of a digital product passport and their activities documented. For this purpose, the conditions for data exchange were to be examined within three use cases and the added value of a digital product passport for these stakeholders and other parties involved was to be worked out. Furthermore, the legal and contractual requirements for data exchange were to be researched, and related implementation issues and necessary framework conditions were to be presented. In addition, interfaces and technical requirements for the implementation of the data exchange should be identified and described with special regard to security and sovereignty.

To meet these requirements, the contractors St. Pölten University of Applied Sciences and Brainbows GmbH put together an interdisciplinary team of experts and developed and implemented a multi-method design with the aim of ascertaining the technological, organizational, and legal conditions for the implementation of a digital product passport and deriving recommendations for the client.

The assignment took place on 01 March 2023 with a term of 6 months. The report was submitted on time.

Acknowledgements

This report was written in close cooperation with our project partner Brainbows, in particular Martin Weishäupl, Markus Schneidergruber and Thomas Matzak, whom we would like to thank at this point for the smooth and motivated cooperation as well as organizational and content-related support.

Further acknowledgements go to Verena Mussnig, program manager at the FFG, as well as Ingo Hegny and Ernst Kössl from the BMK for their support throughout the project.

Last but not least, we would like to thank all authors and contributors to this interdisciplinary project. Nine experts from three different research institutes – the Institute of Innovation Systems, the Institute of Information Security and the Institute of Integrated Mobility – have contributed to the development and timely completion of this study, which was challenging both in terms of content, methodology and timely constraints.

Tassilo Pellegrini
Project Lead

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Executive Summary

This report investigates the technical, legal, and organizational requirements for realizing a Digital Product Passport (DPP) capable of accommodating various products, industry sectors, and stakeholders. Its purpose is to derive insights and research questions to advance the subject matter und provide the Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK) with empirically based recommendations for the development of a publicly funded project call.

Investigating Digital product Passports requires a holistic understanding of the landscape that considers the diverse needs and rationales of different sectors and stakeholders. This also includes the notion that there won't be one universal version of a DPP encompassing all existing products and services, in the manner of one-size-fits-all. Rather, the infrastructure, applications, and services for the creation, processing, and presentation of trustworthy product and sustainability data must be tailored to meet different requirements, in terms of technical preparation, legal and organizational embedding, and the benefits that stakeholders with diverse expertise and life contexts derive from a DPP.

A multi-method design with the aim of ascertaining the technological, organizational, and legal conditions for the development and implementation of a digital product passport was developed under special consideration of sector-specific and consumer-specific approaches and expectations towards a DPP. The authors derived the following recommendations:

General recommendations:

- **Recommendation 1:** Clarification is needed how a DPP infrastructure shall be institutionalized including the division of responsibilities and accountabilities among the affected sectoral stakeholders with a special focus on the persistent, long-term availability of product data and under special consideration of nuanced disclosure and access control.
- **Recommendation 2:** Clarification is needed about methodological recommendations on capturing, documenting, and processing product data to generate sustainability

KPIs in accordance with the specificities of the products concerned under close alliance with the sectoral stakeholders.

- **Recommendation 3:** Easily accessible, comprehensive, and free awareness building and training measures should be offered to companies (especially SMEs) that lack the necessary knowledge and capacities to implement and maintain a DPP.
- **Recommendation 4:** Training material needs to refer to and acknowledge already existing sector-specific disclosure regulations on product information and their relevance for serving a DPP. Herein it is of vital importance to not overburden companies with additional disclosure requirements that are out of their control or that could hamper their legitimate interest in IPR protection or secrecy.
- **Recommendation 5:** Recommendations should be given on licenses and usage rights applied to publicly disclosed data, ideally by applying a uniform license model that does not hamper its reuse especially for business purposes. Herein, permissive licenses could be more attractive licensing models compared to copy-left licenses that come with specific restrictions when combined with other licenses.
- **Recommendation 6:** To ensure interoperability at the system and data level and to avoid vendor lock-ins it is vital to stick to open standards in the syntactical and semantic description of product-related data in machine-readable form for their exchange and reuse across various systems and applications. Openness needs to be ensured at the level of interfaces (APIs), data models (ontologies and schemas for metadata), as well as the terminologies (controlled vocabularies for product descriptions) and uniform identifiers (universal and persistent resource IDs) to enable automated and context-sensitive data exchange.
- **Recommendation 7:** Open standards do not necessarily interfere with the legitimate interest in protecting and controlling the access to data, although technical solutions to implement both aspects into one environment are still challenging, given that the necessary IT infrastructure is mostly privately controlled. Emerging technological concepts such as distributed ledgers and dataspaces offer viable solutions but are either in an early stage of development (such as dataspaces) and/or require adjustments at the level of corporate IT governance (i.e., when it comes to distributed ledgers), especially when security issues are concerned.
- **Recommendation 8:** The heterogeneity of stakeholders involved in a DPP requires nuanced approaches to documenting and displaying product-related information, especially when this information is meant to provide a basis for informed decisions. Measures need to be taken that investigate appropriate visualization techniques for various levels of interest in and intellectual capabilities to understand and process

product information in accordance with the stakeholders' informational needs. This is especially relevant for consumers.

- **Recommendation 9:** DPPs shall be designed to enable better market insights and generate operational efficiency in production workflows across the product's life cycle, especially during the end-of-live phase. This includes a better conceptualization and understanding of circularity for specific product types and a transfer of knowledge between the supply chain actors about desired performance indicators, ideally streamlined with policy objectives on cleaner production.
- **Recommendation 10:** Projects developing and testing technical solutions for persistent data provision and storage for product information should provide sand boxes and experimental environments that allow system stakeholders to gain experience and knowledge about the efforts for and impacts on their established data management practices and workflows under special consideration of issues associated with security, trust, and secrecy.

Sector-specific Recommendations

In addition to the general observations described above that following sector-specific challenges should be addressed:

Building and Construction

- Evaluate and ensure maximum reusability of existing product information contained in product sheets and other documentations provided by manufacturers of building and construction materials.
- Screen existing product registries and repositories for syntactic and semantic interoperability and identify weak spots in the machine-readable representation of this data at the ontological and terminological level.
- Investigate the appropriate level of disclosure and machine-readable representation of compositional information of building and construction materials, offering solutions for the nuanced role-based accessibility of this information across the product life cycle.
- Investigate techniques to persistently attach appropriate identifiers to building and construction materials or – where not possible – to document this information over long time periods (up to decades) so that this information is preserved for future generations.

- Develop measures to mitigate an imminent skill shortage for domain experts familiar with the digital documentation of product information on building and construction materials.
- Develop measures to increase the level of digitization and datafication in the building and construction sector to mitigate an imminent skill shortage for IT professionals in this area.
- Pay attention to cost burdens stemming from implementation and maintenance efforts of a DPP under special consideration of SMEs.
- Investigate compliance issues for manufacturers and construction companies with respect to warranty obligations and privacy preservation arising from the long-term availability of building and construction information.

Battery Life Cycle Management

- Evaluate and ensure maximum reusability of existing product information contained in product sheets and other documentations provided by battery manufacturers and service providers specialized in state-of-health solutions.
- Screen existing product registries and repositories for syntactic and semantic interoperability and identify weak spots in the machine-readable representation of this data at the ontological and terminological level.
- Investigate the appropriate level of disclosure and machine-readable representation of compositional information of batteries, offering solutions for the nuanced role-based accessibility of this information across the product life cycle.
- Investigate techniques to persistently attach appropriate identifiers to batteries or – where not possible – to document this information along the product lifecycle under special consideration of change of ownership.
- Investigate how to better document and streamline the flow of materials, components and products across a battery’s life cycle to ensure maximum extension of lifetime through repairability, reuse and recycling.
- Investigate interactions between IPR protection, usage rights, and disclosure of technical specifications along an extended battery lifecycle.
- Investigate warranty issues and responsibilities for second-life applications of used batteries under special consideration of product-safety.

End-of-Life / Waste Management

- Investigate the necessary granularity and machine-readable description of information on materials and substances for the purpose of workflow efficiency in sorting, recycling, and disposal.
- Investigate techniques to efficiently extract and collect product information from dumped products at the item or batch level.
- Develop measures to mitigate an imminent skill shortage for domain experts familiar with the digital documentation of product information for the end-of-life phase and purpose of disposal.
- Develop measures to increase the level of digitization and datafication in the waste management sector to mitigate an imminent skill shortage for IT professionals in this area.
- Pay attention to cost burdens stemming from implementation and maintenance efforts of a DPP in the waste management sector under special consideration of SMEs.
- Investigate the legal liabilities of the waste management sector as an enabler for the reuse and second life of waste and warranty issues deriving from this.

Consumers

- Investigate appropriate levels of information richness and complexity-reducing visualizations provided to consumers in a cascaded manner so that different degrees of knowledge about and interest in product information can be served.
- Develop techniques and solutions that preserve the privacy of users, especially when they are willing to share product usage data or interact with DPPs in general.
- Envision and design user-friendly services for consumers with varying degrees of intellectual, cognitive, or physical capabilities to draw additional benefits from DPPs beyond the mere provision of factual information.
- Consider attitudinal and lifestyle related factors in the user-friendly provision and compilation of product information.
- Investigate usage policies and licenses that allow consumers to actively participate in a DPP ecosystem.

Introduction

The concept of a circular economy, which strives to promote resource efficiency and minimize waste by reusing materials, is gaining momentum as a sustainable alternative to traditional linear economic models. However, this concept is still in its early stages of development, particularly in terms of data management and standardization (Mulhall et al., 2022).

But the transition to a sustainable circular economy relies on a robust data foundation. Such data not only serves as the basis for evidence-based actions but also acts as a prerequisite for digital applications and tools that facilitate the shift to an environmentally sustainable economic and social system centered around the principle of circularity. Within this transformative context, a vital step emerges – introducing the Digital Product Passport (DPP), a concept defined in the EU Commission's proposal for a new Ecodesign Directive (European Commission, 2022a).

The DPP can be envisioned as a large-scale data infrastructure of sector-specific solutions "*to electronically register, process and share product-related information amongst supply chain businesses, authorities, and consumers. This is expected to increase transparency, both for supply chain businesses and for the general public, and increase efficiencies in terms of information transfer*" (ibid).

The Digital Product Passport is not confined to a single purpose. Its mission encompasses many objectives, all of which converge toward sustainable and circular practices. The envisioned DPP aims to gather and provide product-specific data essential for gaining a better understanding of a product's eco-design, such as insights into 1) a product's composition, reparability, reusability, maintenance, refurbishment, and recyclability, 2) the presence of substances of concern, 3) its resource and energy efficiency, carbon footprint, and instructions for appropriate disposal. Such comprehensive data has the potential to foster the development of more durable, easily reusable, repairable, recyclable, and energy-efficient products and services and to empower various stakeholders with valuable information to make informed investment, procurement, and consumption decisions. Hence, the DPP engages diverse actors, such as companies, consumers, public organizations, investors, and beyond across the DPP ecosystem.

In addition, the evolution of Digital Product Passports is driven by the large-scale integration of advanced data capture, processing and management technologies which enable real-time data tracking, secure data sharing, and information exchange across supply chains, thus facilitating the implementation and governance of circular business practices.

Through its role as a communication tool among various stakeholders (Thomas Götz et al., 2022), DPPs can contribute to circular economy awareness and participation. Furthermore, the DPP serves as a vital source of evidence for various interest groups. It enables them to verify and enforce legal compliance on the part of manufacturers. By having access to comprehensive and reliable data, stakeholders can ensure that products meet regulatory standards and align with sustainability goals. However, the realization of DPP is not without challenges. Technical issues, regulatory complexities, legal concerns, and the need for cross-sector collaboration are hurdles that must be sensitively navigated and solved.

The legal and regulatory framework for Digital Product Passports is currently in progress, primarily driven by the European Commission within the context of the European Green Deal and the EU's industrial strategies. The key document outlining this framework is the Proposal for Ecodesign for Sustainable Products Regulation (European Commission, 2022a) published in March 2022. This directive defines the DPP, its scope, and its informational requirements. However, while the regulatory framework is taking shape conceptually, certain aspects, particularly technological specifications and operation guidelines for the DPP system, still require further development and clarification (Plociennik et al., 2022b). The process of refining technological specifications and operational guidelines is not only a technical endeavor but also one that requires collaboration and consensus-building among diverse stakeholders. To put it short: Engineering a digital product passport is not the problem. Doing it for everybody is the challenge.

Scope of this report

This project investigates the technical, legal, and organizational requirements for realizing a Digital Product Passport capable of accommodating various products, industry sectors, and stakeholders. This approach requires a holistic understanding of the landscape that considers the diverse needs and rationales of different sectors and stakeholders. This also includes the notion that there won’t be one universal version of a DPP encompassing all existing products and services, in the manner of one-size-fits-all. Rather, the infrastructure, applications, and services for the creation, processing, and presentation of trustworthy product and sustainability data must be tailored to meet different requirements, in terms of technical preparation, legal and organizational embedding, and the benefits that stakeholders with diverse expertise and life contexts derive from a DPP.

To tackle this complexity, this report investigates the concept of a DPP from various perspectives. This includes a normative framing of the concept (chapter 2), a technological analysis of existing approaches (chapter 3), and the investigation into the company perspective on a DPP. For the latter case we investigated three sectors that are central to the transition towards a circular and environmentally sustainable economy and that are currently most affected by a DPP in terms of regulatory governance, namely: the building and construction sector, the battery manufacturing sector, and the waste management sector.

Efficiently managing product information in the building and construction sector is an important step to reduce its environmental impact and better understand the complex interdependencies with other sectors. According to the European Commission “*the built environment has a significant impact on many sectors of the economy, on local jobs and quality of life. It requires vast amounts of resources and accounts for about 50% of all extracted material. The construction sector is responsible for over 35% of the EU’s total waste generation. Greenhouse gas emissions from material extraction, manufacturing of construction products, as well as construction and renovation of buildings are estimated at 5-12% of total national GHG emissions. Greater material efficiency could save 80% of those emissions*” (European Commission, 2023a).

The battery manufacturing sector bears responsibility for contributing to global issues such as climate change, air pollution, and toxicity. Transportation accounts for a substantial share of greenhouse gas emissions, with direct energy-related carbon dioxide (CO2) emissions making up 24% of the total. In this sector, passenger vehicles make the largest contribution with a share of over 45%. For achieving a significant reduction in greenhouse gas emissions, the use of light weight battery electric vehicles is considered. However, for the time being the production phase of batteries has a larger environmental impact than that of cars with internal combustion engines. Electric vehicle production accounts for over 61-78% of its life cycle CO2 emissions (Safarian, 2023). CO2 emissions from the production of electric cars amount to 14.6 tons (60.8 gCO2/km), which is 132%

and 123% of the emissions from petrol and diesel cars respectively (Safarian, 2023). To minimize these impacts and comply with the EU circular economy plan, batteries would have to remain in the value chain as long as possible. This would be possible by recycling the batteries already in use (Koroma et al., 2022).

Although the waste management sector lies horizontally to all other economic sectors, it is important to recognize that the construction and the battery manufacturing sector (as well as the textile sector) contribute significant amounts of waste and problematic substances that can be either avoided or recycled. The construction sector generates 30-40% of solid waste annually. Over 35% of this waste ends up in landfills. This includes waste generated from demolition, construction and renovation work. Especially the construction and demolition waste have a negative impact on the environment, due to ever increasing amounts in landfills. In this context, end-of-life batteries are also becoming increasingly important. With over 125 million electric vehicles on the market in 2030, 11 million tons of electric vehicle lithium batteries will end up in landfills. This compares to the 190,000 tons of industrial batteries disposed of annually in the EU. Currently, hardly any industrial batteries are recycled or properly disposed of in the EU, which leads to the emission of harmful substances and subsequently to an increase in human health problems (Ismaeel and Kassim, 2023). Efficient resource exploitation, material recovery, and energy savings can help mitigate the waste problem. Implementing waste minimization methods, waste segregation strategies, and resource management can recover approximately 80-90% of currently dumped waste (Ismaeel and Kassim, 2023).

Beside these sector-specific investigations, this report additionally investigates the perspectives of end-consumer towards and the perceived benefits they derive from a DPP. Existing research reveals that consumers have not been subject to the young area of research unfolding on DPPs. Thus, gaining a better understanding of the usage behavior related to product information and the perception of aggregated product data as a DPP is of vital importance for robust design decisions and demand-driven rollout strategies.

Report structure

To this end, this report is structured as follows:

Chapter 2 provides an overview of the Digital Product Passport, covering its conceptual and legal foundations. It discusses stakeholders from the sectors building, battery manufacturing, and end-of-life/waste management. The sectors have been chosen in close alliance with the contractee for the following reasons: First, these sectors will be among the first to be operationally affected by a DPP, thus offering a rich body of literature and insights; second, these sectors have a comparatively large environmental footprint; and third, the sectors differ in their degree of supply chain internationalization and local embeddedness. Policy frameworks like the European Green Deal and data governance's importance are highlighted, along with relevant projects and initiatives.

Chapter 3 advances the discourse by presenting recommendations for protocols, standards, and interface specifications for a DPP infrastructure, with particular attention to security and data sovereignty. The chapter explores DPP's technological foundations, including research projects and initiatives, regulatory requirements, core components involved in DPP implementation, and proposed DPP architectures and technologies. The overarching aim of this chapter is to provide a comprehensive understanding of the domain's current state and potential advancements.

Chapter 4 covers companies' perspectives through in-depth interviews with representatives from the building and construction, battery manufacturing, and end-of-life/waste management sectors. The interviews focus on technological, organizational, and legal aspects, discussing the added value for participants and stakeholders of a product passport, challenges, and sector-specific relevancy scores. Lastly, the chapter highlights the benefits of DPP from extensive literature research.

Chapter 5 transitions into the consumer domain, presenting a quantitative online survey conducted among the Austrian population. It focuses on three key aspects: consumers' information-gathering behavior, the perceived relevance of the Digital Product Passport information, and willingness to share usage data. The chapter includes methodology, data model, survey results, and interpretation, offering valuable insights into the consumers' perspectives as vital stakeholders of the Digital Product Passport.

Chapter 6 concludes this report with recommendations on technological, organizational and legal aspects of DPPs in accordance with the investigated sectors, and research questions that should be addressed to advance the subject matter.

DPP – Definitions, Stakeholders, and Legal Foundations

This chapter gives an overview of the conceptual and legal foundations of a Digital Product Passport illustrating the state of discussion and possible development paths. It covers the following aspects:

- The chapter presents the definitions and objectives of the Digital Product Passport by elaborating on its fundamental concepts. It explains the dual perspectives of the DPP - one from the product level and the other from the system level perspective.
- Next, it discusses the importance of understanding sector-specific stakeholder constellation and their positioning within the sector's supply chain by highlighting the functional roles of three sectors: building and construction, battery manufacturing, and end-of-life/waste management.
- It outlines the broader policy frameworks and regulations, particularly the European Green Deal, regulations that aim to foster cleaner production practices, and regulations that impact corporate governance. Moreover, the chapter outlines the emerging regulatory frameworks that will shape the implementation of DPPs.
- It emphasizes the critical role of data governance in the DPP context, including the authority to make decisions and establish regulations for data collection, storage, processing, and sharing across the DPP ecosystem.
- Lastly, the chapter highlights various projects and initiatives focused on developing and implementing different types of product passports.

State of Discourse

Digital Product Passports (and conceptual predecessors thereof) are a relatively novel topic. To assess the state of research and development on the digital product passport (DPP), we conducted a literature search following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) by Page et al., (2021) (see Figure 1).

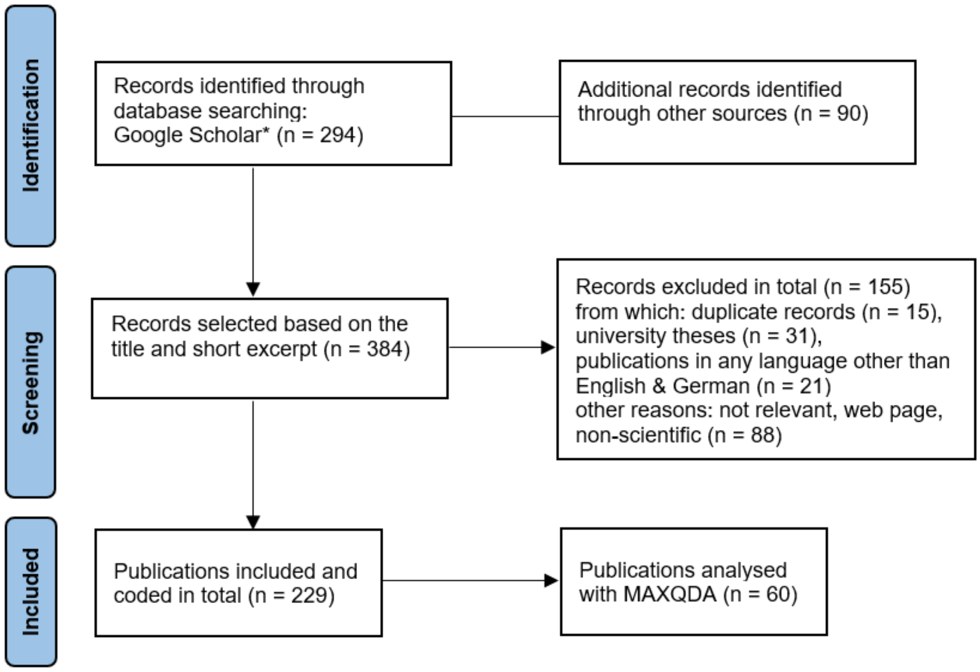

Figure 1: PRISMA flow diagram for selection of DPP-related literature

We employed the terms "product passport," "material passport," and "battery passport," along with various derivatives, as part of the search query. In an initial step, we utilized the Google Scholar database, incorporating data up to its latest update on 9 May 2023 resulting in 294 records. To further enhance our sample, we cross-referenced the identified records with the query results from the journal databases, SpringerLink, Elsevier, and Sage Publications. This additional step yielded 90 more records, which were subsequently included for in-depth analysis. To assess the relevance of the gathered publications, we conducted a meticulous screening of titles and short excerpts, leading to the inclusion of 229 records for further investigation. From these we extracted and systematically analyzed a subsample of 60 scientific publications for the analytical and methodological purposes which also provided the corpus for the theoretical backing and investigations carried out in this report. Figure 2 depicts the publication pattern and unfolding of the discourse on DPPs since 1982, when the term was first mentioned by Eichstädt (1982).

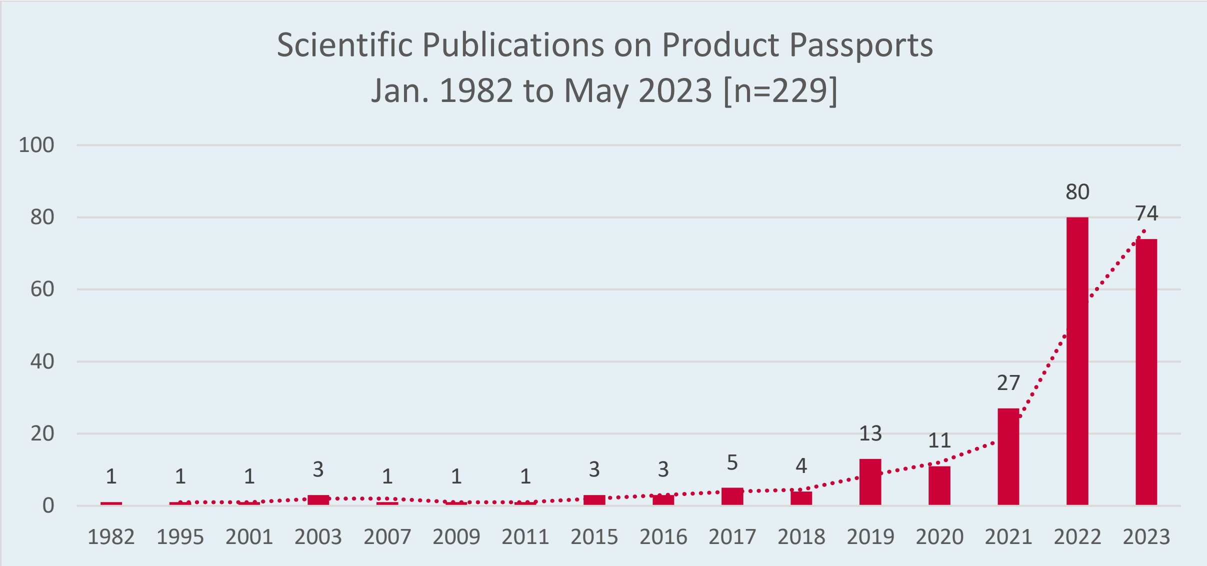

Figure 2: Scientific Publications on Product Passports

The chart compellingly illustrates the novelty of the topic as a subject of scientific discourse, with a remarkable 67% of all publications related to a (digital) product passport (or an equivalent thereof) being released within the last 3 years. Prior to the year 2021, the concept had received limited attention in scientific inquiry. Not surprisingly, this publication pattern closely aligns with the unfolding regulatory measures at the European level and international level as will be outlined in chapter 2.4.

DPP – Definition(s) and Objectives

Providing product information to various groups of interest – be they the public or stakeholders in sector-specific value chains – has been a cornerstone of several market and consumer regulations for several decades. The growing amount and fragmentation of product related information has sparked various initiatives to think about new ways of collecting, administering, and using such information for various purposes along the supply and value chains from which the Digital product Passport (DPP) is one of the latest endeavors. In the following sections we will take a closer look at its conceptual predecessors and try to elaborate on the necessity and obstacles for a unified definition.

The German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) defines a Digital Product Passport (DPP) as "*a data set that summarizes the components, materials and chemical substances or also information on repairability, spare parts or proper disposal for a product. The data originates from all* *phases of the product life cycle and can be used for various purposes in all these phases (design, manufacture, use, disposal) [translated from German by DeepL]"* (BMUV, 2023).

Correspondingly, the global standardization organization GS1 defines DPPs as "*a set of sustainability data that enables circular products and business models*" (GS1, 2023).

According to the European Health and Digital Executive Agency (HaDEA, 2023) the main objectives of a DPP are:

- To enable sharing of key product related information that is essential for products' sustainability and circularity, including those specified in Annex III of ESPR (Ecodesign for Sustainable Products Regulation - (European Commission, 2022a)) proposal, across all the relevant economic actors.
- To accelerate the transition to circular economy, boosting material and energy efficiency, extending products lifetimes, and optimizing products design, manufacturing, use and end of life handling.
- To provide new business opportunities to economic actors through circular value retention and optimization (for example product-as-a-service activities, improved repair, servicing, remanufacturing, and recycling) based on improved access to data;
- To help consumers in making sustainable choices; and
- To allow authorities to verify compliance with legal obligations.

These definitions and objectives provide a conceptual framing of a Digital Product Passport that builds upon a legacy of approaches and solutions in the realm of product related information systems (King et al., 2023). Among these initiatives have been the Material Pass (Honic et al., 2019; Atta et al., 2021; Kedir et al., 2021; Göswein et al., 2022), the Battery Pass (Berger et al., 2021, 2022; Blümke and Hof, 2022), the Cradle-to-Cradle® passports (McDonough and Braungart, 2003; Jacob Sterling and Maersk Line, 2011) or the Asset Administration Shells (or Digital Twins) (Kuenster et al., 2023) to name just a few. While these initiatives share specific objectives such as collecting and sharing dispersed product-related data and information, it needs to be acknowledged that all these systems have been conceptualized and partially tested and implemented under sector-specific rationales and stakeholder constellations.

As laid down in Art. 10 of the revised Ecodesign Directive (European Commission, 2022a), the EU Commission's objective of implementing a Digital Product Passport seeks to enhance and unify existing initiatives, while expanding its reach in terms of stakeholder participation, technological standardization, and institutional governance. As a result, the term "DPP" encompasses two key aspects:

Firstly, a DPP encompasses product- and sector-specific solutions designed to effectively handle product-related data within a framework of interoperability and differentiated access control. This entails tailoring the DPP to specific industries while ensuring compatibility and efficient data exchange.

Secondly, a DPP serves as an overarching concept (Ducuing and Reich, 2023) that encompasses a large-scale data infrastructure and its various institutional frameworks. This aspect focuses on establishing a comprehensive system for managing product-related data, supported by multiple levels of institutional integration.

In summary, the DPP concept involves both the development of a robust data infrastructure with institutional support and the implementation of industry-specific solutions that promote interoperability and controlled access to product-related data.

DPP from a product level perspective

From a product level perspective, the Digital Product Passport serves as an informative and transparent biography of the product, documenting its entire lifecycle - from the raw materials used in its construction, through manufacturing and usage, to its disposal or repurposing. Essentially, DPP is a technological tool for establishing a connection between traceability and transparency in product-related information (Ospital et al., 2022). Moreover, there is a suggestion that DPPs hold the potential to play a crucial role in enhancing the circularity of products (Reich et al., 2023).

In light of these potential benefits, the proposal for the new Ecodesign Directive (European Commission, 2022a) defines various information categories (Art. 5), performance criteria (Art. 6) and information requirements (Art. 7) necessary to document and improve a product’s eco-design requirements, namely:

- durability;
- reliability;
- reusability;
- upgradability;
- reparability;

- possibility of maintenance and refurbishment;
- presence of substances of concern;
- energy use or energy efficiency;
- resource use or resource efficiency;
- recycled content;
- possibility of remanufacturing and recycling;
- possibility of recovery of materials;
- environmental impacts, including carbon and environmental footprint;
- expected generation of waste materials.

These product requirements are further elaborated in Annex 1 and 3 of the proposal and define a DPP's informational scope including:

- information required under Articles 7(2) and 8(2) or by other Union law applicable to the relevant product group;
- the unique product identifier at the level indicated in the applicable delegated act adopted pursuant to Article 4;
- the Global Trade Identification Number as provided for in standard ISO/IEC 15459-6 or equivalent of products or their parts;
- relevant commodity codes, such as a TARIC code as defined in Council Regulation (EEC) No 2658/87 1;
- compliance documentation and information required under this Regulation or other Union law applicable to the product, such as the declaration of conformity, technical documentation or conformity certificates;
- user manuals, instructions, warnings or safety information, as required by other Union legislation applicable to the product;
- information related to the manufacturer, such as its unique operator identifier and the information referred to in Article 21(7);
- unique operator identifiers other than that of the manufacturer;
- unique facility identifiers;
- information related to the importer, including the information referred to in Article 23(3) and its EORI number;
- the name, contact details and unique operator identifier code of the economic operator established in the Union responsible for carrying out the tasks set out in Article 4 of Regulation (EU) 2019/1020, or Article 15 of Regulation (EU) 2023/988 [reference missing in original – added by the authors] on general product safety, or similar tasks pursuant to other EU legislation applicable to the product.

The provided information illuminates each step in the product's journey, detailing components, materials, and chemical substances, and information related to repairability, spare parts, and proper disposal methods. This transparency is not confined to tangible features of the product, but also extends to the product's sustainability, circularity, and environmental impact. This provides a multi-dimensional view of the product, emphasizing its role in the broader sustainability agenda.

Under this lens, the product transcends its material nature to become a collection of data - a story that can be told and retold, studied, and understood by various stakeholders across its lifecycle. Consumers can make informed purchasing decisions, manufacturers can optimize designs for circularity, and policymakers can enforce compliance with sustainability norms.

Although it is not yet clear which of these criteria will be mandatory for which product groups once the proposal will come into force, it illustrates the informational scope and functional purpose of a DPP as a digital support measure for the transition towards a circular economy.

The DPP at the product level also facilitates new business models, such as product-as-a-service (Beuren et al., 2013), and can contribute to better repair, servicing, remanufacturing, and recycling practices. Ultimately, the product level DPP is about providing key insights into a product's existence, enabling better utilization, and contributing to a circular economy.

DPP from a system level perspective

At a system level, a DPP becomes an even more vital tool, serving as an integral cog in the machinery of a sustainable, circular economy. Here, the DPP transitions from a repository of product-specific data to a broader, interconnected network of information sharing among various stakeholders along a product’s supply chain.

According to King et al. (2023) a DPP ecosystem needs to be capable of integrating complex interdependencies between a heterogeneity of actors with differing information needs, economic rationales and behavioral constraints either directly or indirectly involved into the supply chain. Its purpose is to enable and support new modes of interdependencies between multiple stakeholders caused by increasing circularity.

"A Digital Product Passport Ecosystem (DPPE) is a socio-technical System of Systems, which is collaboratively owned by the producers, users, and disposers of products. A DPPE evidences sustainable business practice and product design values, encourages change in consumer and disposer behaviour, and enables greater collective efforts towards a circular economy by all product stakeholders (resource, producer, user, disposers) and economic stakeholders. It does this by defining the metrics for sustainability and circularity for a given product and across product lifecycles, which requires a whole-life assessment against social and environmental impact performance metrics, then translates these into a comparable set of attributes for uniquely identifiable product designs. The DPPE provides a mechanism for uniquely identifying, describing, and exchanging product and actor data between actors. It also requires evidence to support the claims made by actors and evidence of a clear chain of custody of the product, its parts and associated events. The DPPE provides the information necessary to identify hazardous, problematic, and valuable materials, maintain the useful life of the product, and how to dispose of it optimally. The DPPE operates within acknowledged constraints (such as commercial interests, data quality and data ownership, a variety of sustainability metrics, privacy concerns, legacy systems, cost, skills, and current capacity) to achieve the sustainability values and goals of societal stakeholders." (King et al., 2023)

In conclusion, they propose a universal definition of a Digital Product Passport Ecosystem, namely: *"A System owned by O to do W by A by means of T given the constraints of E in order to achieve X for C"* (King et al., 2023).

Hence, the DPP at the system level is not merely about collating data but also about creating a robust, large-scale infrastructure for data management. It serves as a unifying concept under which various sector-specific initiatives are harmonized and interoperability is ensured. This helps to integrate a wide variety of data sources and makes them accessible to relevant stakeholders in a standardized, efficient manner.

Stakeholders in a DPP Ecosystem

As outlined in the preceding chapter, a DPP ecosystem embodies a complex institutional framework encompassing a diverse array of stakeholders and operating under multiple tiers of governance.

On the operational front, the ecosystem encompasses all entities intricately linked to a DPP's data infrastructure, actively contributing data to advance the DPP's policy goals and ideally reaping tangible business benefits from this engagement. According to the World Business Council For Sustainable Development (2023), these entities include:

- **Raw Material Producers:** These stakeholders engage in the extraction or cultivation of natural resources integral to product manufacturing. A DPP facilitates to record and disseminate environmental and social impacts, encompassing ESG-related factors like deforestation, emissions, water and soil integrity, and adherence to rigorous sustainability benchmarks. Furthermore, it functions as a catalyst for bolstering the traceability of raw materials, fostering resource efficiency, and nurturing circular practices.
- **Brands/Designers:** At the forefront of conceptualization and design, these stakeholders wield significant influence over product development. A DPP facilitates comprehensive insights into the origins, composition, and ecological footprints of raw materials. It empowers deliberate comparisons between recycled and virgin materials, thereby facilitating design strategies geared towards minimizing resource consumption, maximizing durability, and simplifying repair, reuse, and recycling protocols.
- **Manufacturers:** Tasked with the transformation of raw materials into finished goods, manufacturers play a central role in the product lifecycle. Through monitoring and reporting, a DPP empowers them to track their environmental footprint, encompassing factors such as water consumption, emissions, waste generation, and production-related pollution. The platform actively encourages the implementation of resource-efficient practices along the product life-cycle while promoting collaborative efforts across the supply chain, thereby fostering the emergence of circular solutions. As highlighted by Adisorn et al. (2021), manufacturers emerge as key players in disseminating DPP-specific product information.
- **Distributors:** Charged with the responsibilities of product transportation, storage, and delivery, distributors wield a substantial influence over the last stages of the product journey. A DPP functions as a dynamic tool, facilitating the quantification and mitigation of transportation emissions, reduction of packaging materials, and minimization of waste. Furthermore, it assumes the role of an enabler, equipping distributors with transparent insights into the ecological and societal attributes of products. This, in turn, empowers consumers to make informed and environmentally conscious purchasing decisions.

- **(Re-)Users/Repairers:** These stakeholders, encompassing users, maintainers, repairers, and resellers, actively contribute to prolonging product lifespan and minimizing waste. By facilitating access to a wealth of information regarding a product's environmental and societal impacts, a DPP empowers these actors to make informed decisions. Additionally, the platform provides an avenue for disseminating user manuals, repair instructions, and information about spare parts availability, warranty terms, and responsible disposal guidelines—ultimately extending the longevity of products.
- **Collectors/Recyclers/Refurbishers/Remanufacturers:** As stewards of products during their end-of-use phase, these stakeholders assume a critical role in the circular economy. A DPP serves as an essential resource, affording them access to intricate details regarding product composition, disassembly procedures, hazardous substance content, and the potential for material recovery. Beyond this, the platform facilitates the documentation and communication of circular initiatives, spanning repair histories, recycled material integration, and the quality of remanufactured goods.

A DPP extends well beyond the confines of the data supply chain, impacting a diverse spectrum of individuals and entities intricately tied to public policy and regulatory governance institutionalizing an DPP. This encompassing group includes public entities such as regulatory agencies, NGOs, NPOs, and advocacy groups, all of whom possess a vested interest in overseeing the shift toward a circular economy. Within the context of a DPP ecosystem, these stakeholders play pivotal roles in utilizing DPP-related data for diverse policy objectives for the public and private benefit.

Their significance becomes particularly pronounced in the endeavor to streamline and standardize the exchange of product-related information throughout the entirety of the value chain, ensuring that pertinent information is delivered in alignment with the unique requirements of each stakeholder along the data value chain. Embracing this holistic approach facilitates the establishment of a comprehensive framework for the management of product-related data, fortified by multiple layers of institutional integration. This approach fosters a culture of open data sharing and collaborative efforts, resulting in heightened transparency, the advancement of sustainable practices, and the emergence of novel business prospects.

A recent analysis by King et al. (King et al., 2023) yields a proposal for a cohesive model of a DPP ecosystem. This model introduces a discerning categorization of stakeholders into three distinct groups: core product stakeholders, who stand at the heart of the DPP ecosystem; solution stakeholders, who contribute tangentially to the ecosystem; and product regulations stakeholders, who play a role in shaping the policy objectives upheld by the DPP ecosystem. These groups, in turn, can be further segmented to highlight actors undertaking specific functional roles essential for the effective maintenance of a DPP. Figure 3 illustrates their findings.

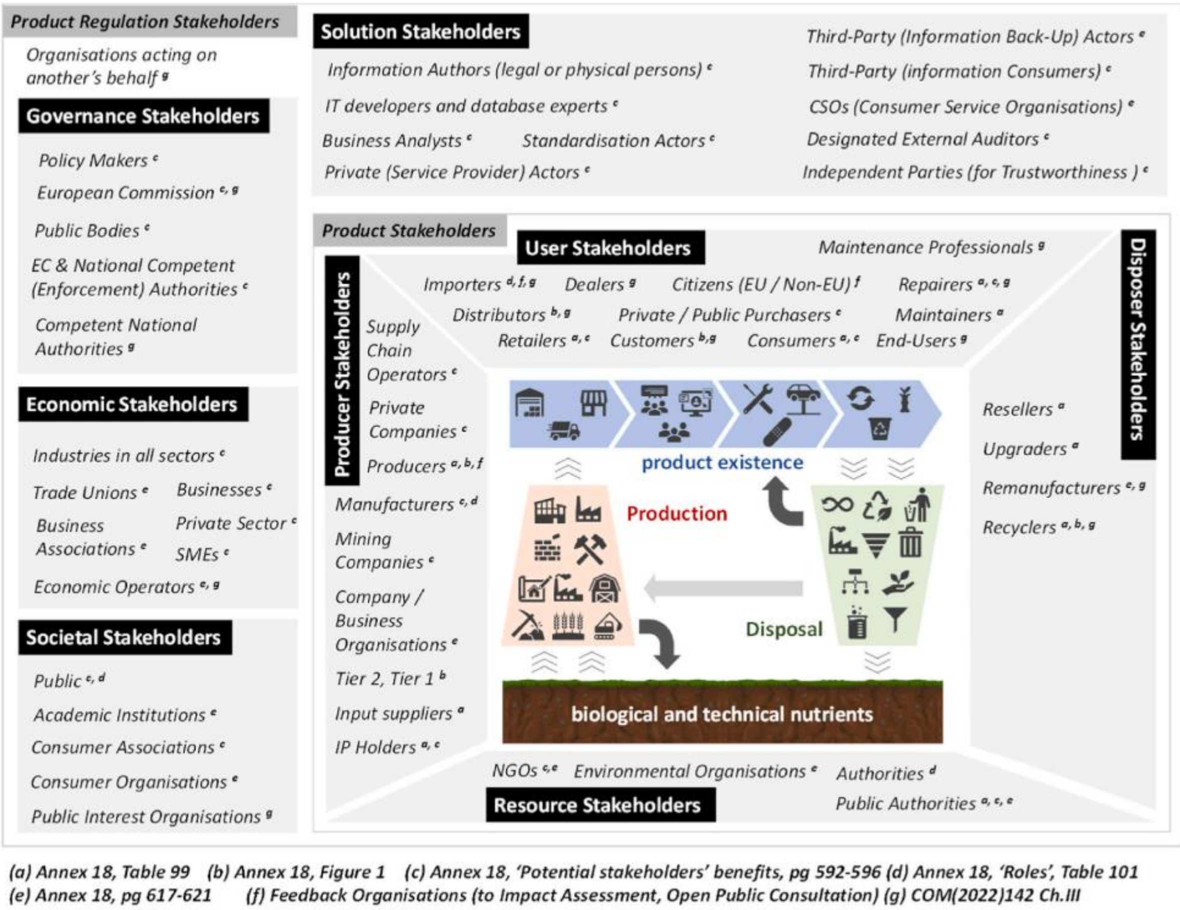

Figure 3: A unified abstraction of a DPP Ecosystem (King et al., 2023, p. 5)

The nature of these functional roles may vary based on the specific sector to which a DPP is being applied. Therefore, possessing a comprehensive picture of the sector-specific stakeholder ecosystem and their respective positions within the supply chain of that sector becomes crucial.

According to a study, since there is a vast diversity of needs and requirements among various economic actors and stakeholders for the digital product passport, the development of the DPP should be carried out in phases. The diversity of needs and requirements varies based on the value chain stage, the type of industry, and other related aspects. However, developing a system that meets all requirements without integrating shorter feedback loops into the implementation process is unattainable. Therefore, introducing new capabilities and functionalities should occur gradually (Solita and Gaia Consulting, 2022).

In the subsequent sections we take a closer look at the stakeholders of the sectors that have been investigated in this study: 1) building and construction, 2) battery manufacturing, and 3) end-of-life / waste management. The first two sectors - building and construction and battery manufacturing - have been chosen as a subject of investigation due to the long legacy of product information management within these domains. The end-of-life / waste management sector has been chosen for its key position in enabling and improving circular product flows beyond the traditional conception of a linear product life cycle. By systematically analyzing the literature available in these sectors we extracted the various sector-specific functional roles within a DPP ecosystem.

Building & Construction Stakeholders

Efficiently managing product information in the building and construction sector is a necessary step to reduce its environmental impact and better understand the complex interdependencies with other sectors. According to the European Commission "*the built environment has a significant impact on many sectors of the economy, on local jobs and quality of life. It requires vast amounts of resources and accounts for about 50% of all extracted material. The construction sector is responsible for over 35% of the EU's total waste generation. Greenhouse gas emissions from material extraction, manufacturing of construction products, as well as construction and renovation of buildings are estimated at 5-12% of total national GHG emissions. Greater material efficiency could save 80% of those emissions"* (European Commission, 2023a).

First recommendations for improving the environmental impact of the building and construction sector by more efficient information management date back to 2009 (Blum, 2009) and have since then been extended and complemented by numerous other works. Most of this work is located in the context of "**building information management (BIM)**" (Atta et al., 2021; Honic et al., 2023, 2019; Kovacic et al., 2019; Sesana and Salvalai, 2018) and the corresponding "**material passport**" (Debacker et al., 2016; Göswein et al., 2022; Hansen et al., 2018; Honic et al., 2021; Kedir et al., 2021; Luscuere and Mulhall, 2018; Luscuere, 2017; Munaro et al., 2019; Munaro and Tavares, 2021; Panza et al., 2022), a sector-wide endeavor to improve the documentation of building and construction materials used within buildings and other forms of built infrastructure, or investigate specific IT technologies and solutions to support the sustainability and circularity of the construction sector (Ganter and Lützkendorf, 2019; Kedir et al., 2021; Mariangiola Fabbri, 2017; Schaubroeck et al., 2022a, 2022b). The sector also came up with a recommendation for a specification called "**Buildings As Material Banks (BAMB)**" (Heinrich and Lang, 2019) released in 2020.

Drawing from an extensive literature analysis, we compiled a DPP ecosystem locating sector-specific stakeholder roles within the various dimensions identified by King et al. (King et al., 2023). The results are depicted in Figure 4.

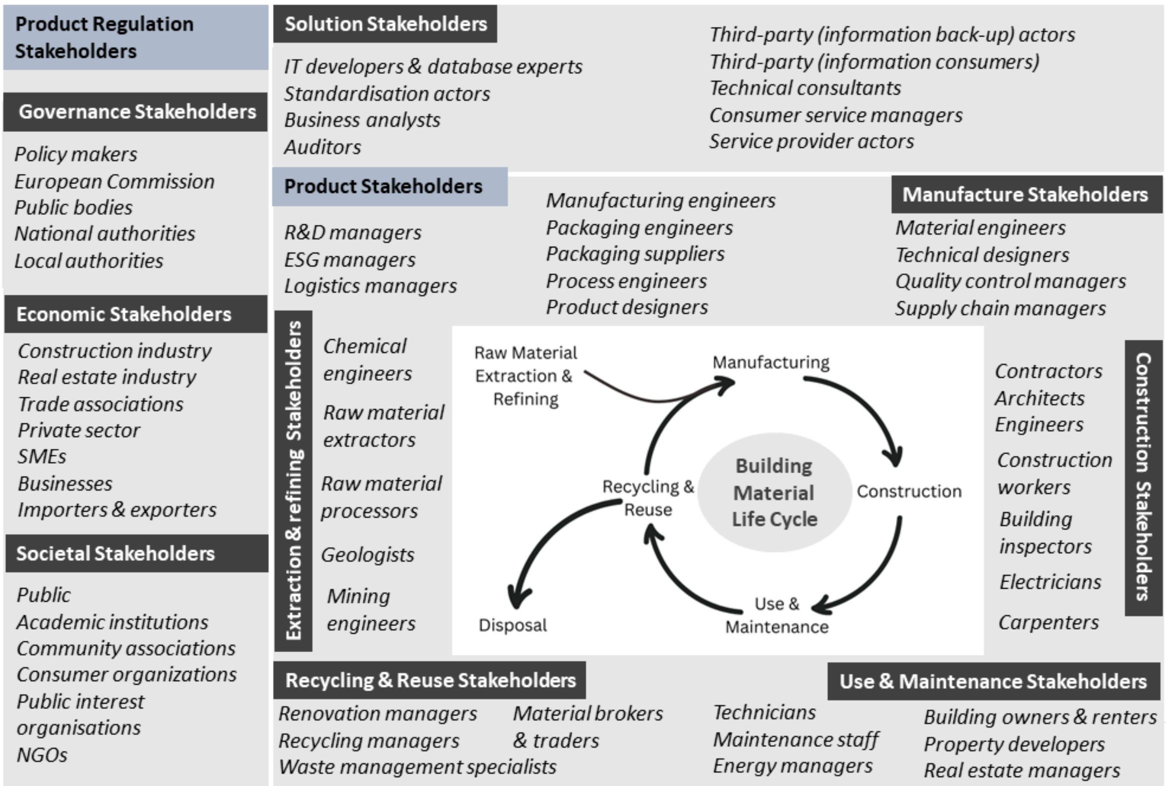

Figure 4: DPP Stakeholders in the Building & Construction Sector

For our case study carried out in chapter 4 on the building and construction sector we interviewed stakeholders covering the following roles: 3 manufacturers, 3 construction companies and 1 service provider.

Battery Life Cycle Stakeholders

The battery manufacturing sector bears responsibility for contributing to global issues such as climate change, air pollution, and toxicity. Transportation accounts for a substantial share of greenhouse gas emissions, with direct energy-related carbon dioxide

(CO_2) emissions making up 24% of the total. In this sector, passenger vehicles make the largest contribution with a share of over 45%. For achieving a significant reduction in greenhouse gas emissions, the use of light weight battery electric vehicles is considered. However, for the time being the production phase of batteries has a larger environmental impact than that of cars with internal combustion engines. Electric vehicle production accounts for over 61-78% of its life cycle CO_2 emissions (Safarian, 2023). CO_2 emissions from the production of electric cars amount to 14.6 tons (60.8 gCO_2/km), which is 132% and 123% of the emissions from petrol and diesel cars respectively (Safarian, 2023). To minimize these impacts and comply with the EU circular economy plan, batteries would have to remain in the value chain as long as possible. This would be possible by recycling the batteries already in use (Koroma et al., 2022).

To foster the transition towards a climate-neutral transportation sector and mitigate the environmental impacts of the underlying battery industry various proposals have been made, from which the **Battery Passport** is the most prominent (Berger et al., 2023b, 2023a, 2022, 2021; Blümke and Hof, 2022; Walden et al., 2021). Supporting the reuse, recycling and recovery of used batteries is one of the core aspects in this endeavor (Bai et al., 2020; Koppelaar et al., 2023) and needs to be supported by a DPP (Jansen et al., 2023, 2022)

Drawing from an extensive literature analysis, we compiled a DPP ecosystem locating sector-specific stakeholder roles within the various dimensions identified by King et al. (King et al., 2023). The results are depicted in Figure 5.

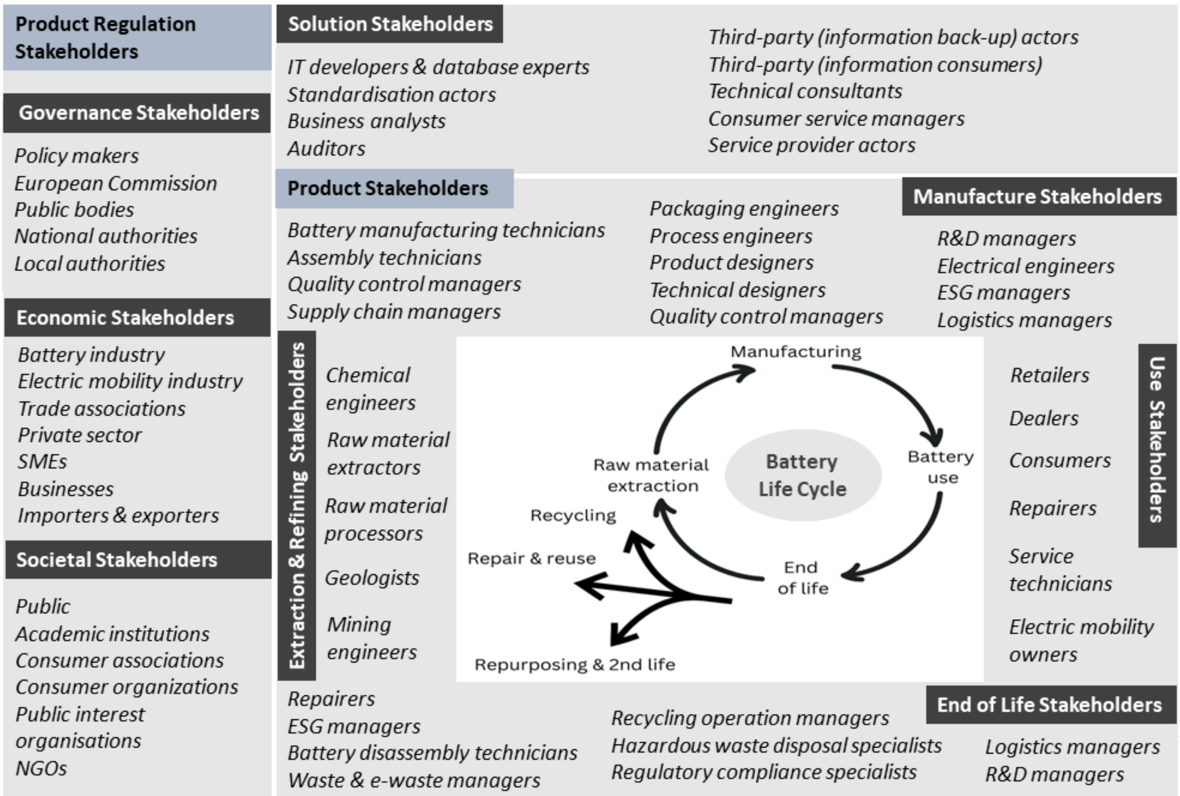

Figure 5: DPP Stakeholders in the Battery Manufacturing Sector

For our case study carried out in chapter 4 on battery life cycle management we interviewed stakeholders covering the following roles: 3 manufacturers, 1 service provider, 1 recycler and 1 industry association.

End-of-Life / Waste Management

Although the waste management sector lies horizontally to all other economic sectors, it is important to recognize that the construction and the battery manufacturing sector (as well as the textile sector) contribute significant amounts of waste and problematic substances that can be either avoided or recycled. The construction sector generates 30-40% of solid waste annually. Over 35% of this waste ends up in landfills. This includes waste generated from demolition, construction, and renovation work. Especially the construction and demolition waste have a negative impact on the environment, due to ever increasing amounts in landfills. In this context, end-of-life batteries are also becoming increasingly important. With over 125 million electric vehicles on the market in 2030, 11 million tons of electric vehicle lithium batteries will end up in landfills. This compares to the 190,000 tons of industrial batteries disposed of annually in the EU. Currently, hardly any industrial batteries are recycled or properly disposed of in the EU, which leads to the emission of harmful substances and subsequently to an increase in human health problems (Ismaeel and Kassim, 2023). Efficient resource exploitation, material recovery, and energy savings can help mitigate the waste problem. Implementing waste minimization methods, waste segregation strategies, and resource management can recover approximately 80-90% of currently dumped waste (Ismaeel and Kassim, 2023).

Given the horizontal position of the waste management sector within a circular economy, questions have been raised as early as 2003 (Hallmann et al., 2003; Spengler and Schröter, 2003) what a DPP for this sector should look such as tracking of problematic substances (Rumetshofer and Fischer, 2023), improve recycling rates (Koppelaar et al., 2023) and harmonize information flows and data disclosure practices between manufacturing and end-of-life actors (Plociennik et al., 2022a). An integrative approach is introduced by Panza et al. (2022), advocating a digital twin for an "**internet of materials**" that puts a stronger emphasis on the end-of-life phase.

Drawing from an extensive literature analysis, we compiled a DPP ecosystem locating sector-specific stakeholder roles within the various dimensions identified by King et al. (King et al., 2023). The results are depicted in Figure 6.

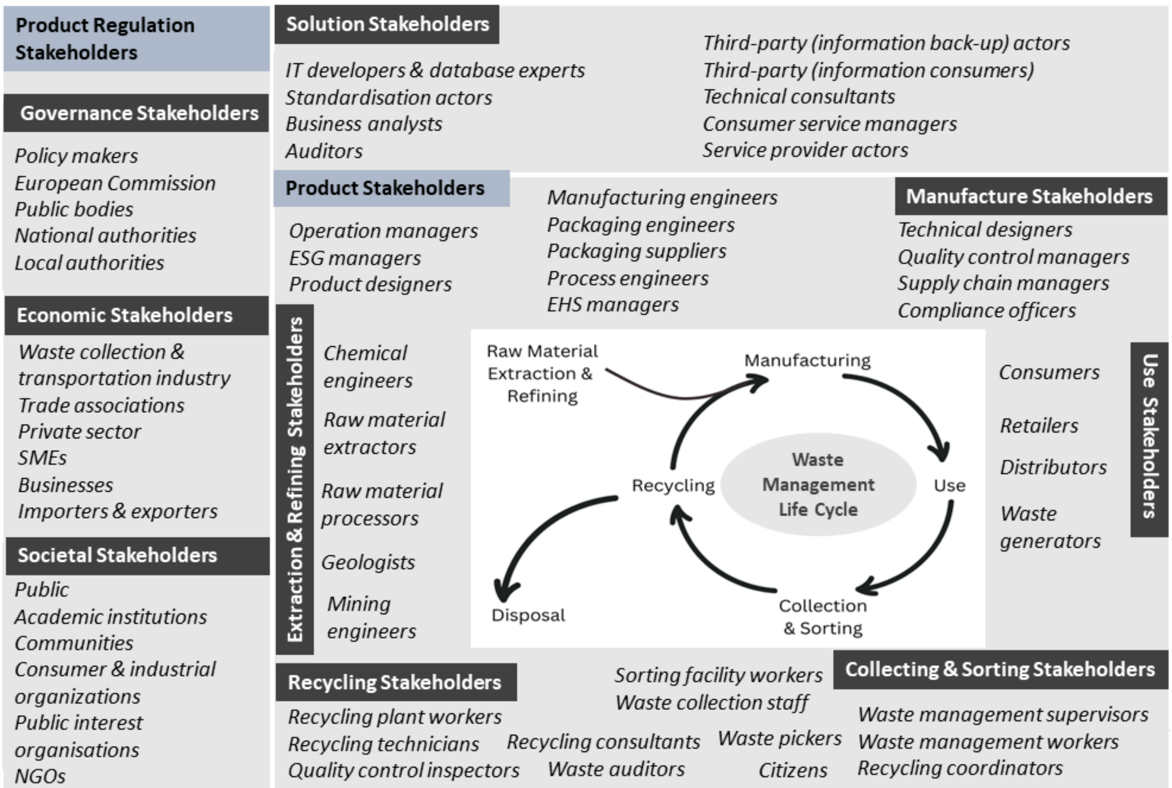

Figure 6: DPP Stakeholders in the Waste Management Sector

For our case study carried out in chapter 4 on end-of-life and management we interviewed stakeholders covering the following roles: 2 waste collectors, 3 recyclers, and 1 service provider.

Legal Foundations and State of DPP Governance

A DPP is embedded within a complex fabric of strategies and regulations that contribute to the twin transition of the European Union towards an environmentally sustainable and digitally supported circular economy. In the following chapters we take a view at the policy perspectives of a DPP and briefly discuss the current state of DPP governance.

A broader policy perspective of a DPP

Before discussing the legal foundations of a DPP it is important to consider the broader policy framework in which such a measure is embedded. Figure 7 illustrates and explains the broader regulatory regime.

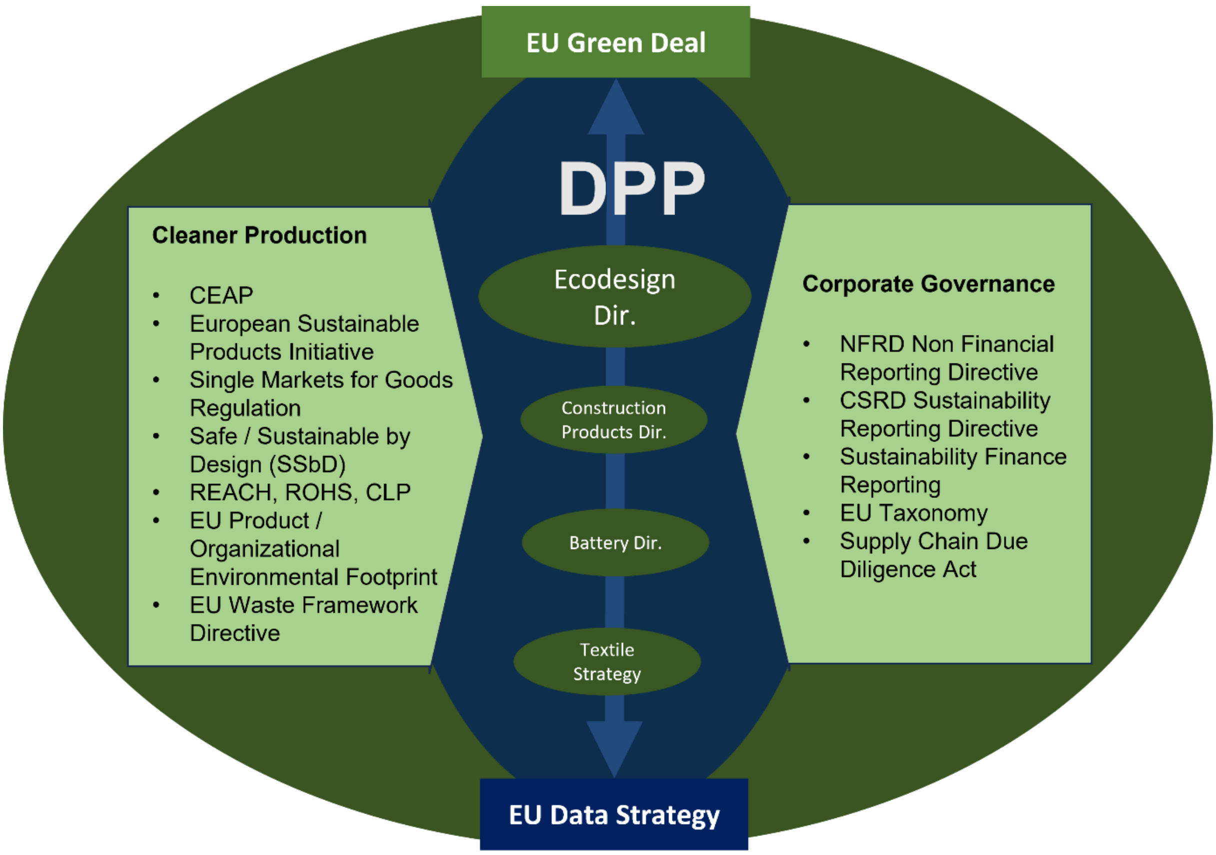

Figure 7: DPP Policy Framework

In November 2019, the European Parliament declared a climate emergency asking the European Commission to adapt all its proposals in line with a 1.5 °C target for limiting global warming and ensure that greenhouse gas emissions are significantly reduced. This basically resulted into a policy framework known as the European Green Deal (European Council, 2022) whose main objective is “*to provide a roadmap for Europe becoming a climate-neutral continent by 2050” (ibid). This roadmap is laid out in in the* “Fit for 55” package (European Council, 2023), which contains “*a set of proposals to revise and update EU legislations and to put in place new initiatives with the aim of ensuring that EU policies are into line with the climate goals agreed by the Council and the European Parliament*” (ibid). The main objectives of these policies target the decarbonization of the European energy system and propose accompanying measures to mitigate negative social effects resulting from the costs associated with the transition from a linear to a circular socio-economic growth model.

The last aspect – namely the transition towards a circular economic system – is especially relevant for the understanding and design of a DPP, as new data and information infrastructures will be required to govern and manage this transition and its fundamental impacts on the economy and the society at large. Hence, a DPP should be understood as a technological concept facilitating this change. It was first mentioned in 2020 in the appendix of the EU Commission’s “European strategy for data” (European Commission, 2020a) which states that "*digital ‘product passports’ will be developed, that will provide information on a product’s origin, durability, composition, reuse, repair and dismantling possibilities, and end-of-life handling.*"

The effects of a DPP on both society at large and companies, in particular, can be categorized into two distinct groups: firstly, regulations aimed at fostering cleaner production, and secondly, regulations that impact corporate governance.

Cleaner Production

First and foremost, a DPP’s primary purpose is to facilitate cleaner production of goods and services in correspondence with the EU’s Circular Economy Action Plan (CEAP) published in the year 2020 (European Commission, 2020b) and the European Sustainable Products Initiative (ESPR) which resulted in the Commission’s proposal for a new Ecodesign Directive in 2022 (European Commission, 2022a). These initiatives are further bound back to the Single Markets for Goods Regulations (European Union, 2023) mainly via domain- and sector-specific regulations and compliance standards such as the chemicals industry, the automotive sector or the building and construction sector, to name but a few.

Accordingly, a DPP unfolds in correspondence with the EU's Chemicals Strategy for Sustainability (CSS) which among other things caiters the development of criteria for safe and sustainable by design for chemicals (SSbD). SSbD aims at facilitating the industrial transition towards a safe, zero pollution, climate-neutral and resource-efficient production and consumption, addressing adverse effects on humans, ecosystems and biodiversity from a lifecycle perspective (Caldeira et al., 2022). This further complies with recent changes in the REACH Regulation (European Parliament, 2006) on the registration, evaluation, authorization and restriction of chemicals that govern a stricter registration regime for substances with lasting environmental impacts (ECHA, 2021).

Additionally, the recently published (July 5, 2023) EU Commission’s proposal for a targeted revision of the Waste Framework Directive (European Commission, 2023b) incorporates the Ecodesign Directive with the primary goal to counter the destruction of unsold products and hold large corporations – especially in the food and textiles sector – accountable through mandatory information disclosure on the organization’s and its products’ compliance with the ecodesign requirements laid out in the Ecodesign Directive.

It is further complemented by EU Commission’s proposal (European Commission, 2021) on the Product Environmental Footprint (PEF) and Organization Environmental Footprint (OEF) methods “*as a common way of measuring environmental performance and communicating the life cycle environmental performance of products and organisations*” (European Commission, 2023c).

Corporate Governance

A DPP further affects various aspects of corporate governance, especially in the context of sustainable finance and due diligence, ESG management and corporate communications (European Commission, 2023d). Herein, a DPP is a technological means to collect ESG relevant data that can be re-used for reporting and auditing purposes. This goes in line with the EU Commission’s objective to foster transparency and accountability of corporations for any actions that an environmental or social impact and promote sustainable finance.

With the Corporate Sustainability Reporting Directive (CSRD) (European Commission, 2022b) that came into force in January 2023 the non-financial reporting obligations will extended towards mid-sized enterprises and replace the previous Non-Financial Reporting Directive (NFRD) (European Parliament, 2014). The new directive contains a higher scale and scope of ESG-related reporting duties. Reporting and data disclosure need to comply with the European Sustainability Reporting Standard (ESRS) (EFRAG, 2023) which forces companies to collect, store and disclose ESG data in a highly structured manner.

A DPP should also be contextualized in the EU Taxonomy Regulation (European Parliament, 2020) for sustainable finance, holding companies accountable by disclosing the environmental impacts of their economic activities and how these contribute to the taxonomy's environmental objectives. A DPP can contribute to the Taxonomy Regulation in two ways: first, it can serve as a data source that links the micro-perspective of products with the meso- and macro-perspective of organizational behavior, and second, it is per se an economic activity that contributes to the EU Taxonomy's policy objectives as a digital solution to mitigate environmental harms.

Further attention should be paid to intersections with upcoming regulations in the context of Supply Chain Due Diligence (European Commission, 2022c). The aim of this Directive is "*to foster sustainable and responsible corporate behavior and to anchor human rights and environmental considerations in companies' operations and corporate governance. The new rules will ensure that businesses address adverse impacts of their actions, including their value chains inside and outside Europe*" (European Commission, 2022d). This information will extend a company's accountability along its products' supply chains and can provide valuable information to create well-informed sovereign consumers.

Legislative Initiatives on DPPs

In the following section we will outline the emerging regulatory regime within which a DPP shall unfold and provide reference to authoritative sources that put DPP-related policy objectives into practice.

Ecodesign for Sustainable Products Regulation

The core document referring to a DPP is the proposal for a new Ecodesign for Sustainable Products Regulation (European Commission, 2022a), published on 30 March 2022. This document builds upon and partially repeals the existing EU Ecodesign Directive (European

Commission, 2009) from the year 2009 and is meant to become the cornerstone of the Commission's approach to more environmentally sustainable and circular products. In the following we will review those passages relevant to a DPP.

According to the European Commission, the proposal establishes a framework to set eco-design requirements for specific product groups to significantly improve their circularity, energy performance and other environmental sustainability aspects (European Commission, 2023e). While at the time of writing it is not finally set, when this proposal will come into practice, the proposal aims to enable the setting of performance and information requirements for most categories of physical goods placed on the EU market, with the exception of food, feed, and medical products, as well as plants, animals and microorganisms and products of human origin, for which other regulations apply (Art. 1).

In its current version, the proposal approaches a DPP from industry agnostic perspective. But as industry-specific sub regulations might be reasonable, Art. 4 of the proposal explicitly mentions that product-specific eco-design rules can be published on top of the existing framework.

Articles 5, 6 and 7 specify the so called "ecodesign requirements" (Art 5), performance criteria (Art. 6) and information requirements (Art. 7) that are necessary and appropriate to establish and document sustainable and ecologically friendly products.

Articles 8 to 13 define conceptual and technical cornerstones of a DPP such as its objective (Art. 8) and requirements with a special focus on interoperability (Art. 9), its technical design and operation (Art. 10), the management of identifiers at the operator and facility level (Art. 11), a product passport registry (Art. 12), and procedural issues with respect to customs controls (Art. 13). These articles will be further investigated in chapter 3 of this report.

Besides the core text, it is important to consult the proposal's Annices, which hold valuable information and explanations about a DPP, such as product parameters that should be documented (Annex 1), the procedure for defining performance requirements (Annex 2), further clarifications of documentation requirements of a DPP (Annex 3), as well as protocols (Annex 4) and conformity declarations (Annex 5) for the implementation and maintenance of a DPP.

The proposal has often been criticized for its vagueness and industry agnostic approach on the one side, its complexity due to references and intersections with product- and sector-specific sustainability regulations, and its prescriptive tendency on the other side, evoking resistance primarily from manufacturers (Hinchliffe and Akkerman, 2017).

Proposal for a revised Construction Products Regulation

The most important legal document specifying a DPP for the Building and Construction sector is the proposal for the revision of the so called "Construction Products Regulation (CPR)" (European Commission, 2022e) that was adopted on 30 March 2022 after a six-year consultation phase that started in July 2016. The proposal contained an impact assessment of various measures proposed for the revision that offered four scenarios (A to D) to be evaluated by domain experts. Scenario D which contains an explicit reference to a DPP was chosen as the most preferred set of actions namely "*Align with the Ecodesign for Sustainable Products Regulation on climate and environmental sustainability and on the Digital Product Passport."* (ibid. p. 10).

The proposal further states that it aims at "*[minimizing] compliance costs through a well-performing standardisation process, by clearer provisions, incentivising re-use of products, less additional national requirements and creating a level playing field for all manufacturers, especially SMEs, in all Member States. Moreover, the planned work sharing and the technical fine-tuning with the Ecodesign for Sustainable Products Regulation will avoid unnecessary costs for businesses, especially SMEs", and further states that "[all] of the proposal's related information and documentation may be processed in digital form (e.g., Digital Product Passport) and stored, shared and accessed durably in an information system*" (ibid, p. 11).

Finally, Article 78 explicitly mentions a DPP: *"The Commission is empowered to supplement this Regulation by means of delegated act according to Article 87, by setting up a Union construction products database or system that builds to the extent possible on the Digital Product Passport established by Regulation (EU) ... [Regulation on ecodesign for sustainable products]."* (ibid. p. 95)

The proposal does not give any further information on the specificities of a DPP for the building and construction sector.

Proposal for revised EU Battery Regulation

The proposal for the new Battery Regulation published in 2020 (European Commission, 2020c) which shall replace the currently existing Battery Directive (European Commission, 2006) and its amended version, contains various facts that directly contribute to the Ecodesign Directive's objectives.

The proposal for the new Battery Regulation puts a strong emphasis on reuse and recycling of disposed batteries and related products with new regulations affecting the battery industry at latest by the year 2024 (Art. 7).

Article 64 postulates that an electronic exchange system for accessing, sharing, managing, exploring, publishing, and reusing of battery-related data shall be established by the year 2024, which shall be used by the affected companies for documentation purposes.

Article 65 establishes the concept of a "battery passport" that shall be used for the documentation of industrial batteries and batteries used for e-mobility with capacities above 2 KWh and shall be extended over time. Each batterie shall be identifiable by a unique identifier and a role-based access mechanism shall be established that allows to collect, manage and disclose battery-related data in a fine grained and differentiated manner, mitigating the risk of "over disclosure" and conflicts of interest with respect to IPR management and legitimate interests in secrecy.

Herein, Annex 13 of the proposal proposes a list of appropriate information categories that shall be made available by a battery passport to serve the regulation's objectives.

The EU Commission's proposal sparked some sector-specific initiatives such as the EU Battery Passport initiated by the German Federal Ministry of Economic Affairs and Climate Action (BMWK-Federal Ministry for Economics Affairs and Climate, 2022), the Global Battery Alliance (Global Battery Alliance, 2023), or Catena-X, a proposal for a documentation standard for the automobile industry that supports the transition towards a de-carbonized mobility system.

EU Strategy for Sustainable and Circular Textiles

On March 30, 2022, the EU Commission published its "strategy for sustainable and circular textiles" (European Commission, 2022f) that shall be advanced towards a new regulation in the forthcoming years (without any further clarification). Chapter 2.4. of the corresponding communication (European Commission, 2022g) introduces some information requirements for a textile-specific product passport in combination with appropriate labeling techniques (chapter 2.5) that allow consumers easy assessability of textiles' compliance with ecodesign criteria and measures to improve circularity. No further information has been available since then.

State of DPP Governance

Information exchange between stakeholders is a fundamental aspect of the DPP ecosystem. This exchange is not only crucial within specific sectors but also across multiple sectors when a product's life cycle spans various industries. Therefore, collaborative efforts and seamless data sharing between different sectors play a decisive role in ensuring the sustainability of products throughout their diverse life cycle stage (Walden et al., 2021).

Piétron et al. emphasize the critical role of strategic data governance in the context of the digital product passport. They propose that a digital circular ecosystem, whether centralized or decentralized, should fulfill two key functions: providing reliable product information and enabling standardized data flows among independent actors. In addition, data governance includes the authority to make decisions and establish rules for data collection, storage, processing, and sharing within and between organizations (Piétron et al., 2023).

From an institutional perspective, a DPP is embedded within a multi-level system of actors and policies that shape its objectives and define the scope of legitimate actions that contribute to achieving these objectives. These actions are governed by rules that have collectively been agreed upon during a policy process that unfolds along various stages and levels of abstraction. According to Ostrom et al. (2014) these levels are:

- The meta-constitutional level, at which a societal problem is identified as such by specific actors (i.e., strategies such as Green Deal or Digital Strategy);
- The constitutional level, at which a general set of rules are being defined that frame the problem by determining who is eligible to create a set of rules that govern collective action (i.e., CEAP or ESPI);
- The collective-choice level, at which these rules are being developed and institutionalized as a framework for operational actions to solve the problem (i.e., EU Ecodesign Directive, amendments of other directives); and

- The operational level, at which these rules are implemented and affect day-today decisions by those affected by these rules (i.e., implementation at national level).

According to Weible and Sabatier (2017) these levels of abstraction can be used to estimate the maturity of a policy process and implement feedback loops for continuous improvement of the policy process at the various levels of abstraction.

When applying this analytical framework to the policy process of the DPP, it is legitimate to say that given the various proposals provided by the EU Commission the policy "DPP" is currently the level of collective choice at which norms are being debated and decided upon to solve the policy's underlying problem and desired objectives. For the institutionalization of a DPP this primarily means to define the scale and scope of data governance measures being performed that incorporate the norms defined within the policy frameworks underlying a DPP. These need to be conveyed into data policies defining the code of conduct at the level of sectors, products (such as CEAP priorities), and actors. And finally develop appropriate data licenses that explicate and codify the terms of trade (ideally in machine-readable form) under which data exchange between the various stakeholders is executed. Drawing parallels to the model of open data governance as developed by Litschka and Pellegrini (2019), a governance model for a DPP could look as follows (see Figure 8):

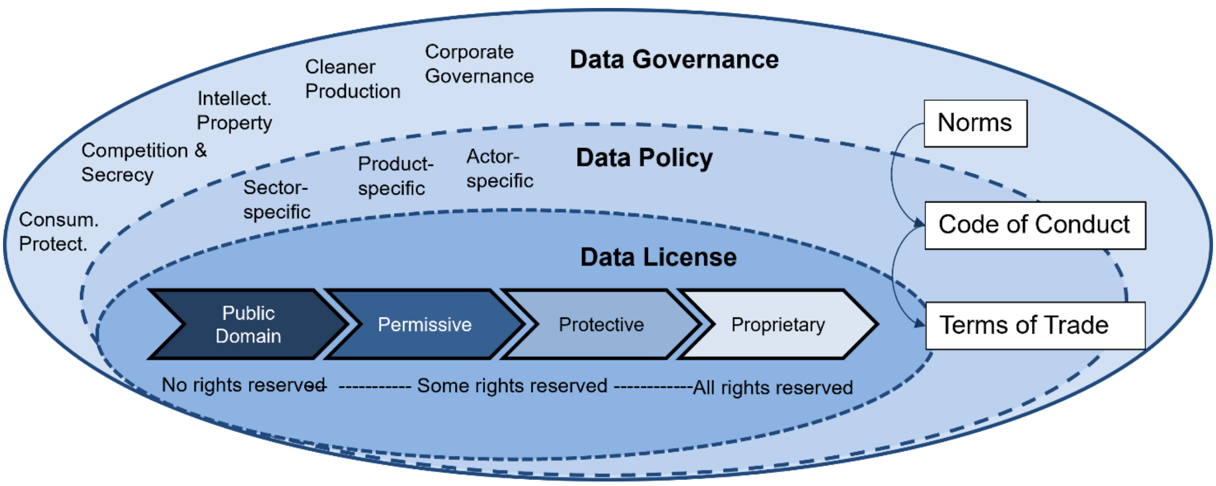

Figure 8: Multi-level Governance model for a DPP

The phase of collective action is a tremendously sensitive stage within the policy process, as conceptual questions of data governance need to be broken down to practicable actions that need to be agreed upon by those stakeholders affected. At this stage it is of vital importance to engage and promote a rational, fact-based and open discourse, in which all stakeholders can get heard and contribute their opinions to the subject matter which is usually performed during and beyond the consultation phases carried out during the proposal phase of a legislative initiative. But the discourse also needs to transcend the narrow boundaries of the legislative process and should ideally include the broader public to ensure practical applicability of the proposed measures and their appropriateness to meet the policy objectives.

According to Ducing & Reich (Ducuing and Reich, 2023) who analyzed the policy process of the DPP, policy issues related to the management and exchange of product-related data via a DPP include:

Transparency, Accuracy and Trust: Misleading or false information can lead to consumer dissatisfaction, legal disputes, and damage to brand reputation. This is basically addressed by existing or upcoming regulations on cleaner production and corporate governance at the European and national level and provide the affected stakeholders – especially consumers – with reliable data for informed decisions. Governance needs to ensure that information is sufficiently disclosed and presented in a way that serves these policy objectives.

Standardization: Establishing standards and protocols for the machine-readable representation of product information is a prerequisite to enhance interoperability and comparability at the system-, model- and data-level. In the context of the DPP this is basically performed by various EU- or nationally supported collaborative projects such as CIRPASS, standardization bodies such as GS1 and or sectoral initiatives such as Catena-X. Standardization also needs to consider challenges arising from emerging and disrupting technologies impacting the creation and processing of product information, and how their level of deployment among the various sectors. Additionally, AI-supported data management potentially increases energy consumption and resource usage. As a result, it is essential to carefully balance the benefits of product data governance with the ecological footprint of information and communication technologies (Piétron et al., 2023).

IPR, Secrecy and Licensing: Product information is usually protected under various jurisdictions such as Copyright, Database Rights, Contract Law. Nevertheless, a DPP requires the nuanced disclosure of product information for various stakeholders with varying degrees of (conditional) access explicated in data usage policies. The combination of open and closed licenses – ideally in machine-readable form – will set the contractual foundation necessary to efficiently manage data access while respecting legitimate interests to protect and control the usage of product information. This is also confirmed by the findings drawn from the use cases discussed in chapter 4.

Privacy, Security and Sovereignty: As more product information moves online or into digital formats, data security and privacy become more prominent. Collecting and sharing product information may involve personal data, especially in the case of smart products. Ensuring that data privacy laws and regulations are followed is crucial to protecting consumers' rights and it enables companies and consumers to retain a high level of sovereignty about their data. However, the issue such as security and privacy management are identified as a gap in the literature and need to be addressed (Jansen et al., 2023).

Responsibility, Accountability and Sustainability: This concerns the clear definition of who is responsible for the provision, update, and availability of product information, especially with respect to persistent data storage and availability, corrective measures, or safety issues. It also needs to consider environmental and ethical aspects, including the sourcing of materials, the environmental impact of products, and adherence to ethical standards. Issues falling under this realm are currently not being addressed properly which causes a lot of uncertainties among the stakeholders as indicated by the results outlined in chapter 4 of this report.

They identify a critical lack of discourse leading to specific problems and uncertainties associated with the implementation and operation of a DPP and associated data governance issues. They come to the following conclusion:

“*First, the governance of DPPs should allow for a broad range of data-related activities to be conducted in a flexible manner, adaptable to a changing environment, to the dynamic nature of DPPs, and to the wealth of stakeholders having conflicting (sometimes legally protected) interests. This also implies, concretely, that the governance of DPPs should recognize and enable coordination and intermediation tasks, which lie at the core of DPP systems. Second and relatedly, the governance of DPPs should be trustworthy, in the sense that it should contribute to bringing trust to all stakeholders when interacting. Third, the governance of DPPs should contribute to ensuring data and information quality and up-to-dateness and, more generally, the suitability of data and information with the needs. This logically entails both CE and data professionalism on the one hand and the presence of enforcement mechanisms on the other. The presence of enforcement mechanisms has* *been little discussed []. Fourth, the governance of DPPs should reflect or possibly embed the objectives of the circular economy (CE), which finds itself in an odd situation. On the one hand, the CE constitutes a political project to gear the economy toward the general interest, namely a more circular and sustainable (economic) model. On the other, the CE is based on the market economy, with the idea that markets should be regulated so as to deliver on the CE objectives. This should logically be reflected not only in the objectives served by the DPP system but also in its very design and governance*" (Ducuing and Reich, 2023).

They conclude:

"*We find that data governance is significantly overlooked or considered only from a pure technological perspective (techno-solutionism), which is likely to jeopardize DPPs."* (Ducuing and Reich, 2023).

This argumentation is backed by Piétron et al. who point out that the ambiguous technical specifications on data collection and data standards, along with the absence of comprehensive material tracking guidance, might result in high coordination costs, which could hinder the successful implementation of circular ecosystems. Therefore, they propose the creation of publicly coordinated product data platforms that could complement DPPs, ensuring intellectual property rights protection while enhancing data accessibility. However, they acknowledge that economic incentives and political regulations also play crucial roles in driving such transformations. Simply having access to data might not be sufficient to bring about the desired changes (Piétron et al., 2023).

DPP - Technical Foundations and Core Technologies

This chapter offers a comprehensive exploration of the technological foundations of a Digital Product Passport (DPP), covering the following key aspects:

- It presents a detailed listing of relevant research projects and key initiatives that focus on developing architectures and core technologies for DPP solutions.
- It outlines the technical and data requirements of DPPs as defined by regulatory bodies, providing valuable insights into compliance considerations.
- It provides a characterization of the core components involved in DPP implementations, along with an analysis of the challenges associated with each of these components.
- Lastly, it conducts a comprehensive review of existing and proposed DPP architectures and technologies, while also critically reflecting on the challenges identified during their implementation.

By delving into these critical areas, this chapter aims to provide readers with a comprehensive understanding of the current landscape and potential advancements in the Digital Product Passport domain.

DPP-related Research Projects and Key Initiatives

In September 2022 the Wuppertal Institut für Klima, Umwelt, Energie gGmbH published an extensive report on "Current Approaches to the Digital Product Passport for a Circular Economy" listing 76 projects and initiatives working scientifically or practically on the development and implementation of various kinds of product passport (Jansen et al., 2022). The survey and its data are available under a public license and are accessible online.[1]

[1] The report is available at https://epub.wupperinst.org/frontdoor/deliver/index/docId/8042/file/WP198.pdf, accessed July 13, 2023

We took this report as a ground truth and extended the list of projects and initiatives for the period between September 2022 and May 2023, applying a slightly adopted coding scheme. For this period, we were able to identify one EU project (CIRPASS) that is closely related to the concept of a DPP and three national initiatives indirectly addressing DPPs in the context of industrial adjustments and transformation towards a circular economy (see Table 1).

Complementary list of DPP projects and initiatives

Title	Country / Countries	Operator Model	Lead Actor(s)	Focus	Product or Market Maturity	Relevancy Score	Priority	DPP/Material Passport	Source
OeKB ESG Data Hub	Austria	Single private	OeKB Group	Environment, Social and Governance	Implemented / On the market	1= DPP just mentioned	Misc.	Other	https://www.oekb-esgdatahub.
Climatelab	Austria	Public-private partnership	Impact Hub Vienna	Climate Neutrality Goals	Implemented / On the market	1= DPP just mentioned	Misc.	Other	https://climatelab.at/en/home/
Cirpass	EU-members	Public-private partnership	European Commison	Gradual piloting and deployment of a standards-based DPP	In Development	3= DPP as core topic	Electric vehicle & Battery	DPP	https://cirpassproject.eu/
Green Data Hub	Austria	Single public	Data Inteligence Offensive	Collect, share and use green and sustainable data in a trustwothy way	Implemented / On the market	1= DPP just mentioned	Misc.	Other	https://www.greendatahub.at/?lang=en

Table 1: Complementary list of DPP projects and initiatives

Probably the most important and prominent list entry investigating a DPP is the EU project CIRPASS (CIRPASS, 2023) which is subject of reference several times throughout this report and will be discussed in further detail below. In addition to the CIRPAAS project, we further introduce the following initiatives that contribute to the advancement of a DPP: GS1, Asset Administration Shell, IDUnion Project and Catena-X.

CIRPASS Project (https://cirpassproject.eu/)

Amidst the European Commission's increasing interest in leveraging emerging technologies for green and digital transformations, a particular focus has been placed on the development of the Digital Product Passport (DPP). To advance this initiative, the Commission funded the CIRPASS project, targeting the progressive implementation of product passports in the electronics, batteries, and textile sectors.

The list of projects is available at https://docs.google.com/spreadsheets/d/1XKQd_67uz-OkjwNPlO4bI7xQu2-FzqJf/edit#gid=1748122183, accessed July 13, 2023

The methodology employed by CIRPASS involves representatives from various early DPP pilots to foster a strategic and inclusive community. This community is dedicated to the seamless design and rollout of a future European DPP. The goal is to create a balanced and collaborative approach, ensuring the successful realization and widespread adoption of the European DPP.

CIRPASS aligns with numerous European initiatives, including the European Green Deal, the Circular Economy Action Plan’s Sustainable Product Initiative, the EU Digital Strategy’s Circular Electronics Initiative, and the EU Data Strategy.

The project aims to develop standardized and open digital solutions for product identification, tracking, mapping, and information sharing throughout the product life cycle. A key focus is to engage private and public stakeholders along the value chains and leveraging existing technologies, such as Data Spaces and distributed ledger technologies.

At this early stage, the project's main deliverables include the development of at least three digital product passport prototypes—one for each key value chain—and a roadmap for the gradual deployment of the DPP. These deliverables will be based on analysis of existing and upcoming legislation, standards, and ongoing activities related to product passports and Data Spaces in the electronics, batteries, and textile sectors.

GS1 Initiative (https://www.gs1.org/)

GS1 is a network of not-for-profit organizations that develop, negotiate, and maintain global standards for cross-enterprise processes. The Global Office of GS1 is based in Brussels, and there are numerous national GS1 organizations worldwide. For instance, GS1 Austria, GS1 Germany, and GS1 Switzerland operate in the DACH region. Over two million companies worldwide utilize GS1 standards.

In terms of standardization, GS1 is an issuing agency under the ISO/IEC 15459-2 registration procedure, which is part of the ISO/IEC 15459 structure for automatic identification and data capture techniques. The primary standard of the GS1 identification system is the Global Trade Item Number (GTIN), an ISO standard. The GTIN is a unique identifier used for product identification in open supply chains and is commonly seen encoded in barcodes on retail items, including online retail. Within the GS1 system, separate standards exist for identifiers, encoding/formats, and data carriers such as barcodes. Additionally, batch/lot numbers identify production batches of products sharing the same GTIN, while serial numbers uniquely identify each individual instance of a product. These are combined with the GTIN to create a globally unique identifier.

In the field of medical devices, the European Commission and the FDA have designated GS1 as an Issuing Agency (IAC) for Unique Device Identification (UDI). In a recent report, GS1 revealed its intention to propose a data architecture based on its standards that could serve as a product passport data structure, using open and global GS1 standards as a foundation.[2]

The GS1 identification standards allow for the encoding of additional information, such as expiry dates and best before dates, using high-capacity barcodes like QR codes and Data Matrix codes. By combining a serial number with a GTIN, the GS1 identification system enables the identification of a final product throughout its entire life cycle, serving as an asset identifier.

Asset Administration Shell (https://reference.opcfoundation.org/I4AAS/v100/docs/)

The Asset Administration Shell (AAS), known in German as „Industrie 4.0 Verwaltungsschale“, is a comprehensive framework for the interoperability of Industry 4.0 components organized within production systems. Actively promoted in Germany by the Platform Industrie 4.0, the AAS is considered pivotal in digitally transforming production processes according to the platform. A variety of publications on the AAS and related topics are available on the platform's website.[3] Moreover, the Industrial Digital Twin Association (IDTA)[4] was established to encourage the application of the AAS.

Serving as a virtual, digital, and active representation of an asset, the AAS covers both abstract and physical entities. It aims to provide a digital twin, capturing an asset's characteristics and behaviors in compliance with the specifications laid down by member organizations of the Industry 4.0 Platform and the Industrial Internet Consortium. The AAS

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[2] https://gs1.eu/activities/digital-product-passport/gs1-data-architecture-for-the-dpp/
[3] https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/Details_of_the_Asset_Administration_Shell_Part1_V3.html
[4] https://industrialdigitaltwin.org/

aims to establish digital connectivity within an Industry 4.0 system for assets, thereby facilitating the exchange of data and information within and between industrial enterprises. As such, the AAS acts as a framework in which all relevant information about an asset, encompassing features, characteristics, properties, statuses, parameters, and measurement data data can be described.[5]

To access this wealth of information about an asset, various methods, including QR codes, are proposed.[6] Further, the AAS framework supports the creation of submodels, each focusing on different aspects of an asset. For instance, a submodel might cater to the needs of maintenance staff by emphasizing an asset's wear and tear patterns, while another could aid in inventory management by focusing on availability and lifecycle data. These submodels offer a structured way to present specific information to diverse target audiences. Within the AAS ecosystem, the use of verifiable credentials is anticipated to ensure the authenticity and integrity of asset-associated information. They are designed to confirm the data's credibility and foster trust among the entities involved.

Central to the AAS framework is the concept of digital representation, which signifies information accurately reflecting the characteristics and behaviors of an entity, such as an asset. In this context, the Asset Administration Shell effectively embodies the digital twin implementation for Industrie 4.0, encapsulating all essential information for a complete digital representation of an asset.

IDunion Project (https://idunion.org/)

The IDunion project is a research initiative funded by the German Federal Ministry for Economic Affairs and Climate Action.[7] It aims to develop a secure infrastructure for verifying data based on a decentralized database. The project brings together a diverse range of participants, including private companies, associations, government institutions, and educational bodies, to collaborate on building this infrastructure. Multiple pilot implementations are being conducted to test various use cases, with software components provided by consortium partners.

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[5] https://reference.opcfoundation.org/I4AAS/v100/docs/4.1
[6] https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/Hardshell-softcore_ppt.pdf?__blob=publicationFile&v=1
[7] https://idunion.org/

The main goal of the project to establish an open ecosystem for decentralized identity management that is globally applicable and aligned with European values and regulations. It focuses on leveraging GS1 standards to enable secure and trustworthy digital identities for individuals and organizations.

By utilizing Verifiable Credentials[8] (VCs), IDunion aims to enable users to control and share their personal data in a privacy-preserving manner. VCs, a fundamental component of the IDunion project, are digital representations of credentials or claims that can be issued, shared, and verified in a secure and decentralized manner. The operating principles of VCs involve multiple entities, including issuers, verifiers, holders, and decentralized registers. Issuers are responsible for creating VCs by generating and signing them with their digital signatures. Verifiers, on the other hand, are entities that verify the authenticity and validity of VCs. Holders are individuals or organizations who possess and control their own VCs. To ensure trust and integrity, VCs can be registered in a decentralized register. These registers maintain a record of VCs and their associated metadata, facilitating easy retrieval and verification. Verifiers can access the register to retrieve VCs and verify their authenticity.

The project seeks to foster collaboration among various stakeholders, including businesses, government entities, and technology providers, to create a reliable and interoperable infrastructure for digital identity management. The consortium includes organizations from research, industry, government, and academia, all working towards the common goal of creating an open and interoperable ecosystem for digital identities.

In terms of research topics and use cases, the IDunion project focuses on several areas: for instance, the regulatory compliance and European regulations such as eIDAS (electronic Identification, Authentication and Trust Services).

Catena-X (https://catena-x.net/)

Catena-X is a German initiative that aims to establish a digital ecosystem for the automotive industry, focusing on enabling transparent and secure data exchange between participating entities. In the context of digital product passports, Catena-X is of relevance as it seeks to create a standardized framework for the exchange and management of

[8] https://www.w3.org/TR/vc-data-model/

product-related information throughout the automotive value chain. The eventual goal is for manufacturers, suppliers, and other stakeholders to collaborate more efficiently. By implementing Catena-X, these entities can ensure data integrity and enhance the traceability of products.

Catena-X works on various standards addressing different tiers of the Catena-X Operating Environment. These include 1) data discovery services, 2) semantics to model data relations, digital twins, and governance processes, 3) APIs for data chains, registries and data poling, 4) identity and access management features, 5) services for product lifecycle and quality management, and 6) automotive-related sustainability documentation methods and metrics (including data models for product and process passports).

Hereby Catena-X distinguishes between various roles such as (1) Core Service Provider, (2) Enablement Service Provider, (3) Business Application Provider, (4) On-Boarding Service Provider, (5) Consulting Provider, (6) Data Provider and Consumer, and (7) Conformity Assessment Body. They designed various production-related use cases to illustrate the benefits of Caten-X standards with respect to:

- Traceability: continuous data chains over the life cycle
- Sustainability: standards and methods for saving CO2
- Behavioral Twin: behavioral forecasts from the network
- Demand & Capacity Management: fewer bottlenecks, more security
- Live Quality Loops: consistency instead of parts tourism
- Circular Economy: maximum use of resources
- Product Carbon Footprint: primary data for precise CO2 recording

According to their website, the Catena-X consortium is funded by the German Federal Ministry for Economic Affairs and Energy's "Future Investments in the Vehicle Industry" funding program (www.kopa35c.de) and will perform the core development work during the funding period until mid-2024.

Technical Requirements and Data Requirements for a DPP

Ecodesign for Sustainable Products Regulation Proposal

In March 2022, the European Commission published the proposal for a new Ecodesign for Sustainable Products Regulation (ESPR). The proposal builds on the existing Ecodesign Directive, which currently only covers energy-related products and establishes a framework to set ecodesign requirements for specific product groups to improve their circularity, energy performance and other environmental sustainability aspects. With this regulation, the European Commission intends to work towards products that are as sustainable, environmentally conscious, and circular as possible.

In the regulation, the product passport concept is envisioned as "*the creation of a digital product passport to electronically register, process and share product-related information amongst supply chain businesses, authorities, and consumers. This is expected to increase transparency, both for supply chain businesses and for the public and increase efficiencies in terms of information transfer. It is likely to help facilitate and streamline the monitoring and enforcement of the regulation carried out by EU and Member State authorities. It is also likely to provide a market-intelligence tool that may be used for revising and refining obligations in the future*" (European Commission, 2023e).

Technical Requirements for a DPP

In a recent report[9] compiled by the CIRPASS project, the technical requirements of DPPs in the ESPR proposal are specified as follows:

- The DPP should complement existing non-digital forms of transmitting information and include sustainability-related data beyond ecodesign regulations.
- The DPP must provide free access to data for all stakeholders along the value chain, including customs authorities. The data should be machine-readable, searchable, and structured, based on open standards and interoperable formats.
- Differentiated access levels will be allowed based on the type of information and stakeholder involved to balance accessibility and intellectual property (IP) protection.

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[9] Report published by the CIRPASS project: https://cirpassproject.eu/wp-content/uploads/2023/03/ESPR-short-summary-Final.pdf

- Actors will have the ability to introduce or update information in the DPP, and the time that a DPP is available will be determined in further regulatory decisions.
- Measures will be taken to help small and medium-sized enterprises (SMEs) manage risks and costs associated with DPP implementation.
- A DPP will be specific to each item, batch, or product model, depending on the complexity of the value chain and product characteristics. It can also be assigned to intermediate goods or materials.
- The DPP should be easily accessible by scanning a data carrier, such as a watermark or QR code, which should be physically present on the product, packaging, or accompanying documentation.
- Certain features of the DPP system will be standardized across all product categories, including permitted data carriers, unique identifiers for products, operators, and facilities, access rights management, data storage and processing, and data authentication.
- The Commission will establish a product passport registry to store unique identifiers linked to products on the market, however, the DPP itself will be based on a decentralized data system managed by economic actors.

Data Requirements for a DPP

Furthermore, the document enumerates various general data requirements stipulated by the ESPR proposal, all of which are expected to be included within the Digital Product Passport (DPP) system:

- Unique product identifier;
- Global Trade Identification Number (GTIN) or equivalent for products or their parts, following ISO/IEC 15459-6 standard;
- Relevant commodity codes, such as a TARIC code;[10]
- Compliance documentation, including the declaration of conformity, technical documentation, or conformity certificates;
- Requirements related to substances of concern;
- User manuals, instructions, warnings, or safety information;
- Information related to the manufacturer;
- Unique operator identifiers for entities responsible for product certification tasks;

[10] Tarif Intégré de la Communauté code, a unique identification code used within the European Union (EU) for classifying goods in international trade.

- Unique facility identifiers;
- Information related to the importer;
- Voluntary EU Ecolabels;
- Information on the product's performance in relation to its parameters;
- Information for consumers and end-users on installation, usage, maintenance, repair, and environmentally friendly disposal or return of the product at the end of its life;
- Information for treatment facilities on disassembly, recycling, or end-of-life disposal;
- Other relevant information that may affect how parties other than the manufacturer handle the product.

Battery Regulation Proposal

In December 2020, the Commission presented a proposal for a regulation concerning batteries and waste batteries.[11] The proposal has three objectives: strengthening the functioning of the internal market (including products, processes, waste batteries and recyclates), by ensuring a level playing field through a common set of rules; promoting a circular economy; and reducing environmental and social impacts throughout all stages of the battery life cycle.

The proposed regulation aims to enforce mandatory rules for batteries above a capacity of 2 KWh sold in the EU market, including portable, automotive, electric vehicle, and industrial batteries. These rules cover sustainability, safety, labelling, and information requirements. The proposal also includes provisions for proper end-of-life management, such as setting new targets for collecting waste portable batteries (65% by 2025 and 70% by 2030). Additionally, the proposal introduces guidelines for businesses regarding product requirements and procedures; it proposes a

DPP system, called the "Battery Passport", to facilitate the exchange of battery information.

[11] https://data.consilium.europa.eu/doc/document/ST-5469-2023-INIT/en/pdf

Technical Requirements of the Battery Passport

The DPP-related requirements for a Battery Passport system, as described in the regulation, can be summarized as follows:

- The Battery Passport should be interoperable with other digital product passports mandated by Union legislation.
- Consumers, economic operators, and relevant actors should have free access to the Battery Passport based on their access rights.
- The Battery Passport should be accessible through a QR code containing a unique identifier assigned by the battery's market operator. The QR code should be printed or engraved on all batteries.
- The Battery Passport should be based on a decentralized data system managed by economic operators. The data included in the Battery Passport should be stored by the responsible economic operator or authorized operators acting on their behalf. Authorized operators should not be allowed to sell, reuse, or process the data beyond what is necessary for their storing or processing services.
- The technical design of the Battery Passport should ensure secure data transmission and comply with privacy rules.
- All information in the Battery Passport should be based on open standards, interoperable formats, and machine-readable, structured, and searchable.
- The Battery Passport should remain available even if the responsible economic operator ceases to exist or stops its activities in the EU.

For a comprehensive breakdown of these requirements, please refer to a recent report by the CIRPASS project.[12]

Characterization of DPP Components and Associated Challenges

In the following, we adapt the classification framework developed and applied in the CIRPASS project and aspects of the reference architecture from the GS1 initiative. According to these approaches, the components of a DPP can be delineated through four pillars as depicted in Table 2:

[12] https://cirpassproject.eu/wp-content/uploads/2023/05/The-DPP-as-defined-in-the-Battery-Regulation-proposal.pdf

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model		Batch	Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 9: Unified Architecture of a DPP

First, a unique and persistent product ID for the product, including batch and/or serialization is needed. This product ID can exist independently from the data carrier and defined in application standards of issuing agencies such as GS1.

Second, a persistent product data carrier allows the product ID to be machine-readable for automatic identification. Eminent examples of data carriers encompass the 1D barcodes, QR codes, Data Matrix codes, RFID tags, NFC tags, or Bluetooth tags and digital watermarks.

Third, a digital connector bridging the physical product to the digital place of information on the product, such as a URL address. For instance, the “GS1 Digital Link” is an example of a digital connector, which is an open standard that defines how identifiers, such as product identifiers (GTINs), location and organisation identifiers (GLNs), can be encoded in a URL.

Fourth, an IT architecture for facilitating data exchange, comprised of standardized vocabularies, data exchange protocols and formats, stakeholder-dependent access mechanisms, distributed storage and management of information, and stakeholder-dependent interaction layers.

For each of the pillars a set of main characteristics and respective challenges are identified:

Challenge 1: Product ID

Type of product ID

- (Does the ID of the product exist on a category level, or on an instance level of the goods?)

The type of product ID is determined by whether the identification exists on a category level, or on an individual instance level of the goods. This differentiation is important as it directly impacts the degree of information specificity that can be associated with each product. Systems requiring unique identification at the instance level can leverage technologies like Radio Frequency Identification (RFID) or Near Field Communication (NFC). These technologies enable the assignment of unique serial numbers to each tag, thus facilitating item-level identification. On the other hand, for systems requiring only category-level identification, traditional barcodes or QR codes can suffice. These identification mechanisms generally represent a class or model of products rather than individual items. Thus, depending on the requirements of granularity and specificity, different types of product IDs can be selected.

Granularity

- (What is the level of granularity provided by the ID system?)

The granularity of a product ID system refers to the level of detail represented by the identification system. Granularity can vary across different systems, ranging from broad classifications such as the model level to more detailed identification at the individual item level. The chosen level of granularity is often dictated by the requirements of the specific system in use and the nature of the goods or products it caters to. In situations where multiple levels of granularity are required, layered or hierarchical identification systems could be adopted. These systems offer a structured approach to identification, allowing for differentiation at various levels such as model, batch, and individual item. For instance, GS1 standards provide a versatile solution in this context. They enable different levels of granularity, utilizing Global Trade Item Numbers (GTINs) for identifying product models and serial numbers for individual instances. The level of granularity directly impacts the scope and usability of the product data, with higher granularity allowing for more detailed and specific product tracking, traceability, and data analysis.

Challenge 2: Product Data Carrier

Machine Readability

- (Is the identifier at the data carrier machine-readable and processable?)

The question of whether an identifier at the data carrier is machine-readable and processable is crucial for a DPP system's operational efficiency. Machine readability ensures that data can be captured swiftly, accurately, and automatically, without the need for manual entry. This is especially vital when dealing with a large volume of goods or in high-speed operational contexts. Current technologies such as QR codes, barcodes, RFID, and NFC tags all provide machine-readable solutions. More advanced technology like digital watermarks, that can make entire product surfaces machine-readable, is also becoming more prevalent. However, it's important to note that specific conditions or product requirements may necessitate non-machine-readable identifiers. An example of this is an engraved article number on a piece of metal. While not as streamlined as their machine-readable counterparts, these systems can still play a role in contexts where durability or resistance to harsh conditions is essential.

Resolver

- (Does the ID link directly to information on the web, or is there an intermediate resolver?)

The functionality of a DPP system can also be impacted by whether the product ID directly links to product information or requires an intermediate resolver. Direct links to product information streamline access but may lack the flexibility of resolvers, which can perform additional data processing or provide enhanced security measures. Resolvers are typically implemented using APIs that process identifiers and return the corresponding data. The GS1 Digital Link standard, for instance, transforms GS1 identifiers into URLs that directly link to online data associated with the product, providing an example of an integrated resolver.

Robustness

- (Does the data carrier retain its functionality over time?)

Data carrier robustness refers to whether the data carrier retains its functionality over the product's lifecycle, which is vital to ensure seamless and continuous access to the relevant information. Various factors, such as environmental conditions or the physical demands of the product lifecycle, can challenge data carrier robustness. Durable data carriers like RFID tags, which can be encased in protective materials, can mitigate some of these risks. On the software side, data redundancy methods, such as database mirroring or distributed storage, can help ensure data carrier robustness by maintaining data accessibility even if some data carriers fail or become unreadable.

Persistency of data

- (Is the retrievable information persistent?)

The persistency of data, or the ability for the retrievable information to remain consistent and accessible over time, is a crucial characteristic of a well-functioning DPP system. Ideally, once data is stored, it should remain available barring any necessary updates or intentional modifications. Blockchain technology (Sharma et al., 2022) can ensure data persistency by rendering the data immutable once it's written to the blockchain. Similarly, distributed databases (Liu et al., 2019) can help maintain data persistence by storing multiple copies of the data across different locations, ensuring that even if one node fails, the data remains accessible from other nodes.

Challenge 3: Digital Connector

ID Minting

- (Who is in control of the generation of product identifiers, and is this process centralized under a single entity?)

The question of who controls the creation of the identifier and how they can be persistently attached to a product is pivotal. In a centralized system, a single entity or consortium usually manages the ID creation, which allows for streamlined management and fewer conflicts but poses potential challenges concerning the concentration of control. In contrast, decentralized ID creation, where identifiers are minted by individual parties, fosters independence and robustness against a single point of failure. For centralized ID minting, traditional relational database systems with unique primary keys can ensure that every product ID is unique. For decentralized ID creation, blockchain technologies or Decentralized Identifiers (DIDs) (Brunner et al., 2020), which operate in a distributed network, can be leveraged.

Data Storage Location

- (Should data be stored in a centralized or decentralized system?)

Whether the data should be stored in a centralized or decentralized system depends on several factors, including data accessibility, security, and privacy, along with cost and performance considerations. Centralized storage systems, such as private infrastructure providers AWS S3[13], Google Cloud Storage[14], or Azure Blob Storage[15]; or as public infrastructure provided by nonprofit organizations may offer more straightforward management and cost-effectiveness. Still, they introduce a central point of failure and potential privacy concerns. Decentralized storage systems, like InterPlanetary File System (IPFS) (Bauer, 2022), Filecoin[16], or DAT protocol[17], can provide better resilience and

[13] https://aws.amazon.com/s3/
[14] https://cloud.google.com/storage/
[15] https://azure.microsoft.com/de-de/products/storage/blobs/
[16] https://filecoin.io/filecoin.pdf
[17] https://dat-ecosystem-archive.github.io/book/

privacy, along with improved data sovereignty, but may face challenges concerning latency and cost.

Challenge 4: IT Architecture

Data Transport

- (How can we ensure secure and efficient data transport?)

Secure and efficient data transport is a cornerstone of any successful DPP system. This process involves securely transmitting data between different system components while ensuring high performance and availability. Transport Layer Security (TLS) protocols (Siriwardena, 2020), for instance, can be used for encrypting data in transit, thereby ensuring secure communication over a network. Moreover, using APIs (such as REST (Richardson and Amundsen, 2013) or GraphQL[18]) that are built to handle different types of data formats (like JSON, XML) and support compression techniques can significantly enhance the efficiency of data transport.

Openness

- (To what extent should the system's openness be maintained, including considerations around standardization, proprietary aspects, and data ports?)

The level of openness in a DPP system is typically a strategic choice and depends on factors like business requirements, security considerations, IP protection, and the ecosystem of stakeholders. Open standards tend to promote interoperability, reusability, and transparency, and foster a collaborative ecosystem. However, proprietary systems can offer more control over system functionalities and the ability to create differentiated value. Technologies supporting openness include open-source databases, open data formats like JSON or XML, and open APIs (like REST or GraphQL).

[18] https://graphql.org/

Access Control

- (What kind of access control mechanism should be used?)

Access control is critical to ensure that only authorized individuals or systems can access certain pieces of data. The method of access control could vary from role-based (RBAC) (Sandhu et al., 1996), where access is granted based on user roles, to attribute-based (ABAC) (Kuhn, 2007), where access is determined by the attributes of the user, resource, environment, etc. RBAC can be implemented using traditional authentication systems, while ABAC can use more advanced models like XACML (Ferraiolo et al., 2016) or frameworks like OAuth (Hardt, 2012) and OpenID Connect[19] that provide more flexible and granular access control based on claims about authenticated users.

Data Use

- (How should data use permissions be managed?)

Data use permissions should be managed with a usage control framework that ensures compliance with legal and regulatory obligations and enforces usage rights to protect data privacy and prevent unauthorized access or misuse. Digital Rights Management (DRM) (Liu et al., 2019) systems can be employed for more granular control over data usage. These systems can be built using advanced cryptographic techniques like Public Key Infrastructure (PKI) (Albarqi et al., 2015), Zero-Knowledge Proofs (ZKPs) (Morais et al., 2019), or decentralized identity technologies like Blockchain.

Data Management

- (What data management technologies should be used?)

Various data management technologies can be employed. Immutable recording of data can be achieved via blockchain technology, providing transparency and trust among parties. For identity management, digital wallets and verifiable credentials offer secure storage and validation of user identities, respectively. Anonymization and privacy-preserving techniques like homomorphic encryption, differential privacy, or federated learning can be used to protect user data. For product traceability, tagging technologies

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[19] https://openid.net/specs/openid-authentication-2_0.html

like QR codes, NFC, and RFID provide a means of uniquely identifying and tracking products throughout their lifecycle.

Decentralization of Data Storage

- (Should product data be stored in a decentralized manner?)

Decentralized storage can provide benefits in terms of data sovereignty, resilience, and potentially privacy, but it might also bring additional complexities in data management. Distributed ledger technologies (DLTs) like blockchain or decentralized storage systems like InterPlanetary File System (IPFS) or Filecoin providing the technology for decentralized data storage. However, challenges related to cost, performance, and data management complexity need to be adequately addressed.

Semantic Interoperability

- (How can we ensure semantic interoperability in the DPP system?)

Semantic interoperability ensures that product data can be consistently understood and used across different systems and applications. This can be achieved by adopting standard ontologies, vocabularies, and data models, and leveraging linked data principles. Technologies supporting semantic interoperability include RDF (Resource Description Framework) for representing structured data, OWL (Web Ontology Language) for defining ontologies, and SPARQL for querying RDF data (Kollia et al., 2011). When used in conjunction with Linked Data principles, these technologies ensure that data is not only syntactically interoperable (i.e., it can be exchanged and parsed), but also semantically interoperable. This means that the meaning of the data is preserved and understood across systems, a concept embodied by knowledge graphs.

Analysis of and Reflection on Selected Architectures and Core Technologies

A key aspect covered in this report is the discussion and review of existing approaches: we analyzed different architectural approaches that have been proposed and implemented by industry leaders, standardization bodies, and research organizations. The implementation details, strengths, limitations, and use cases of these architectures are examined, providing valuable insights into the design considerations and trade-offs associated with their implementations. In the following, a selection of works (see Table 3) is described and classified according to the four characterizing pillars (discussed above) and their main characteristics:

Titel	Literature / Initiative	Domain
Digital Product Passport: The ticket to achieving a climate neutral and circular European economy?	Literature	Several domain passports, e.g., battery, furniture / textile, construction industry, metal industry
Overcoming Information Asymmetry in the Plastics Value Chain with Digital Product Passports	Literature	No specific domain
MATERIALS PASSPORTS - BEST PRACTICE	Literature	Material passport
Information management throughout the life cycle of buildings – Basics and new approaches such as blockchain	Literature	Building passport
Atma.io	Initiative	Textile passport, electronics passport, battery passport
Battery Pass (BP)	Initiative	Battery passport
Circular.fashion	Initiative	Textile passport
DigiPrime	Initiative	Battery passport, textile passport, mechatronics & electronics passport, cross-regional value chain, circular innovation hubs
EPEAT Ecolabel	Initiative	Electronics passport
FEDeRATED	Initiative	No specific domain
itmatters	Initiative	Textile passport
Peppol	Initiative	No specific domain
Toxnot	Initiative	Material passport

Table 2: List of reviewed literature and initiatives

Selected Literature

Digital Product Passport: The ticket to achieving a climate neutral and circular European economy? (2023), by Steffen Foldager Jensen, Jesper Hemdrup Kristensen, Sofie Adamsen, Andreas Christensen, Brian Vejrum Waehrens

This paper analyses and summarizes the key aspects of a DPP – especially from a business perspective – and states recommendations for the design and implementation of a DPP across specific use cases in several industries, including furniture manufacturing, the construction industry, and the metal industry.

Product ID

- Type: product group specific
- Granularity: depending on use case, product specific

The paper recommends, that due to reliability and comparability reasons, data in DPPs should be product group specific. For example, the case of the circular product redesigns and material solutions provider Niaga®[20] is stated.

There is no single recommendation concerning the granularity of the product IDs. It is however stated that the granularity must be decided on for the individual use cases and that it is reasonable to start with less complex yet clearly defined product groups (product specific).

Product Data Carrier

- Machine Readable: yes
- Resolver: -
- Robustness: -
- Persistency of data: -

There are no specific recommendations for the machine readability of the product data carrier. However, in the use case of Niaga® the paper presents the company's own solution on that issue, called Niaga® tag. This tag, specifically developed for furniture manufacturers, contains a machine-readable QR-code that grants access to a unique product pass containing information about what the product is made of and how it can be returned. The paper does not contain recommendation about the use of a resolver, the data carrier's robustness or the persistency of data.

Digital Connector

- ID minting: -

[20] https://www.niaga.world/en

- Data storage location: decentralized

The paper does not give information about how the product IDs should be mined. It is however recommended that the data is stored decentralized.

IT Architecture

- Data Transport: -
- Openness: discussing open-access databases
- Access Control: role based
- Data Use: permission-based
- Data Management discussing blockchain, verifiable credentials, QR
- Decentralized storage of product data: no recommendation

The paper acknowledges that data transparency is a critical issue for businesses, as there needs to be a balance between transparent data sharing and business confidentiality. It is therefore proposed to implement different levels of data access. When it comes to the use case of the already described Niaga tags it is possible to protect IPR sensitive information with different levels of access for different user types with diverse needs (e.g. recyclers or consumers).

Furthermore, the paper notes that DPPs are a valuable tool to tackle verification, data robustness and greenwashing and that therefore, a verification process must be implemented to ensure correct and reasonable data.

Here, the use case of Hydro CIRCAL is presented. Hydro is an aluminium producer that together with a customer in the field of furniture producing has developed a DPP pilot based on blockchain technology. Certificates are kept on a blockchain and offer reliable sustainability data that can be utilized by DPPs. The passport verifies essential details like the date and location of manufacturing, material composition, and environmental impact. However, the paper notes that it is still unclear whether technologies like blockchain, data spaces or knowledge graphs will be included in DPPs.

Lastly, it is noted that DPP architectures must be designed in a way that there is interoperability not only between DPP systems but also between DPPs and other systems.

Among other benefits, it could be advantageous if the operational implementation of DPPs is carried out by trusted intermediaries.

In accordance with the characterisation proposed by CIRPASS, the following matrix results, as depicted in Table 4:

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary		Data ports	Others	
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials		Others		
	Convenience	Wallet	Data Ports		Others		
	Data protection	PETs	Anonymization		Others		
	Traceability	Tagging (QR, NFC, RFID)			Others		

Figure 10: Analysis of architecture (Jensen et al., 2023)

Overcoming Information Asymmetry in the Plastics Value Chain with Digital Product Passports (2022), by Holger Berg, Raik Kulinna, Carsten Stöcker, Susanne Guth-Orlowski, Ricky Thiermann, Natalie Porepp

This paper focuses on the use of decentralised identifiers and verifiable credentials as an enabler for a circular economy and DPPs in the field of plastics.

Product ID

- Type: product category
- Granularity: batch

The paper suggests not assigning a decentralised identity to an individual product, but rather to a product batch, particularly for mass-produced items.

Product Data Carrier

- Machine Readable: yes
- Resolver: via Holy Grail 2.0[21]
- Robustness: -
- Persistency of data: -

Machine readability is recommended by the paper, e.g., by using QR codes. Also, the paper describes an approach in which the QR code links back to the decentralised identifier of the product (batch) and its verifiable credentials. The decentralised identifier here has the same syntax as URLs and when the QR code is scanned, the decentralized identifier is decoded and resolves directly to the DPPs information. There is no specific information about the robustness of the DPP and persistency of data. However, it is stated that the product identity needs to move with the product along the value chain and therefore it is again recommended to represent the decentralised identifiers and verifiable credentials through standard 2D codes like QR codes.

Another example for machine-readable codes are digital watermarks. The paper describes the use case of Holy Grail 2.0 that puts recycling information directly on the packaging of the products. The information is stored directly in the code and can be read by recycling machines – however, this reduces the amount of information that can be attached to a product by a significant amount.

Digital Connector

- ID minting: decentralized

[21] Digital Watermarks Initiative HolyGrail 2.0, https://www.digitalwatermarks.eu/

- Data storage location: decentralized

There is a clear recommendation for decentralised ID minting through the ID owner to avoid the risks of single point failure and central governance. To ensure decentralized and trustworthy storage of Decentralized Identifiers (DIDs), they are frequently anchored with distributed ledger (DLT) technologies like the Ethereum protocol. These DIDs serve as a description of the DID subject and, crucially, include the public key necessary for validating electronic signatures.

IT Architecture

- Data Transport: -
- Openness: e.g., Standardized
- Access Control: role based
- Data Use: permission-based
- Data Management discussing blockchain, verifiable credentials, QR / digital watermarks
- Decentralized storage of product data: decentralization is recommended

The paper issues that interoperability is a necessary basis for DPPs. It is therefore important to standardize the data schemas that describe the product, e.g., the semantics, the values and the technical encoding. It must also be possible to update and extend the underlying standards.

Access control is also recommended, e.g., role based. Furthermore, the privacy of shared information needs to be guaranteed and the origin and integrity of the shared data needs to be verified and stored safely from unauthorised access. However, the paper does not state specific measures to do so but using verifiable credentials and the use of blockchain and wallets. Table 5 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary		Data ports	Others	
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 11: Analysis of architecture (Berg et al., 2021)

MATERIALS PASSPORTS - BEST PRACTICE (2019), by Matthias Heinrich, Werner Lang

This paper focuses on the construction value chain and analyses the advantages of and necessary basics for a material passport as well as its implementation into general building practice. However, the paper mostly focuses on the material data for a circular economy and less on the architecture for a system providing the data.

Product ID

- Type: product (category) specific
- Granularity: product, single item

The report does not give clear information about the type or granularity of the product ID, however, it states that the information in the DPP needs to be directly linked to the physical object the information is referring to. It does therefore likely refer to the product or instance level. It also mentions several currently used unique identifiers like the Chemical Abstract Service (CAS) Registry Number or the Global Trade Number (GTIN).

Product Data Carrier

- Machine Readable: Y
- Resolver: -
- Robustness: -
- Persistency of data: -

The report examines machine-readable codes like barcodes or RFID tags and focuses on blockchain technology as the basis for the DPP. No additional information about the product data carrier is provided.

Digital Connector

- ID minting: -
- Data storage location: -

No information concerning the digital connector is provided.

IT Architecture

- Data Transport: -
- Openness: -
- Access Control: -
- Data Use: -
- Data Management blockchain
- Decentralized storage of product data -

As mentioned before, blockchain is mentioned as a valuable basis for data management. However, no other specific information about the IT architecture of DPPs is provided. Table 6 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model		Batch	Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary		Data ports	Others	
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain		Verifiable Credentials		Others	
	Convenience	Wallet		Data Ports		Others	
	Data protection	PETs		Anonymization		Others	
	Traceability	Tagging (QR, NFC, RFID)			Others		

Figure 12: Analysis of architecture (Heinrich and Lang, 2019)

Information management throughout the life cycle of buildings – Basics and new approaches such as blockchain (2019), by M Ganter, T Lützkendorf

This paper focuses on the information management and information flow in the building sector and especially reviews technology like blockchain as the basic technological concept for this. Although it does not directly address the architecture of a DPP, it gives hints to what should be considered when designing a product pass for the building sector.

Product ID

- Type: -
- Granularity: -

No information is provided about the type and granularity of the product ID.

Product Data Carrier

- Machine Readable: Yes
- Resolver: No
- Robustness: -
- Persistency of data: permanently saved / blockchain

While there is no specific recommendation about the design of the ID, the paper states that the data carrier should be machine-readable and compatible with Building Information Modelling (BIM), a virtual model as the digital twin of a building.

Also, it is mentioned that the data should be permanently available, especially in the terms of lifecycle support and its history. In this context the paper mentions blockchain as a feasible concept.

Digital Connector

- ID minting: -
- Data storage location: cloud / blockchain

The paper does not give information about ID minting, however, it discusses data storage on the cloud and blockchain. It suggests that data should be stored in the cloud while building construction and then transferred to the blockchain.

IT Architecture

- Data Transport: -
- Openness: -
- Access Control: -
- Data Use: -
- Data Management blockchain
- Decentralized storage of product data, blockchain

As mentioned before, blockchain is stated as a valuable basis for data management. However, no other specific information about the IT architecture of DPPs is provided. Table 7 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary		Data ports	Others	
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials		Others		
	Convenience	Wallet	Data Ports		Others		
	Data protection	PETs	Anonymization		Others		
	Traceability	Tagging (QR, NFC, RFID)			Others		

Figure 13: Analysis of architecture (Ganter and Lützkendorf, 2019)

Summary of Reviewed Literature

The reviewed literature offers several common themes. Firstly, while there's no universal agreement on the level of ID granularity and type, a consensus exists that beginning with the product or product category provides a solid foundation. Anything more general is considered too vague to yield useful insights about the product, its components, and lifecycle.

All papers unanimously suggest that Digital Product Passports (DPPs) should strive for machine-readable data carriers, such as QR codes. Several successful implementations of this kind of data carrier are highlighted. Despite the feasibility of directly printing information onto the product, it's generally agreed that this method limits data quantity and precludes any possibility of updates or tracking product history.

In terms of permanent data storage, blockchain emerges as a recurring concept. It has already been piloted by Hydro and one of its clients, indicating its potential relevance for future DPP implementations. This also ties into discussions around data management and storage location, where decentralized storage is suggested as a means to mitigate single-point failure and data governance risks.

While some papers don't delve into data minting, "Overcoming Information Asymmetry in the Plastics Value Chain with Digital Product Passports" emphasizes that IDs should be created by the data owner in a decentralized manner.

Regarding interoperability, a high degree of compatibility between DPPs and other existing systems is advocated. This implies a need for system openness. Despite the benefits of transparency, the preservation of business secrets is considered essential, leading to suggestions for role-based access control where each stakeholder only accesses information relevant to them. The concept of verifiable credentials is introduced as part of these discussions.

Finally, one paper presents data spaces as a potential technological underpinning for DPPs, though this appears not to be implemented yet.

Selected Projects and Initiatives

Atma.io (https://www.atma.io/)

Atma.io is an initiative and platform developed by Avery Dennison, which assigns unique digital IDs to various assets. This functionality facilitates the tracking, storing, and managing of all events along the value chain, thus supporting the implementation of a DPP.

Built on a cutting-edge microservices architecture, Atma.io adheres to the principles of domain-driven design. This approach subdivides the system's functionalities into independently scalable and loosely coupled services. Consequently, each component can be developed, operated, and scaled independently, improving system flexibility and responsiveness.

Atma.io also provides RESTful APIs to enable seamless data exchange with external systems and applications. These APIs comply with the GS1 EPCIS standard, simplifying integration with other systems. Additionally, atma.io has devised a standardized methodology for integrating Blockchain and Distributed Ledger technologies.

The initiative has developed a so called “consumer experience template”, (https://rfid.averydennison.com/en/home/products-solutions/iot/spring-23-release-notes.html) which offers a guided way to add DPP relevant information to the atma.io platform. Table 8 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	Type	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	Type	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	ID minting	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	Openness level	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	Level	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	Evidence	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 14: Analysis of architecture Atma.io

Battery Pass (BP, https://thebatterypass.eu/)

The Battery Pass Project is actively working on creating comprehensive content and technical guidelines for a digital battery passport that aligns with the requirements set by the EU Battery Regulation. These guidelines are also demonstrated through pilot projects, showcasing their practical implementation across multiple industries.

The project also accounts for technical considerations such as GAIA-X, SSI, NGSI-LD, and a comprehensive modular Standard Stack that addresses value chain, data processing, and governance issues. While the primary focus of the Battery Pass Project is currently the automotive industry, its application could extend to other industries in the future. Table 9 provides a detailed overview of the project's results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	Type	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	Type	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	ID minting	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	Openness level	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	Level	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	Evidence	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 15: Analysis of architecture Battery.Pass

Circular.fashion (https://circular.fashion/)

Circular.fashion is a German company and project dedicated to promoting sustainability in the fashion industry and creating a closed material cycle to avoid unnecessary waste. The cornerstone of their concept is a comprehensive material database, containing hundreds of fabrics selected for their sustainable properties and future recyclability potential.

The company's primary asset is the circularity.ID Open Data Standard, a digital information carrier that encapsulates a product's history and essential material and product data. Consumers can access this information via a QR code on the garment's tag or through NFC (Near Field Communication).

To facilitate an efficient reverse supply chain for sorting and recycling, Circular.fashion advocates for the integration of automated fiber sorting technology along with RFID (Radio Frequency Identification) or NFC. This enables seamless tracking and identification throughout the process, ensuring effective material management and processing in collaboration with their large-scale partners.

Reference classification framework for mapping DPP-related initiatives Technical Design section								
Product ID	**Type**	Instance			Category			
	Granularity	Model		Batch	Prod. order		Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other	
	Machine readable data carrier	Yes			No			
	Resolver	Yes			No			
Digital Connector	**ID minting**	Centralised			Decentralised			
	Data storage location	Centralised			Decentralised			
IT architecture: Data transport	**Openness level**	Standardized	Proprietary		Data ports		Others	
	Data packaging	Data transfer			API			
IT architecture: Access control	**Level**	Simple			Advanced			
	If advanced	Attribute based			Role based			
IT architecture: Data use	Labelling	Enforcement			Others			
IT architecture: data mgmt. features	**Evidence**	Blockchain		Verifiable Credentials		Others		
	Convenience	Wallet		Data Ports		Others		
	Data protection	PETs		Anonymization		Others		
	Traceability	Tagging (QR, NFC, RFID)			Others			

Figure 16: Analysis of architecture Circular.fashion

Moreover, their solution enables machine-readable data exchange via API (Application Programming Interface) among various systems and stakeholders. The effectiveness of Circular.fashion's approach is detailed in Table 10.

DigiPrime (https://www.digiprime.eu/)

DigiPrime is a decentralized Digital Manufacturing Platform that fosters connected, circular smart factories. Its primary goal is to generate circular business models based on the data-enhanced recovery and reuse of functions and materials. The DigiPrime platform's main features are:

- Multi-node Federation Structure: The platform has designed a flexible and scalable structure that can be replicated across various existing and new sector-specific platforms. This federation structure promotes seamless collaboration and resource exchange, enabling the creation of cross-sectorial circular value chains.
- Semantic Data Infrastructure: The system boasts a robust semantic data infrastructure, which utilizes ontological repositories and semantic search capabilities. This infrastructure effectively manages and standardizes the vast amount of information sourced from diverse nodes, ensuring efficient data integration and retrieval.
- Data Policy Framework: To ensure privacy, security, and proper information governance, DigiPrime has implemented a comprehensive Data Policy Framework. This framework lays down robust policies for privacy protection, data authentication, authorization, and secure sharing among registered users. These measures guarantee the integrity and confidentiality of shared information across the platform.

Several services within the DPP incorporate essential aspects, such as product data traceability, provenance, and anti-tampering mechanisms. To achieve traceability within the platform, we employ blockchain technology and smart contracts. This combination ensures a transparent and immutable record of data, enhancing the reliability and integrity of information throughout its lifecycle. Their pilot cases include the sectors Battery, Textile, Mechatronics & Electronics, Cross-regional value-chain, Circular Innovation Hubs Integration. Table 11 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	Type	Instance	Category				
	Granularity	Model	Batch	Prod. order	Single item		
Product Data Carrier	Type	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes	No				
	Resolver	Yes	No				
Digital Connector	ID minting	Centralised	Decentralised				
	Data storage location	Centralised	Decentralised				
IT architecture: Data transport	Openness level	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer	API				
IT architecture: Access control	Level	Simple	Advanced				
	If advanced	Attribute based	Role based				
IT architecture: Data use	Labelling	Enforcement	Others				
IT architecture: data mgmt. features	Evidence	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 17: Analysis of architecture DigiPrime

EPEAT Ecolabel (https://www.epeat.net/)

EPEAT is a common ecolabel for technology products managed by the Global Electronics Council (GEC). Products that currently meet the EPEAT criteria, also called “active” EPEAT-registered products, are listed on their online registry. Interested stakeholders can access the listing via the platform based on product category, manufacturer or rating. In general, EPEAT consists of three components:

- Performance Criteria: The platform incorporates lifecycle-based performance criteria that focus on four crucial areas: carbon/greenhouse gas reduction, circularity, chemicals of concern, and corporate supply chain due diligence (social) performance.

- Third-Party Conformance Assurance System: To ensure credibility and reliability, EPEAT has established a robust third-party conformance assurance system. This system verifies and validates adherence to the defined performance criteria, providing independent confirmation of compliance with sustainability standards.
- Public Product Registry: The previously described platform that includes a publicly accessible and searchable product registry.

Table 12 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 18: Analysis of architecture EPEAT Ecolabel

FEDeRATED (https://www.federatedplatforms.eu/)

FEDeRATED was an EU CEF project focused on digital cooperation in logistics. The project offers national and cross-border pilots and living labs to test data sharing feasibility for business and public authorities. The objectives of the project are as follows:

- Demonstrate the functionality of the federative platform proposed by the EU Digital Transport and Logistics Forum (DTLF).
- Identify the conditions, including barriers, opportunities, and benefits, that enable stakeholders to utilize federated data sharing platforms.
- Facilitate seamless and cross-border multimodal freight transport, harmonized data interoperability, and data sharing among relevant actors.
- Promote paperless transport across all modes of transportation through collaborative efforts and actions.
- Support eGovernment initiatives, including one-stop shop and only once reporting functionalities, as well as a corridor management information system approach.
- Develop a reference architecture for a sustainable data sharing environment.

The vision of FEDeRATED is to transition from a monolithic perspective of data sharing platforms to a federated network of interconnected platforms. This transformation empowers all supply chain operators to connect and operate their own IT systems or platforms. Unlike traditional platforms that are limited to accessing data within their own databases, the federated platform harnesses decentralized architectures to access data from anywhere in the world. Furthermore, the integration of semantic web technologies, specifically linked data using RDF, allows for enhanced data representation and robust querying capabilities. Table 13 depicts the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	Type	Instance			Category		
	Granularity	Model	Batch		Prod. order	Single item	
Product Data Carrier	Type	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	ID minting	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	Openness level	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	Level	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	Evidence	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)	Others				

Figure 19: Analysis of architecture FEDeRATED

itmatters (https://itmatters.fr/)

itmatters offers comprehensive End-to-End Traceability Solutions that guide retailers in their digital transformation toward a circular economy. With robust Direct-to-Consumer Engagement capabilities, itmatters enhances customer engagement throughout the entire supply chain process. The company aids brands and raw material industry companies in analyzing their fabric and determining the location of growth or production.

Moreover, itmatters supports clients in tracking and authenticating the origin of raw materials using a patented taggant chemical DNA tracer, easily readable with a pocket lab and mobile app. Each fabric-based product collaborating with itmatters can be authenticated throughout its entire lifecycle using a unique, durable, and washable digital identity (washable smart tag, UHF & NFC) embedded into the product.

At its core, itmatters is composed of three components: smart tags, a cloud platform, and a brand-customized web app for direct-to-consumer engagement. However, any data carrier (UHF, RFID, NFC, GS1 digital link, QR Code, Datamatrix, Bluetooth, Lorawan, Sigfox, etc.) can connect with the itmatters' cloud platform. Table 14 provides a detailed overview of the results.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance		Category			
	Granularity	Model	Batch	Prod. order	Single item		
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes		No			
	Resolver	Yes		No			
Digital Connector	**ID minting**	Centralised		Decentralised			
	Data storage location	Centralised		Decentralised			
IT architecture: Data transport	**Openness level**	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer		API			
IT architecture: Access control	**Level**	Simple		Advanced			
	If advanced	Attribute based		Role based			
IT architecture: Data use	Labelling	Enforcement		Others			
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)		Others			

Figure 20: Analysis of architecture itmatters

Peppol (https://peppol.org/)

The Peppol initiative aims to simplify logistics by standardizing the structure and method of information exchange, such as business documents, e-invoices, and purchase orders, in compliance with the Peppol Interoperability Framework. To achieve this, an open network has been created that enables buyers and suppliers to connect via any accredited service provider.

The format used within the Peppol network is built on ISO standards, facilitating the seamless exchange of various types of product-related information. The Peppol Interoperability Framework, mentioned earlier, serves as a comprehensive guide for data exchange through the Peppol eDelivery network.

Peppol incorporates standards from OASIS and CEN, which enable seamless data exchange while also supporting traceability based on specific business requirements. The effectiveness of Peppol's approach is illustrated in Table 15.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance			Category		
	Granularity	Model		Batch	Prod. order	Single item	
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes			No		
	Resolver	Yes			No		
Digital Connector	**ID minting**	Centralised			Decentralised		
	Data storage location	Centralised			Decentralised		
IT architecture: Data transport	**Openness level**	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer			API		
IT architecture: Access control	**Level**	Simple			Advanced		
	If advanced	Attribute based			Role based		
IT architecture: Data use	Labelling	Enforcement			Others		
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)			Others		

Figure 21: Analysis of architecture Peppol

Toxnot (https://toxnot.com/)

Toxnot by 3E aims to simplify supply chain management with their DPP solution. Toxnot provides an efficient system that allows manufacturers to import chemical data seamlessly, gain insights into hazard profiles, generate comprehensive reports, and develop safer products. Organizations use Toxnot to automate transparency reporting and ensure compliance, which simplifies the collection of hazard information and mitigates risks across their global supply chain.

Reference classification framework for mapping DPP-related initiatives Technical Design section							
Product ID	**Type**	Instance		Category			
	Granularity	Model	Batch	Prod. order	Single item		
Product Data Carrier	**Type**	RFID	QR Code	Digital watermark	Bluetooth label	Bar Code	Other
	Machine readable data carrier	Yes		No			
	Resolver	Yes		No			
Digital Connector	**ID minting**	Centralised		Decentralised			
	Data storage location	Centralised		Decentralised			
IT architecture: Data transport	**Openness level**	Standardized	Proprietary	Data ports	Others		
	Data packaging	Data transfer		API			
IT architecture: Access control	**Level**	Simple		Advanced			
	If advanced	Attribute based		Role based			
IT architecture: Data use	Labelling	Enforcement		Others			
IT architecture: data mgmt. features	**Evidence**	Blockchain	Verifiable Credentials	Others			
	Convenience	Wallet	Data Ports	Others			
	Data protection	PETs	Anonymization	Others			
	Traceability	Tagging (QR, NFC, RFID)		Others			

Figure 22: Analysis of architecture Toxnot

The Toxnot Product Passport system is specifically designed to address emerging product passport requirements, facilitate seamless supplier data exchange, and adapt to evolving guidelines. Suppliers can create a Toxnot Digital Product Passport at no cost, and the free account includes the automatic generation of an EU REACH, EU RoHS, CA Prop 65, and Product Circularity Data Sheet. All data fields are aligned with industry-standard initiatives and requirements, and they are regularly updated to reflect evolving terms and usage. The effectiveness of Toxnot's approach is illustrated in Table 16.

Summary of Reviewed Projects

This summary presents a concise summary of various initiatives and platforms that have been contributing to the fields of sustainability, traceability, and the implementation of Digital Product Passports (DPPs). These diverse projects, spanning multiple sectors, leverage cutting-edge technology and innovative methodologies to streamline supply chains, ensure product traceability, and promote a circular economy. The aim is to provide an overview of each project's key features, strategies, and goals to give a holistic understanding of the current landscape of DPP-related endeavors:

Atma.io: This platform assigns unique digital IDs to various assets. By tracking, storing, and managing events along the value chain, it supports the implementation of a Digital Product Passport (DPP). It offers RESTful APIs for seamless data exchange and complies with the GS1 EPCIS standard.

Battery Pass: This project is dedicated to creating comprehensive content and technical guidelines for a digital battery passport in line with EU Battery Regulation requirements. Initially focusing on the automotive industry, its application could extend to other sectors in the future.

Circular.fashion: A German initiative aimed at promoting sustainability in the fashion industry. The cornerstone is a comprehensive material database. They use a circularity.ID Open Data Standard, a digital information carrier, to encapsulate a product's history and essential material data.

DigiPrime: A decentralized Digital Manufacturing Platform aiming to foster connected, circular smart factories. Its main features include a Multi-node Federation Structure, Semantic Data Infrastructure, and Data Policy Framework. DigiPrime employs blockchain technology and smart contracts for traceability.

EPEAT Ecolabel: A widely used ecolabel for technology products managed by the Global Electronics Council (GEC). EPEAT includes lifecycle-based performance criteria, a third-party conformance assurance system, and a public product registry.

FEDeRATED: An EU project focused on digital cooperation in logistics. FEDeRATED aims to demonstrate the functionality of a federative platform, promote paperless transport, and develop a reference architecture for a sustainable data sharing environment.

itmatters: Offers comprehensive End-to-End Traceability Solutions to guide retailers in their digital transformation. It includes a patented taggant chemical DNA tracer for tracking and authenticating the origin of raw materials, coupled with smart tags and a cloud platform for data management.

Peppol: An initiative that simplifies logistics by standardizing the structure and method of information exchange. Peppol uses a network that enables buyers and suppliers to connect via any accredited service provider.

Toxnot: A solution provided by 3E, simplifies supply chain management with their DPP solution. It helps manufacturers to import chemical data seamlessly, gain insights into hazard profiles, generate comprehensive reports, and develop safer products.

While each of these projects contributes uniquely to the realm of DPP implementation, they collectively underline the diverse strategies to achieve traceability and foster circular economy practices. Atma.io's microservices architecture and unique digital IDs set a robust foundation for comprehensive DPP functionality. The Battery Pass Project and DigiPrime, with their focus on industry-specific applications, highlight the importance of DPPs tailored to unique sectoral requirements. Circular.fashion and itmatters emphasize the significance of material and product data, employing QR and smart tags to embed DPPs directly into the products. The FEDeRATED project, Peppol, and EPEAT Ecolabel showcase the potential of DPPs to improve supply chain dynamics, promoting digitization, and standardization of data sharing practices. Lastly, Toxnot's approach underscores how DPPs can simplify supply chain management and mitigate risks by promoting transparency and compliance. While these initiatives showcase different implementations, their shared commitment to digitization, traceability, and circularity substantiates the emerging importance of DPPs in various sectors.

In summary, these platforms and projects are pioneering in implementing and innovating digital product passports, traceability solutions, and platforms to support sustainability and circular economy objectives across different industries.

Reflection on Selected Technologies and Architecture Components

GS1 Digital Link

The GS1 Digital Link is a novel standard that extends the potential of GS1 identifiers, such as the Global Trade Item Number (GTIN), by web integration. It transforms these identifiers into gateways to a myriad of consumer-focused information, thereby fostering brand loyalty, augmenting supply chain traceability, and enabling easy incorporation of business partner application programming interfaces (APIs).

Unlike traditional Uniform Resource Locators (URLs), which typically direct users to specific websites, the GS1 Digital Link allows for connections to various types of business-to-business (B2B) and business-to-consumer (B2C) information. This standard is particularly relevant when incorporating QR codes or Near Field Communication (NFC) tags into products. In the GS1 Digital Link standard, not only is a URL provided for scanning purposes, but the associated GS1 identifiers are also embedded, which allows to resolve various information about the product and to make it available.

Implementing GS1 Digital Link standards is not without challenges. Organizations may need to invest significant time and resources to fully integrate these standards into their existing systems. There may also be technical difficulties related to storing and retrieving large amounts of information associated with each product. Still, the ability to link diverse types of B2B and B2C data can make these challenges worth confronting.

For instance, assuming the GTIN is 09506000134376, a GS1 Digital Link can be created by embedding it into a web address. In the first variant, a (fictional) domain of a brand owner is used, resulting in a URL like https://dalgiardino.com/01/09506000134376. Alternatively, in the second variant, the GS1 domain is used, resulting in a URL like https://www.gs1.org/09506000134376 as depicted in Figure 9.

Figure 23: Example for GTIN integration in GS1

Further, multiple data contents can be linked in a GS1 Digital Link. For instance, consider the following information: GTIN is 09506000134376, expiry date is 31.12.2023, batch number is ABC, and serial number is 123456. By combining these data, a GS1 Digital Link can be created, resulting in a URL such as https://dalgiardino.com/01/09506000134376/10/ABC/21/123456?17=211201 as depicted in Figure 10.

Figure 24: Example for extended GTIN integration in GS1

Moving forward, the GS1 Digital Link standard will continue to evolve, likely expanding to include even more types of data and to facilitate more sophisticated types of interactions. As with any technology, early adopters will likely enjoy a competitive advantage.

Blockchain

Blockchain[22],[23] (also called Distributed Ledger) is a specific data structure storing all transactions that occur in a peer-to-peer network. The data structure consists of linked blocks of data, which are identified by the hash of the block. This hash includes the hash of the previous block among other things, and therefore effectively builds a chain by linking all blocks (transactions) to the direct predecessor. If a peer wanted to change a blocked after it was added to the chain an accepted by the peers, the hashes of all subsequent blocks would need to be recalculated. Originally, such changes are prevented by the strategy of the network to accept new blocks into the chain. The proof-of-work strategy requires the calculation of the hash to be resource-intensive. Changing a block and subsequent blocks would require more computational power than a peer or a group of peers can provide. Another strategy is proof-of-stake requiring less computational power due to validation and voting on blocks.

[22] https://www.enisa.europa.eu/publications/blockchain-security
[23] https://www.enisa.europa.eu/topics/incident-response/glossary/blockchain

Following advantages of blockchain could be helpful for building a digital product pass:

- Decentralization: Blockchain operates on a decentralized network, meaning it is not controlled by a single entity or authority. This decentralization provides a higher level of security and transparency, as no single party has complete control over the data or can manipulate it. In the context of a digital product pass, this ensures that the pass cannot be counterfeited or tampered with, enhancing its integrity.
- Immutable and Transparent Ledger: Blockchain utilizes a distributed ledger that records all transactions in a transparent and immutable manner. Once a transaction is recorded on the blockchain, it cannot be altered or deleted. This feature is vital for digital product passes, as it ensures the authenticity and provenance of the pass can be verified at any time, preventing fraud or unauthorized duplication.
- Security and Trust: Blockchain employs cryptographic techniques to secure transactions and data. Transactions on the blockchain are verified by consensus mechanisms, making it difficult for malicious actors to manipulate or hack the system. This high level of security and trust is crucial for digital product passes, as it instils confidence in users that their passes are genuine and protected from unauthorized use.
- Interoperability and Standardization: Blockchain can facilitate interoperability between different systems and platforms. By utilizing blockchain as the underlying infrastructure for a digital product pass, it becomes easier to integrate with other applications or services that also leverage blockchain technology. This interoperability allows for seamless interactions between different components of the digital product pass ecosystem, enhancing its usability and versatility.

Although the blockchain is designed to be immutable utilizing secure protocols, there are several known attack vectors targeting for instance the block consensus algorithms. Such risks should be kept in mind when designing a digital product pass. The European Union Agency for Cybersecurity (ENISA) published the paper "Distributed Ledger Technology & Cybersecurity - Improving information security in the financial sector" that includes some of those risks.

The blockchain landscape is constantly evolving, with new consensus algorithms and architectures being developed to address the scalability and energy efficiency issues associated with current blockchain technologies. These developments may offer new opportunities for the implementation of DPPs.

Dataspaces

Dataspaces are a concept that is gaining attention from industry and research communities worldwide. It serves as an abstraction for data management in situations where multiple stakeholders are involved and exchange data with each other. The idea is that the easy exchange of data between stakeholders generates value, particularly when combined with data analytics. New trading mechanisms are meant to enable stakeholders to cooperate with each other based on the value of the exchanged data and analytics services. For example, in a smart city scenario, a public transportation company and local businesses might participate in a dataspace where businesses benefit from improved retail demand predictions and the transportation company can optimize traffic management. This, however, requires a data management architecture which allows sharing the participants' data under well-defined and strictly controlled usage policies.

Dataspaces can be built utilizing connectors to connect the stakeholders with each other. A dataspace connector can be described as a trustworthy software component that supports the definition of usage control policies and the verifiable enforcement of those policies. Connectors should build the basis of dataspaces by building the gateways that connect existing systems and their data sources to ecosystems. The idea is that connectors allow enriching data sources with metadata and attaching usage conditions and policies; these conditions can be defined and administrated, and potentially enforced by the connector implementation.

Here are some reasons why dataspace connectors can contribute to building a DPP:

- Data aggregation: Dataspace connectors allow you to gather data from diverse sources, such as databases, APIs, third-party services, and legacy systems. By connecting to these sources, you can aggregate relevant data into a unified format for use within the digital product pass.
- Fast data synchronization: Dataspace connectors can enable near-real-time data synchronization, ensuring that the digital product pass has access to the most up-to-date information. For example, if a user makes a purchase, a dataspace connector can instantly update the pass with the transaction details.

- Efficient data exchange: Dataspace connectors provide a standardized way to exchange data between different systems. They can handle data transformations, format conversions, and data mapping, ensuring that the data from different sources can be seamlessly consumed by the digital product pass.
- Flexibility and scalability: Dataspace connectors offer flexibility by allowing you to connect to a wide range of data sources. Whether it's a cloud-based service, a legacy system, or an external API, dataspace connectors can bridge the gap and enable data access. Additionally, as your digital product pass evolves and requires integration with new systems, dataspace connectors can be extended or replaced to accommodate the changes.

Future advancements in dataspace technology will aim to simplify connector implementation and make data exchanges more efficient. The increasing popularity of dataspaces is likely to spur the development of new tools and standards, enhancing their applicability in DPP ecosystems.

Syntheses of Results

Over recent years many approaches have been developed and tested to manage product-related information in a uniform manner. But just recently attempts have been made to streamline and standardize these approaches and come up with a universal architecture of a DPP capable to serve the various needs and demands of product- and sector-specific stakeholders. Our analysis reveals that at the time of writing modest advances have been made towards a universal architecture of a DPP that is vital for the successful implementation and adoption of such a large-scale data infrastructure. Nevertheless, various challenges remain to be solved at the various levels of a DPP architecture. While some of these can be solved at the technical level, others require a higher coordinative effort at the organizational or even sectoral level, given the different degrees of maturity of affected sectors with respect to digitization and datafication. This circumstance is also reflected in the various collaborative and/or sector-specific initiatives described in this chapter, all contributing to the demands-driven advancement of a DPP.

At the identification layer initiatives such as GS1 contribute substantially to solving the problem of unambiguous identification of products at the instance or category layer. Additionally, they can be advanced to provide various levels of granularity of product information linked to a specific identifier.

At the data carrier layer machine-readability becomes crucial to store and capture data swiftly, accurately, and automatically, without the need for manual interference. Additionally, the data carrier shall allow to resolve IDs in a flexible and secure manner. Again, GS1 can serve as a robust and reliable framework for the demand-driven delivery of product information either stored directly on the carrier itself or in different locations from where this data can be fetched. Nevertheless, it shall be noted that solutions that guarantee the persistent availability of data – especially over very long periods of times such as decades – have not yet been provided and tested – at least in the domain of product information. This is a crucial challenge and needs to be addressed at the sectoral or even regulatory level and goes beyond the question of technological feasibility.

At the data connector layer questions arise about who controls the creation of identifiers and how they can be persistently attached to a product, either directly through physical means such as tags or indirectly through resolvable codes or numbers referencing relevant information in external locations. This also coincides with the questions which information shall be stored centrally, i.e., to guarantee high service levels, and which information shall be provided in a federated or decentral manner, also taking legitimate interests with respect to access control and secrecy into account.

At the architecture layer various issues collide addressing the procedural and functional spectrum of a DPP, influencing aspects such as security, availability and trustworthiness of product data and applications that build upon them. First and foremost, data transport needs to be secure and efficient, allowing the delivery of various data formats at a reasonable performance. Secondly, specific portions of this data need to be open and licensed accordingly, while closed data should be provided utilizing nuanced role-based or attribute-based access control techniques and protocols. This provokes the question about the legally compliant storage and management of usage data and the application of appropriate digital rights management technologies for handling dispersed and heterogenous data from diverse sources and users. And finally, questions remain about the semantics of data representation and the preservation of meaning across systems and applications serving the cognitive capabilities of its users. The semantics of data and information is highly context-dependent and changes over time which needs to be considered in the design and implementation of applications and services building upon data provided by a DPP. This is especially relevant for systems that serve diverse types of stakeholders with varying degrees of knowledge, cognitive capabilities, and requirements towards product information.

The aspect of semantics is strongly coupled to the topic of visualizing and displaying product-related information which is hardly addressed within the existing DPP discourse. This topic touches upon the appropriate abstraction level of product information in accordance with a stakeholder's informational needs and his/her capabilities to process this information for specific purposes. This touches not just upon the amount of information that is provided to the user but also addresses the benefits and flaws of certain forms of information visualization for the purpose of orientation and complexity management. Techniques such as eco-labels or scores can be very effective in reducing the complexity of provided information and guide users through demanding decision scenarios, but they come with a reduction in informational richness, depriving users from important information or even lead to faulty decisions due to ambiguous statements or unintended associations. Hence, a DPP should be capable to provide product information at various levels of abstraction, so that users have the freedom to decide for themselves how deep they want to dive into the subject matter and scrutinize provided information against their personal knowledge, interests, and purposes.

DPP - Company Perspective

This chapter investigates the notion of a DPP among companies operating in the sectors of building and construction, battery manufacturing and waste management. The sectors have been chosen in close alliance with the contractee for the following reasons: First, these sectors will be among the first to be operationally affected by a DPP, thus offering a rich body of literature and insights; second, these sectors have a comparatively large environmental footprint; and third, the sectors differ in their degree of supply chain internationalization and local embeddedness. Each economic sector has specific conditions and challenges of managing product information. Hence, requirements towards and benefits derived from a DPP might differ in accordance with a company's sector and its position in the supply chain. This chapter covers the following:

- It highlights the gained insights into the enterprise perspective on DPP from the in-depth interviews with company representatives from the following three sectors: "building and construction", "battery manufacturing", and "end-of-life/waste management".
- The interviews focus on three aspects of DPP: technological, organizational, and legal considerations, and discuss the following topics: Knowledge about and preparedness for the Digital Product Passport, plans for educational initiatives on the DPP for their workforce, challenges arising from skill shortages, cost burdens and additional factors that are associated with implementing a DPP.
- A section of the chapter addresses the sector-specific relevancy scores, considering specific information provided by a DPPP and benefits derived from them.
- Lastly, the study investigated preferences for specific system architectures for the provision of DPP data and legal challenges deriving thereof.

When appropriate, the results are enriched with paraphrases of individual statements from the survey participants to emphasize specific assumptions and concerns associated with a DPP. The chapter concludes with a synthesis of the results.

Methodology

General remarks: To gain a better understanding of the enterprise perspective towards a DPP we conducted in-depth interviews among company representatives on the state of the art of product information management, the perceived benefits derived from implementing a Digital Product Passport, and associated challenges. The interviewees were specifically asked to comment on technological, organizational, and legal aspects related to Digital Product Passports. For reasons of validity, we investigated the sectors "building and construction", "battery manufacturing" and "end-of-life / waste management", which are also the most elaborated application areas of a DPP from a regulatory and technological perspective.

Participant Selection: To ensure the inclusion of relevant experts, a purposive sampling strategy was employed. Participants were required to be familiar with product information management in general (i.e., as part of their daily production routines and/or legal compliance obligations within their company) and to have at least a basic knowledge about the concept of a DPP. The latter aspect was especially critical as most companies are well familiar with product information management but have just rudimentary knowledge about the concept of a DPP, given the relative vagueness of the concept at the time the survey was conducted. Additionally, participants were required to be involved in decision-making processes regarding digitalization initiatives. The selection process aimed to include participants with varied backgrounds, such as product managers, communication and / or sustainability experts, compliance advisors, and senior executives. The recruiting of the interviewees was conducted by the project partner Brainbows GmbH, an independent, Vienna-based consulting company in the areas of ESG and sustainability management.

Data Collection Procedure: The interviews were conducted using the online communication platform MS Teams, chosen for its ease of use, availability, and flexibility. Prior to the interviews, an informed consent was obtained from the participants, clearly explaining the purpose of the study, the confidentiality of their responses, and their rights as participants. The interview schedule was developed to address the research objectives. The survey applied a semi-structured interview guide that divided the topic into organizational, technological and legal aspects. The interview guide contained a well concerted combination of closed and open-ended questions, giving structure to the conversation but allowing interviewees to provide detailed insights and opinions.

Data Analysis: Thematic analysis was employed to analyze the interview data and identify key themes and patterns. The interviews were transcribed verbatim, and the transcripts were systematically coded to capture meaningful units of information related to the research objectives. Codes were then organized into broader themes and sub-themes, forming a comprehensive understanding of the state of the art, benefits, and challenges associated with Digital Product Passports. The analysis involved iterative processes of coding, comparison, and interpretation to ensure accuracy and reliability.

Ethical Considerations: Ethical guidelines were strictly followed throughout the research process. Participants were assured of their anonymity and confidentiality. They were also informed of their rights, including the option to withdraw from the study at any point without repercussions. All data collected were securely stored and accessible only to the research team.

Limitations: Various limitations need to be mentioned. Firstly, the findings are based on the perspectives and experiences of a small, self-selected group of experts, and therefore, may not be generalizable to the entire population. Secondly, as the interviews relied on self-reported data, there is a possibility of response biases given that the topic itself and data gathering procedure bare a tendency towards social desirability. Owing to the limited sample size, it was not feasible to conduct reliable statistical testing. Consequently, interpretations rely on plausibility checks and are drawn from statements and utterances provided by the interviewees. These limitations should be considered when interpreting the results.

Survey Results and Interpretation

Sample Description

We conducted 19 interviews with a diverse group of industry representatives, totaling 22 participants from 17 different companies. The list of participants is provided in Annex 1 of this report. The interviews took place between May 11th and August 17th, 2023, resulting in 32 hours of recorded material. Among the participants, 7 experts (32%) held chief executive positions within their organizations, while 15 experts (68%) were in mid-level management roles. From the latter group, 6 experts were from the marketing department, covering areas such as product development and innovation, 9 experts had a background in ESG management or a related technical expertise, and one individual had an explicit background in IT and data management.

The sample consisted of a diverse range of company sizes, including 11 large enterprises, 1 mid-sized enterprise, and 7 small enterprises. In terms of industry focus, 7 interviews were associated with the building and construction sector, 6 interviews addressed battery life cycle management, and 6 interviews addressed end-of-life and waste management.

Furthermore, the companies within the sample held different positions within the supply chain. Among them, 6 were manufacturers, 4 were project developers, 4 were sector-related service providers or contractors, and 5 were service providers in the waste & disposal sector.

Knowledge about the Digital Product Passport

As per our recruitment criteria, all interviewees possess a solid understanding of product information management in general, primarily due to existing legal obligations and associated compliance issues related to the subject matter. However, as illustrated in Figure 11 their knowledge regarding a DPP is limited. Most participants state that they are familiar with the concept. They have heard of the DPP and can grasp its concept and policy objectives to some extent. Nevertheless, they find the concept to be rather vague, which poses challenges in providing substantial judgments on the topic. Consequently, all interviewees remain undecided when it comes to planning actions for preparations.

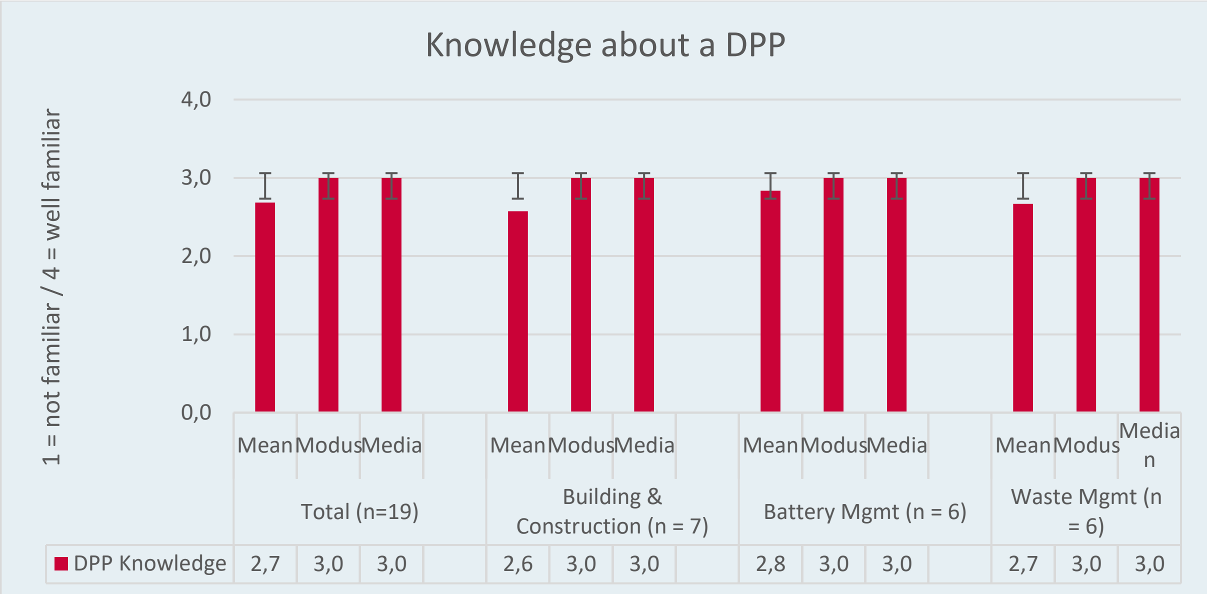


Figure 25: Knowledge about a DPP

Observation: Participants can make sense on the concept DPP but lack substantial knowledge about its impact on their business.

Preparedness for a DPP

Participants were asked about the company's preparedness for a DPP from an organizational, technological, and legal perspective. Some differences can be observed between the sectors.

Organizational Preparedness

Organizational preparedness primarily focuses on determining whether product information is actively managed within the company and if well-defined roles, functions, and accountabilities have been established. As depicted in Figure 12, there are minor variations observed across sectors. Companies operating in the building & construction and battery manufacturing sectors express a slightly higher level of preparedness for a DPP, whereas businesses in the waste management sector approach it with a more cautious perspective.

When asked about plans who should be involved in the implementation and maitenance of a DPP within the organization, the participants unanimously responded that this is a interdisciplinary enbeavour that requires a good coordination and interplay between experts from areas, mainly product management, ESG management and IT management.

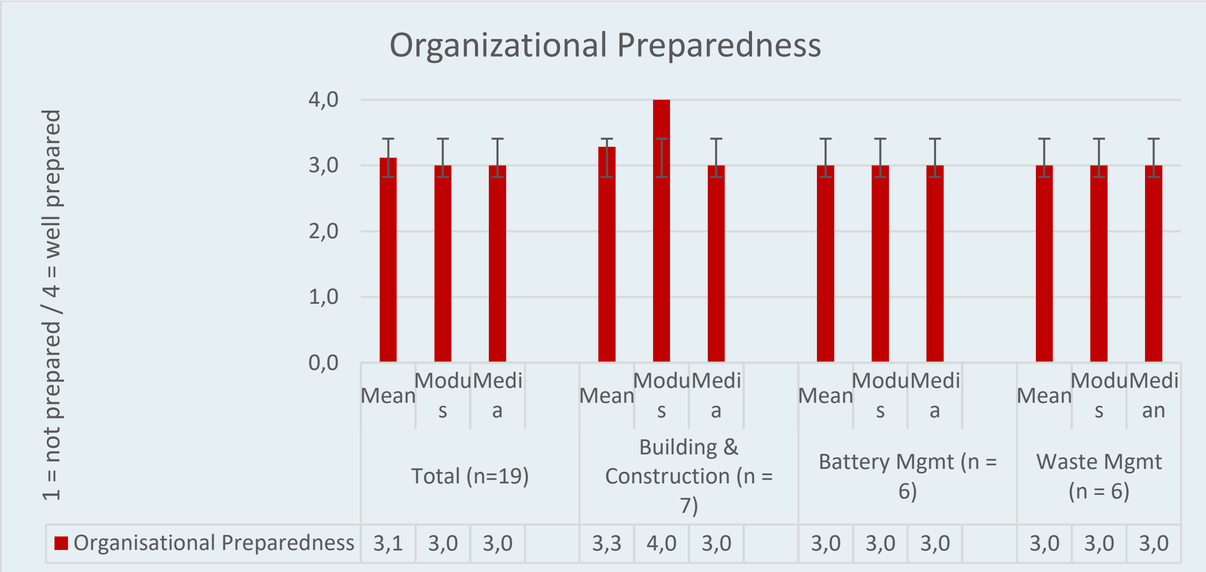


Figure 26: Organizational preparedness for a DPP

Observation: Companies feel that their organization is fit for a DPP, although companies in the building and construction sector feel slightly better prepared than companies from the battery manufacturing sector and waste management sector. All participants acknowledge the interdisciplinary nature of such an endeavor and organizational challenges deriving thereof.

Technological Preparedness

The technological preparedness encompasses various facets related to effectively managing digital product information and establishing and sustaining IT systems for its management. As depicted in Figure 13, the participants feel well equipped to embrace a DPP from a technological standpoint. Notably, companies operating in the battery manufacturing sector exhibit the greatest confidence in tackling technological challenges. However, businesses in the building & construction and waste management sectors approach their assessments with a more cautious outlook.

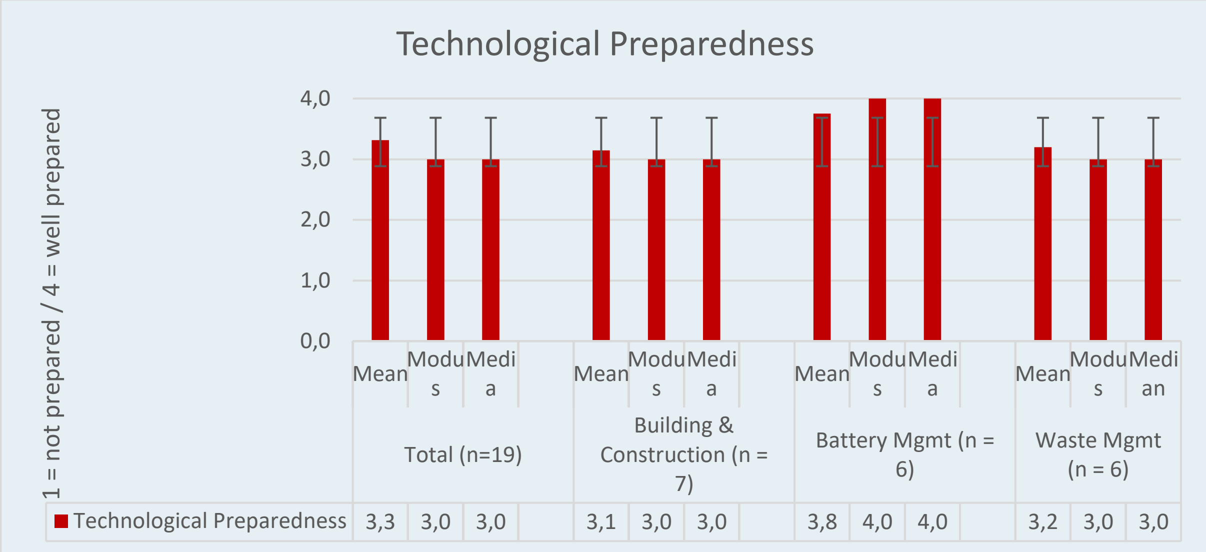


Figure 27: Technological preparedness for a DPP

Observation: Companies feel well prepared for a DPP from a technological perspective with the battery manufacturing sector showing the highest confidence.

Legal Preparedness

Legal preparedness encompasses all the pertinent issues related to the legal aspects of a DPP, including its implications on compliance, risk assessment, and potential interdependencies with other regulations. As depicted in Figure 14, companies in the battery manufacturing sector exhibit the highest level of preparedness for legal considerations associated with a DPP. Conversely, businesses in the building & construction and waste management sectors approach their assessments with a more measured outlook, demonstrating a cautious approach towards potential legal challenges.

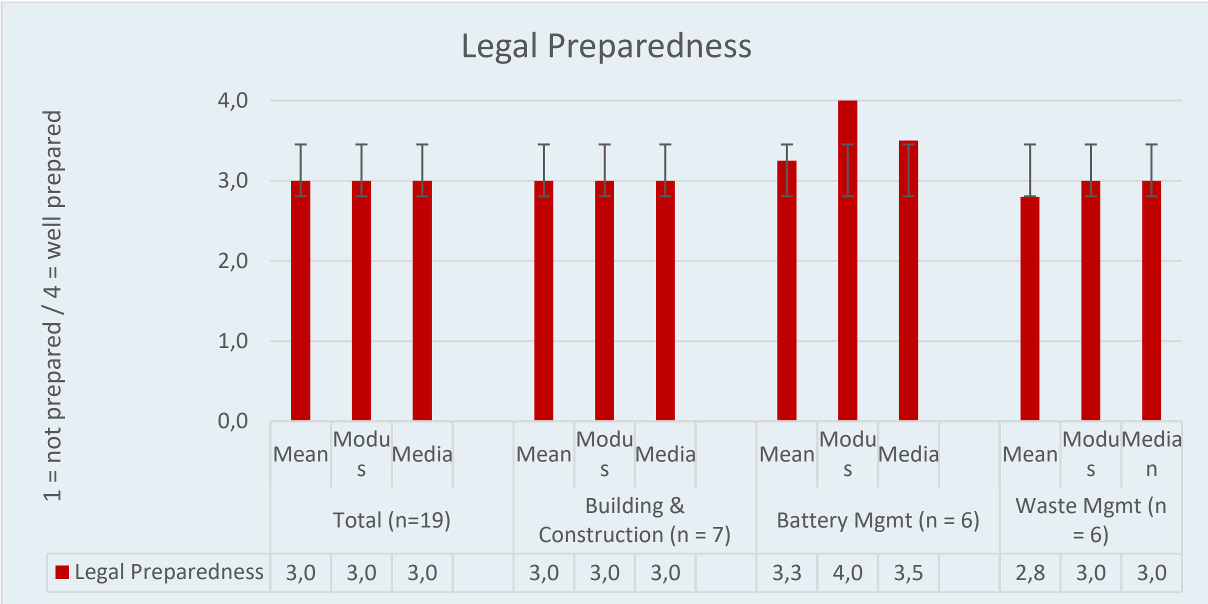


Figure 28: Legal preparedness for a DPP

Observation: Companies feel well prepared for a DPP from a legal perspective with the battery manufacturing sector showing the highest confidence.

DPP Education

In addition to gathering information on participants' preparedness, the survey inquired educational initiatives on the DPP for their workforce. As depicted in Figure 15, the results reveal that approximately one-third of the companies have already implemented or are in the process of planning educational measures. However, a significant two-thirds of the companies currently do not have any educational measures in place. Nonetheless, they express a willingness to initiate such measures once they gain a clearer understanding of how a DPP will influence their day-to-day operations.

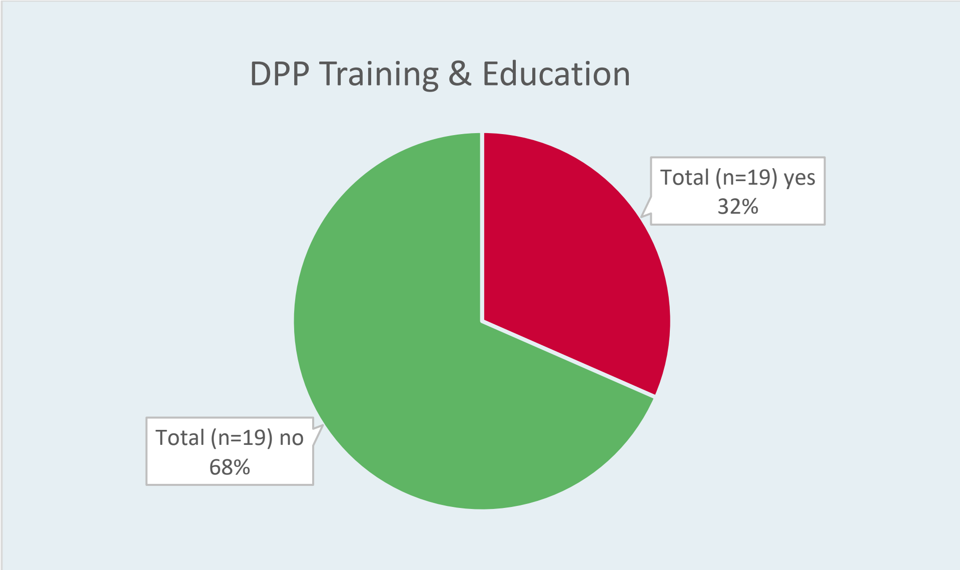


Figure 29: DPP-related education & training

Observation: One third of companies already provides DPP-related trainings to their workforce, while the rest is still on hold, as a DPP'S impact on daily routines is not yet clear to them.

Challenges associated with a DPP

In this section, we inquired specific challenges arising from skill shortages, cost burdens and additional factors that are associated with implementing a DPP. The results reveal the existence of significant circumstances that, although not directly linked to a DPP, may impact its successful rollout.

Skill Shortage: Domain Experts

A successful implementation of a DPP necessitates the involvement of diverse domain experts within the company, including product owners, material specialists, and ESG managers to name but a few. These experts offer specific expertise and data crucial for compiling a comprehensive DPP. However, the demand for these domain experts is expected to increase with the introduction of a DPP, potentially leading to a skill shortage in fulfilling the documentation requirements. While companies in the battery manufacturing sector perceive this challenge as relatively minor, the waste management sector and the building & construction sector could face notable difficulties due to a lack of available domain experts. Particularly, the building & construction sector displays a concerning tendency where this issue could escalate into a significant hurdle. The results are depicted in Figure 16.

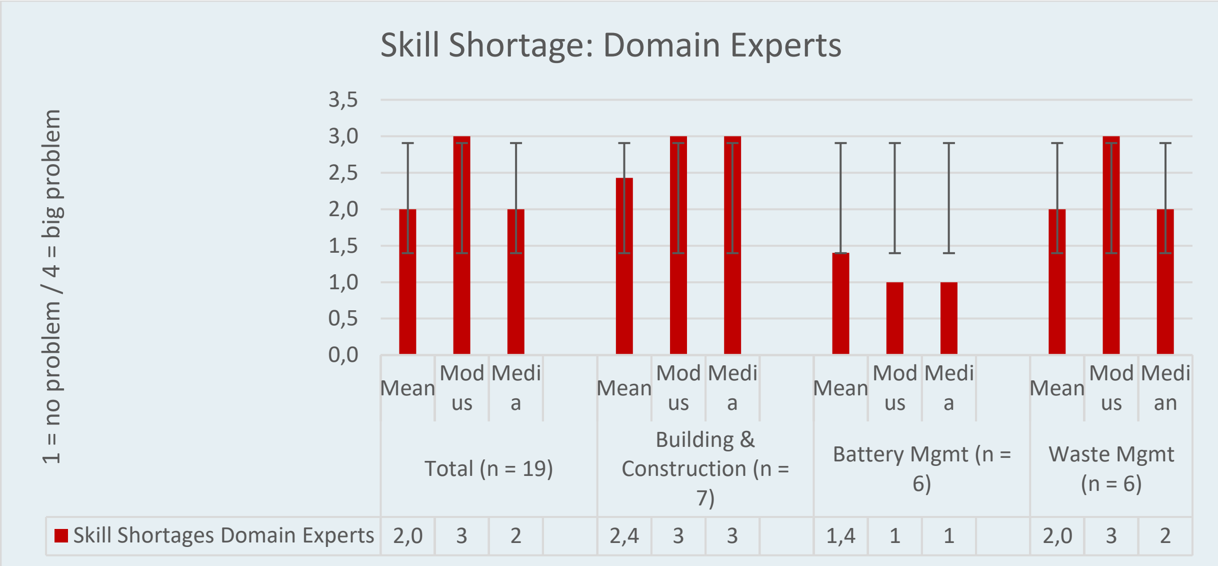


Figure 30: Skill shortage of domain experts

Observation: Domain experts will become more important under conditions of a DPP, which might become a serious issue especially in the building & construction sector.

Skill Shortage: IT Experts

A DPP is primarily an IT project that relies on the expertise of digital professionals, including database specialists, data scientists, developers, and system administrators. While the battery manufacturing sector does not consider a skill shortage of IT experts as a significant concern, the building and construction sector, and especially the waste management sector, may encounter more pronounced challenges in this regard. The availability of skilled IT professionals could become a serious problem for these sectors as they undertake the implementation of a DPP. The results are depicted in Figure 17.

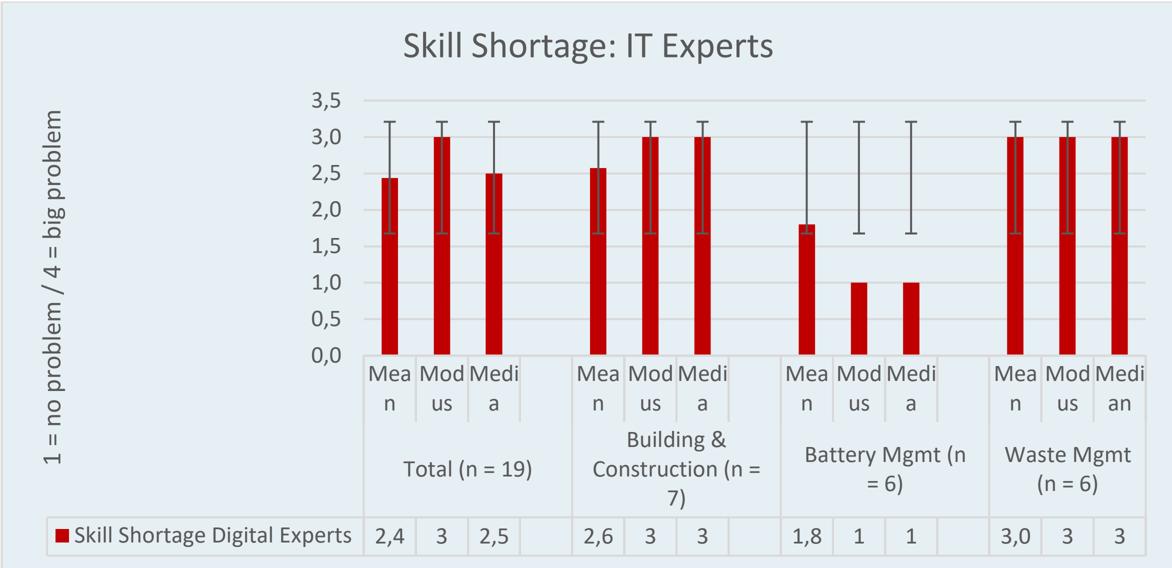


Figure 31: Skill shortage of IT experts

Observation: The building & construction sector, along with the waste management sector, faces the potential of a significant skill shortage among IT experts. This shortage could prove to be a serious issue for these sectors when it comes to the implementation of a DPP.

Costs of Implementation

The implementation and deployment of a DPP within a company entail certain efforts and costs that need to be accounted for, potentially becoming a burden. As depicted below, this perspective is shared by all participants, with companies in the building & construction and waste management sectors regarding it as a more significant challenge compared to those in the battery manufacturing sector. While large enterprises are in a better situation to deal with implementation costs of a DPP, medium and especially small enterprises might face financial pressure during the implementation phase. The results are depicted in Figure 18.

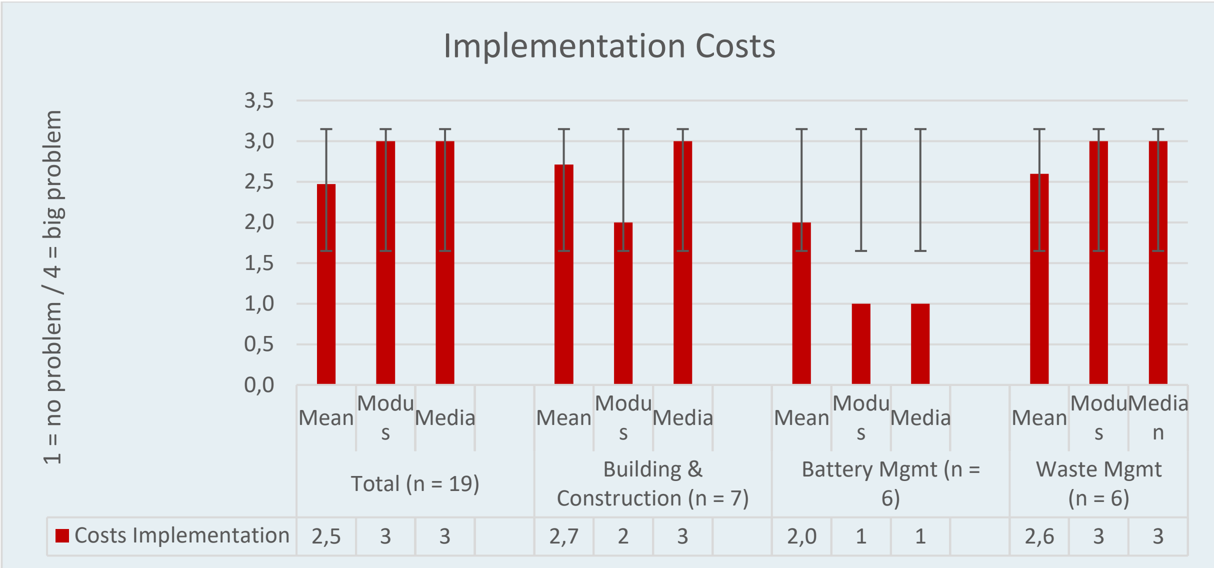


Figure 32: Implementation costs of a DPP

Observation: The costs of implementing a DPP could be challenging especially for companies from the building and construction sector as well as the waste management sector.

Costs of Maintenance

Efforts and costs are inherent in the operation and maintenance of a DPP. The survey reveals divergent perspectives with respect to sector and company size. Companies in the battery manufacturing sector do not perceive this as a significant issue, whereas those in the building & construction sector, and even more so in the waste management sector, approach it with a greater sense of caution, especially if they are medium sized or small companies, which is rather the case for the building and construction sector and the waste management sector. This suggests that these sectors foresee the potential for this to become an issue in the future. The results are depicted in Figure 19.

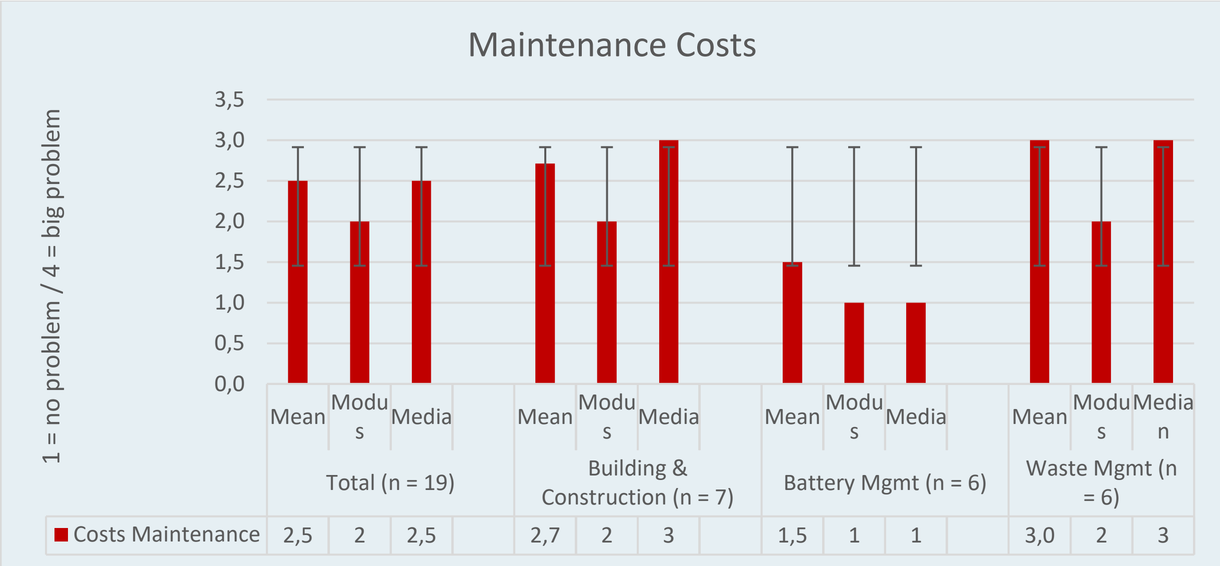


Figure 33: Costs of maintenance of a DPP

Observation: The maintenance costs of a DPP could become a burden for companies from the building & construction sector as well as the waste management sector.

Further challenges mentioned by the participants

During the interviews, participants highlighted various additional challenges they personally encounter in relation to a Digital Product Pass (DPP). The following section presents these challenges, providing a paraphrased explanation for each.

Excessive documentation obligations and compliance efforts: Out of 22 participants, 14 expressed concerns about a significant increase in documentation obligations and associated compliance efforts, not necessarily directly linked to a DPP. The challenges include:

- Lack of harmonization between existing legal initiatives and documentation obligations of product information.
- Fear that a DPP could add to existing obligations, leading to redundancies instead of replacing current documentation requirements.
- Efforts and costs associated with the long-term storage and maintenance of DPP-related data.

Observation: The lack of harmonization between the various legal initiatives (as outlined in chapter 2.3 of this report) and its specific (technological) approaches towards product information management (i.e., product pass vs. battery pass vs. material pass vs. circularity pass) is perceived as a serious obstacle in the implementation of a DPP leading to regulatory overburdening and the risk of compliance failure. Participants raising this issue feel frustrated and fear that this might have a negative impact on the policy objectives associated with a DPP.

Interoperability: 10 participants mentioned interoperability issues as a challenge at various levels of abstraction. These include:

- Harmonization of documentation standards and compatibility of data interfaces to avoid disruptions in data sharing workflows.
- Dealing with multilingualism and terminological heterogeneity in cross-border data sharing scenarios.
- Ensuring cross-system compatibility of digital twins for specific products when working with distributed data.

Observation: Ensuring syntactic and semantic interoperability in the collection and exchange of product related data along (international) supply chains will become a key issue in the successful implementation of a DPP and the validity and reliability of provided data and the trustworthiness of applications making use of them. This also concerns the harmonization of methodologies to operationalize specific benchmarks especially in the context of environmental footprinting.

Organizational complexity and lack of incentives: Six participants highlighted complexity issues associated with the operational aspects of a DPP. These include:

- Heterogeneity and lack of sufficiently qualified technical experts required to run and maintain a DPP.
- Managing interdependencies and complexity resulting from the division of labor, particularly when involving external actors.
- Assigning responsibilities and establishing accountability for a DPP within the organization.

Observation: All participants understand that a DPP requires a good coordination between technical and domain experts to compile a DPP. But especially medium and small enterprises face challenges due to a lack of resources and an overburdening of existing staff with new compliance obligations. In addition, SMEs criticize a lack of support and incentives for disclosing product related data beyond existing disclosure obligations.

Relevance of information provided by a DPP

We asked the participants about the relevance of certain information categories provided by a DPP. These categories have been derived either from legal documents that make a reference to a DPP (European Commission, 2023e, 2022e, 2020c) or from existing scientific literature (Berger et al., 2023a; Clark et al., 2022; Honic et al., 2019; Munaro et al., 2019; Ribeiro da Silva et al., 2023; Sesana and Salvalai, 2018; Walden et al., 2021) that discusses the informational scope of a DPP necessary to serve its policy objectives. The analysis of the data revealed that there are hardly any differences between the estimates provided by the various participants. Obviously, not all information is equally relevant to companies. Of highest importance is

- information about product composition and materials,
- information about the product's health impact, as well as
- information about the product's ecological footprint.

These three information categories are equally important for all sectors as they provide specific information either for strategy-related business decisions or for the appropriate handling of products during the end-of-life phase.

Interestingly, the compliance of manufacturers with social and labor standards received the lowest relevancy scores. This is surprising and probably an artefact from existing routines, given that so far it was nearly impossible to receive and judge this information due to lack of documentation standards and obligations. With the proposal for a Corporate Sustainability Due Diligence Directive (European Commission, 2022d) currently under development at EU level, this might change soon at least for manufacturers. In the waste management sector this information type would still remain least relevant for obvious reasons. The results are depicted in Figure 20.

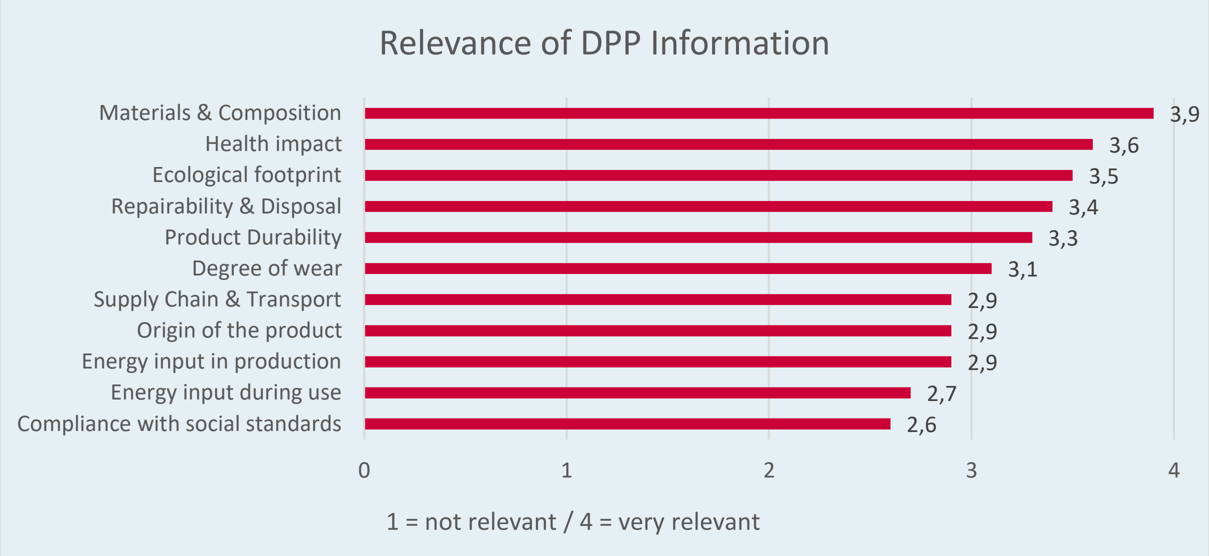


Figure 34: Relevance of information provided by a DPP

Observation: Companies perceive the relevance of specific information very similarly with product composition being of highest relevance, followed by product health impact and ecological footprint. Compliance with social and labor standards plays a minor role – at least under given regulations, especially in the waste management sector. This might change soon.

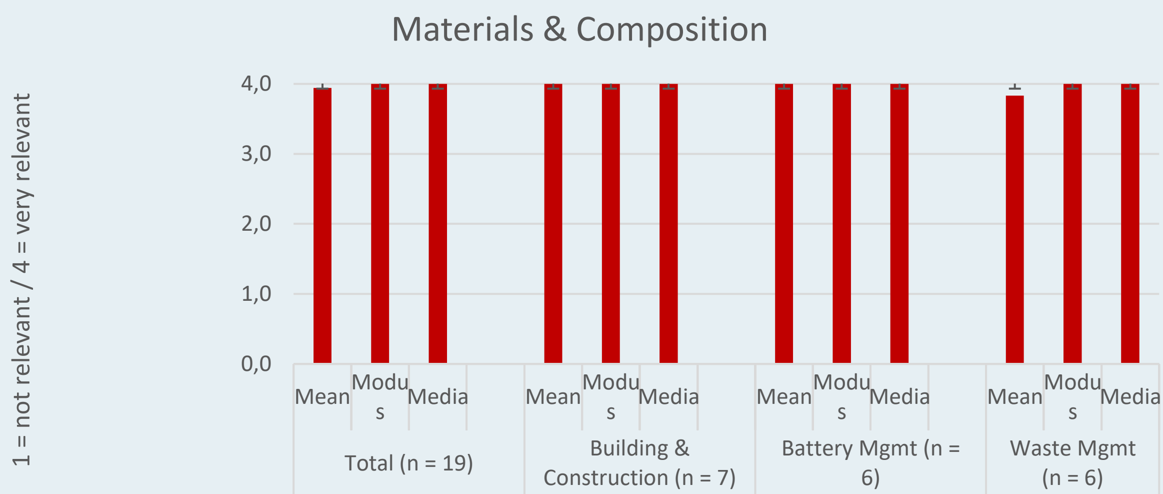
In the following sections we take a closer look at the sector-specific relevancy scores.

Materials & Composition

Information on the material and substance composition of products is one of the core functions of a DPP. This is crucial to ensure the repairability, reuse, and recyclability of products across their various life cycles, as well as to promote environmentally friendly disposal practices. Consequently, this information holds great importance for all stakeholders involved in the value and supply chain.

It is important to note that manufacturers are already bound by extensive documentation and transparency requirements concerning consumer protection, environmental declarations, and product specifications. Knowledge of the product composition can also hold strategic business value, enabling insights into production processes, recipes, and competitive monitoring. Implementing a DPP would inevitably result in greater and easier accessibility to this information, presenting potential conflicts of interest in terms of protection (such as reverse engineering of trade secrets), particularly for manufacturers. Simultaneously, it is perceived as a lever for business diversification by downstream players.

Several participants raised concerns that it is currently not clear at which level of granularity (i.e., substance, component, batch) this information shall be documented, and if this information can be obtained from suppliers given the various tiers of manufacturing and usage of secondary materials within obtained components. Appropriate documentation standards need to be developed at the sectoral level and tested beforehand for feasibility, such as within the Catena X initiative of the automotive sector. The results are depicted in Figure 21.



	Total (n = 19)				Building & Construction (n = 7)				Battery Mgmt (n = 6)				Waste Mgmt (n = 6)		
	Mean	Modus	Media		Mean	Modus	Media		Mean	Modus	Media		Mean	Modus	Media
Materials & Composition	3,9	4	4		4,0	4	4		4,0	4	4		3,8	4	4

Figure 35: Materials and composition

Observation: Information about materials and composition of products are a core feature of a DPP, but participants raise concerns about the complexity and feasibility of collecting such information throughout the supply chain, especially when various tiers of manufacturing and processing of secondary materials are concerned.

Health impact

The inclusion of information regarding the health impact of products, such as nutrition scores, hazardous substances, warnings about potential misuse, and any other adverse health effects, is widely recognized as a crucial aspect of a DPP. This type of information holds particular significance, especially within the building and construction sector, where the longevity and durability of construction materials directly impact the immediate environment. Although the scores are slightly lower in the battery manufacturing and waste management sectors, they still reflect a high level of importance. The results are depicted in Figure 22.

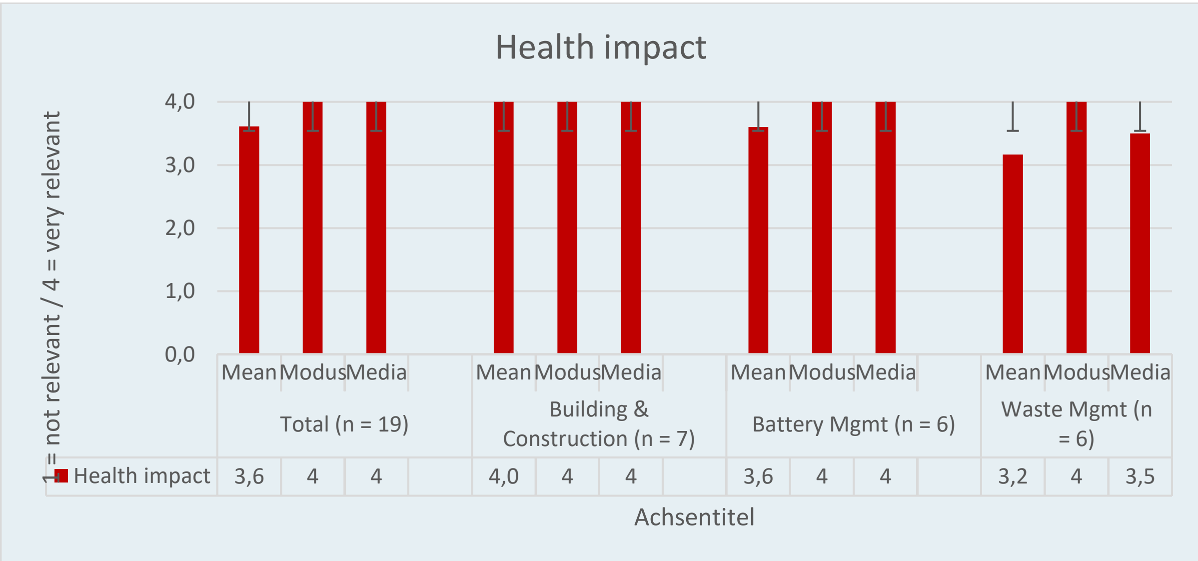


Figure 36: Health impact

Observation: Information about the health impact of products is considered to be an important feature of a DPP which is especially relevant for building and construction materials during their usage and end-of-life phase.

Ecological footprint

Multiple proposals outline the inclusion of ecological impact information in a DPP, encompassing factors such as carbon footprint, resource intensity, and other indicators utilized for ecological benchmarking. This information holds particular significance, especially within resource-intensive sectors, driven by regulatory compliance requirements (e.g., ESG reporting), company ratings (e.g., EU taxonomy), and marketing objectives. Consequently, the building and construction sector and the battery manufacturing sector attribute the highest relevance scores to this type of information, whereas its utility diminishes during the end-of-life phase. The results are depicted in Figure 23.

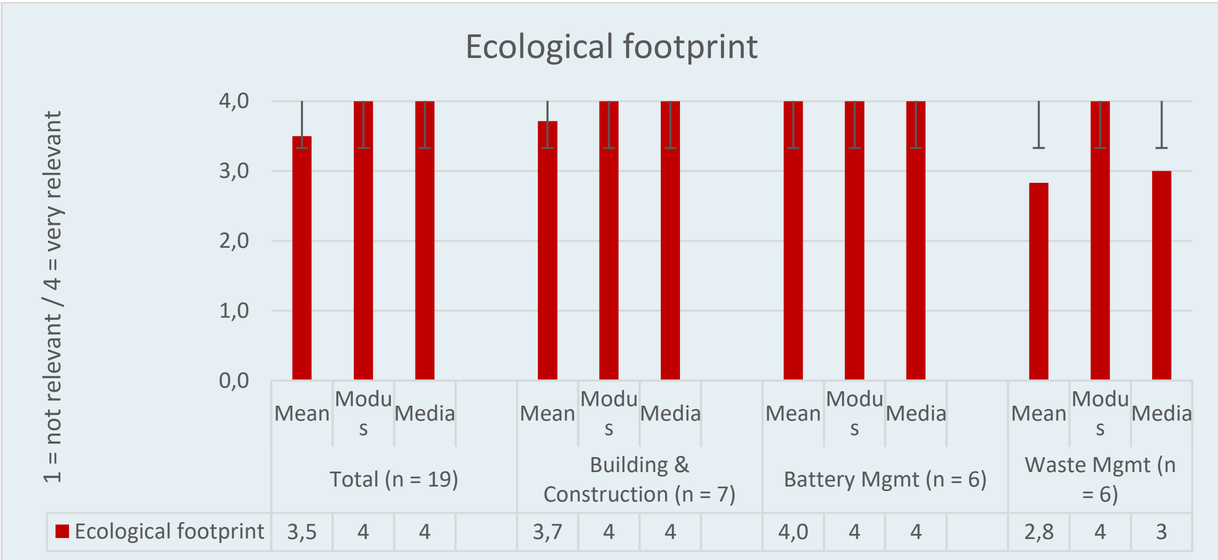


Figure 37: Ecological footprint

Observation: A DPP can be a viable technique to document the ecological footprint of products and making it publicly available to various stakeholders along the supply chain. Nevertheless, it must be acknowledged that ESG-reporting and documentation standards differ in accordance with company size which might make it difficult to establish a coherent and seamless stream of data, especially if SMEs are involved.

Repairability & Disposal

Including information about the repairability of a product, along with instructions for proper disposal of its various parts, could emerge as a central aspect of a DPP. While repairability supports the extension of a product's lifecycle, disposal instructions help mitigate environmental risks associated with hazardous substances and enhance efficiency in the recycling process.

Consequently, this category of information also receives high relevancy scores from all sectors, particularly within the waste management sector, where decisions regarding a product's second lifecycle and further processing are crucial. It is important to emphasize the significance of this information, especially for high-value products like batteries, as extending their lifecycle becomes not only economically reasonable but also plays a significant role in resource conservation and the emergence of secondary markets. The results are depicted in Figure 24.

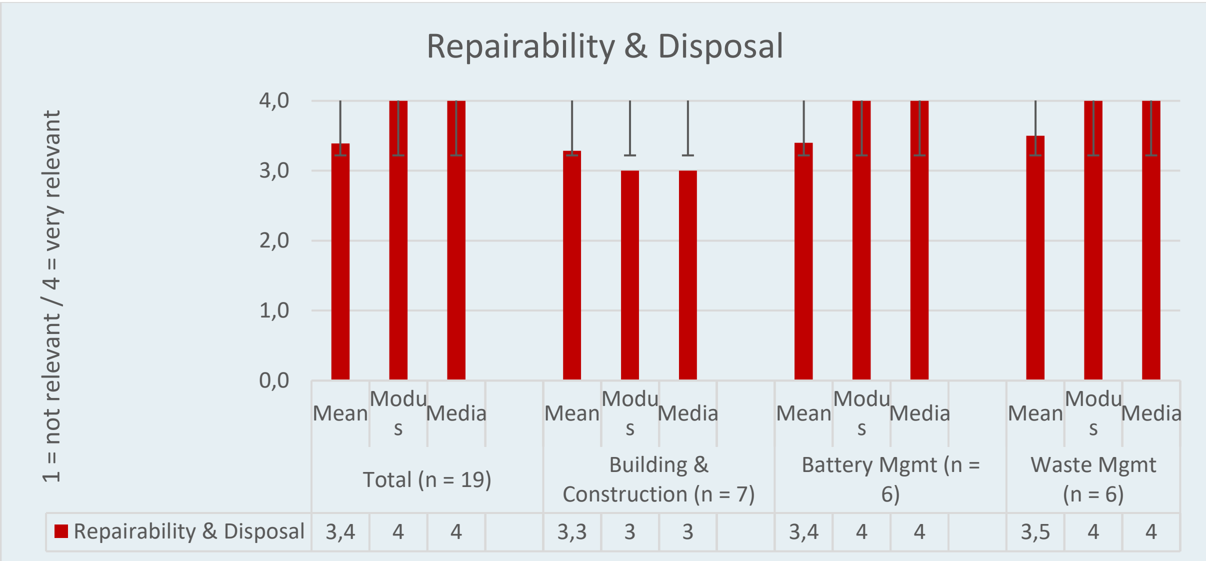


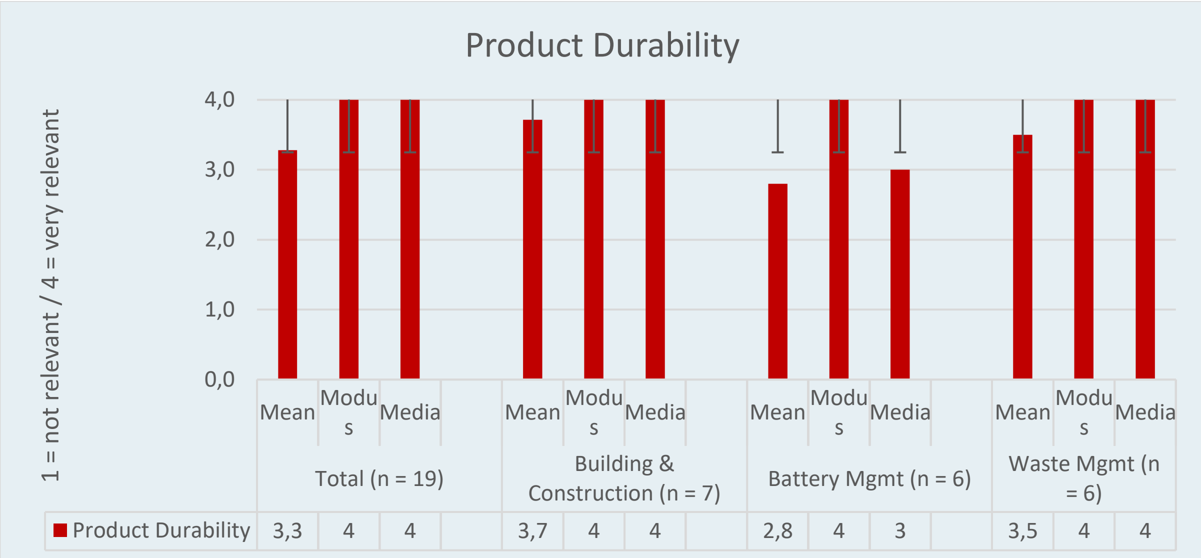
Figure 38: Repairability and disposal

Observation: The inclusion of repairability and disposal instructions into a DPP is highly reasonable, especially for high value products such as batteries. Additionally, such information would be highly useful for the appropriate handling of products during the end-of-life phase, especially when building and construction material is concerned.

Product Durability

Information about a product's durability holds significant importance not only during the consumption phase, as commonly perceived, but also during the manufacturing phase, as the presence of less durable components can impact the product's overall lifespan. Additionally, this information is of high importance to consumers and their entitlement to warranty rights.

According to the survey participants, this category of information particularly resonates within the building & construction sector, where the lifespan of materials and substances directly influences the repairability and maintenance of real estate and infrastructure. Given the long-term perspective associated with such assets, durability information plays a crucial role. Additionally, this category receives high scores in the waste management sector, as it enhances recycling efficiency and serves as a valuable indicator for the reuse of discarded products. In contrast, the battery manufacturing sector places less importance on this information, likely due to effective and relatively simple methods available for estimating a battery's durability in real-time. The results are depicted in Figure 25.



	Total (n = 19)			Building & Construction (n = 7)			Battery Mgmt (n = 6)			Waste Mgmt (n = 6)		
	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median
Product Durability	3,3	4	4	3,7	4	4	2,8	4	3	3,5	4	4

Figure 39: Product durability

Observation: Differences exist about the perceived usefulness of product durability information in a DPP. This information is of high relevance to the building and construction sector as well as the waste management sector. In the context of battery life cycle management concerns have been raised if such information should be documented within a DPP.

Degree of wear

In addition to information about a product's durability, a DPP should also provide insights into the degree of deterioration that occurs during its use or exposure to external influences, such as temperature, moisture, or physical stress. Therefore, information about a product's wear plays a vital role in estimating its remaining durability and serving as a benchmark for decisions regarding further handling.

Consequently, this category of information holds equal importance across all sectors, as it is crucial for assessing the condition of used products and making informed decisions during the end-of-life phase. Unsurprisingly, this information category receives the highest scores within building and construction sector and the waste management sector. Respondents from the battery manufacturing sector raised concerns if such information should be included into a DPP. The results are depicted in Figure 26.

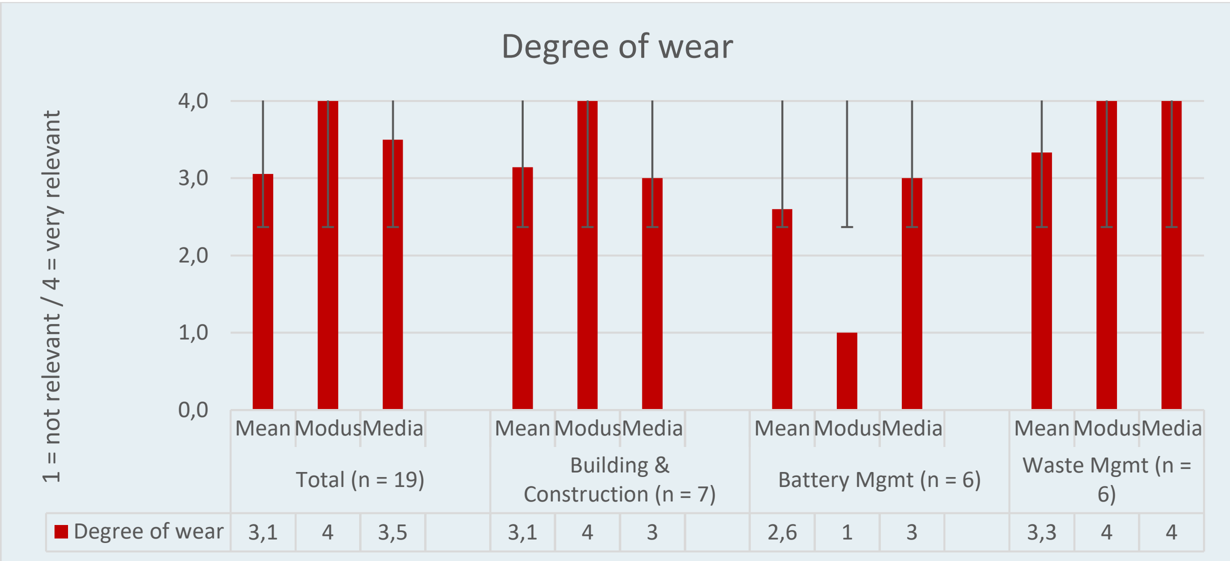


Figure 40: Degree of wear

Observation: Information about the degree of wear of products are highly relevant to the building and construction sector and the waste management sector as they contribute to operational efficiency. Participants from the battery manufacturing sector raised concerns if this information should be documented within a DPP.

Supply Chain & Transport

Information pertaining to the supply chain and modes of delivery of a product is frequently cited as essential to be documented in a DPP, as it contributes to transparency regarding the companies involved on the supply side and the transportation routes during various production and distribution phases.

According to the survey participants, this information category still maintains relatively high rankings compared to other categories. However, its relevance depends significantly on the product type, its sensitivity to transportation, and the local embeddedness of the company. Locally embedded supply chains naturally involve fewer actors and are subject to the same jurisdiction, whereas globally distributed supply chains involve numerous geographically widespread actors often subject to differing compliance and documentation standards. In the latter case, this information category gains greater importance, particularly with the unfolding legal harmonization initiatives in the context of supply chain due diligence.

In this study, participants from the building and construction sector assigned the lowest scores to this information category compared to other sectors, primarily due to the sector's local embeddedness and the sensitivity of construction materials (e.g., cement, bitumen, concrete) to transportation. The battery manufacturing sector and the waste management sector gave slightly higher scores, which can be attributed to the internationally distributed supply chains in the battery manufacturing sector and the relevance of this information for the proper handling of specific substances in the end-of-life phase within the waste management sector. The results are depicted in Figure 27.

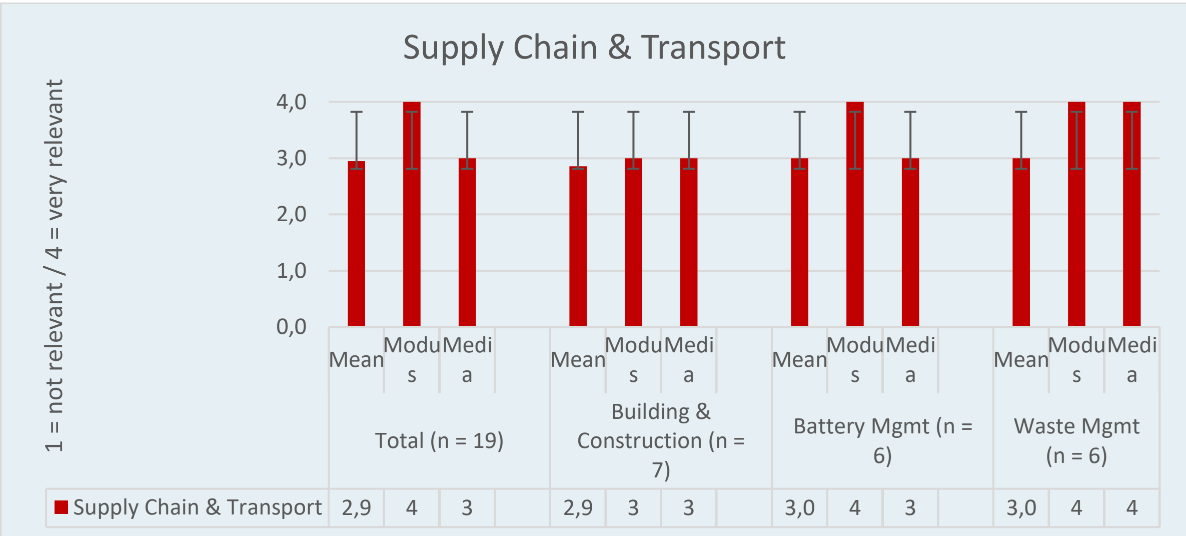


Figure 41: Supply chain and transport

Observation: Survey participants emphasize that the relevance of supply chain information in a DPP varies based on product type, transportation sensitivity, and company localization. Hance, the building and construction sector downplay the value of this information due to local ties and shorter transport routes, while the battery manufacturing and waste management sectors prioritize it for international distribution and substance management.

Origin of the product

A DPP should also include information about the origin of a product. However, it is important to acknowledge the existing confusion regarding the operationalization of the concept "origin", especially in the context of globally manufactured and traded products, and determining the appropriate level of granularity (e.g., material, component, product). While this information may be highly relevant for simply or locally manufactured products, its applicability becomes increasingly challenging with the growing technical and organizational complexity of a product's supply chain.

These challenges are evident in the survey results, with the building and construction sector, characterized by higher local embeddedness, being more capable of providing and utilizing origin information compared to the other sectors. The difficulty of assigning a specific origin to a product is most pronounced in the battery manufacturing sector, which typically has globally distributed supply chains and products with a high degree of compositional complexity. The results are depicted in Figure 28.

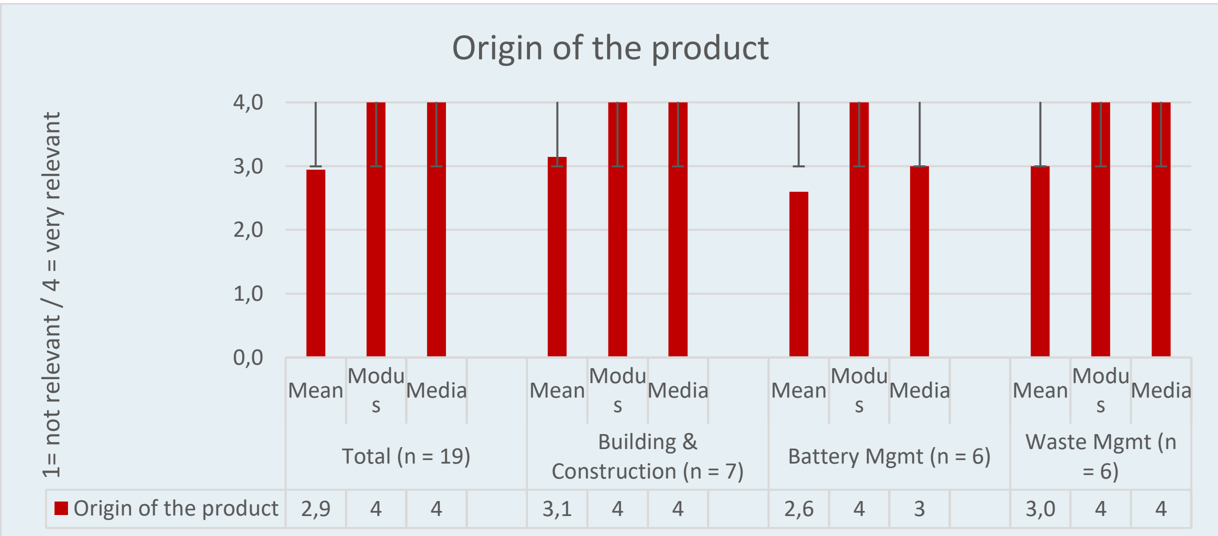


Figure 42: Origin of the product

Observation: While it is difficult to operationalize the concept of "origin" in general, the building and construction sector, characterized by higher local embeddedness, is more capable of providing and utilizing origin information compared to the other sectors. The difficulty of assigning a specific origin to a product is most pronounced in the battery manufacturing sector, which typically has globally distributed supply chains and products with a high degree of compositional complexity.

Energy input in production

Understanding the energy consumption during the production phase serves as a crucial indicator for estimating the resource intensity and environmental impact of a product, thus contributing to specific ESG benchmarks. Additionally, this information enables better estimation of future demand and risks while facilitating the improvement of resource management efficiency.

Although this information holds specific relevance for the building and construction sector and the battery sector, its importance is relatively diminished within the waste management sector, especially when it pertains to product disposal. The results are depicted in Figure 29.

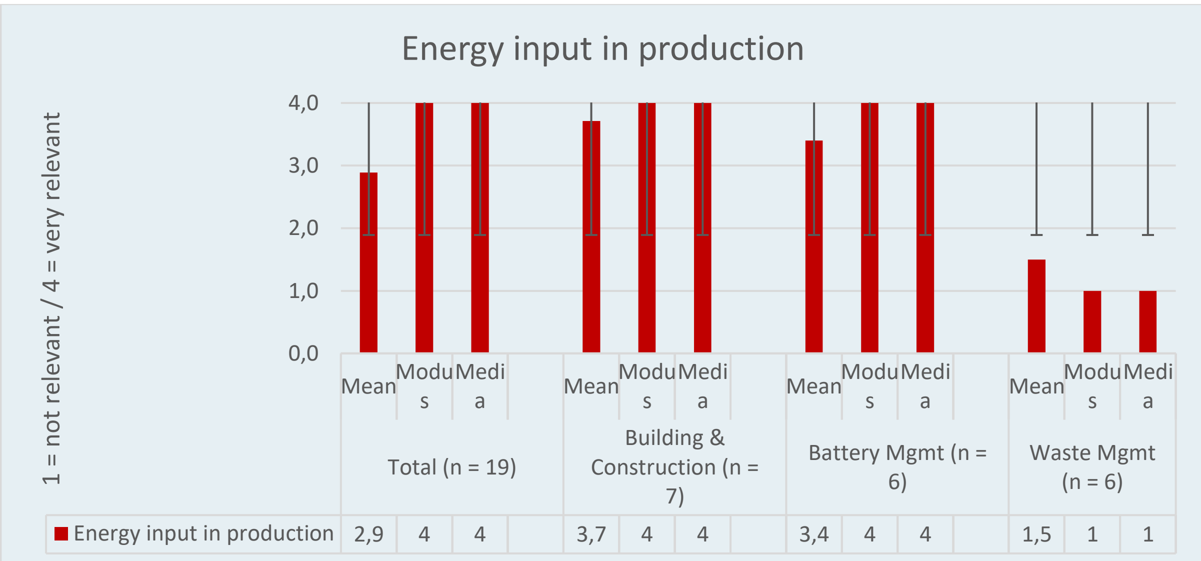


Figure 43: Energy input in production

Observation: Gaining a better understanding of the energy input during the production phase can help companies from the building and construction sector and the battery manufacturing sector to better estimate the resource intensity and environmental impact of a product, facilitating the improvement of resource management efficiency. Obviously, this information is of minor importance to the waste management sector.

Energy input during use

A similar pattern emerges when participants are asked about the relevance of energy input during the usage phase of a product. This specific information category ranks as the second lowest among all categories, influenced by various factors.

The building and construction sector and the battery manufacturing sector still assign relatively high scores to this information category. In these sectors, energy input during the usage phase holds significant importance, particularly for marketing purposes related to energy efficiency and the opportunity costs that consumers consider when choosing among different products. Conversely, for the waste sector, this information bears little importance. This is because, in the waste sector, the usage phase of a product typically concludes during the end-of-life phase, rendering this information obsolete. The results are depicted in Figure 30.

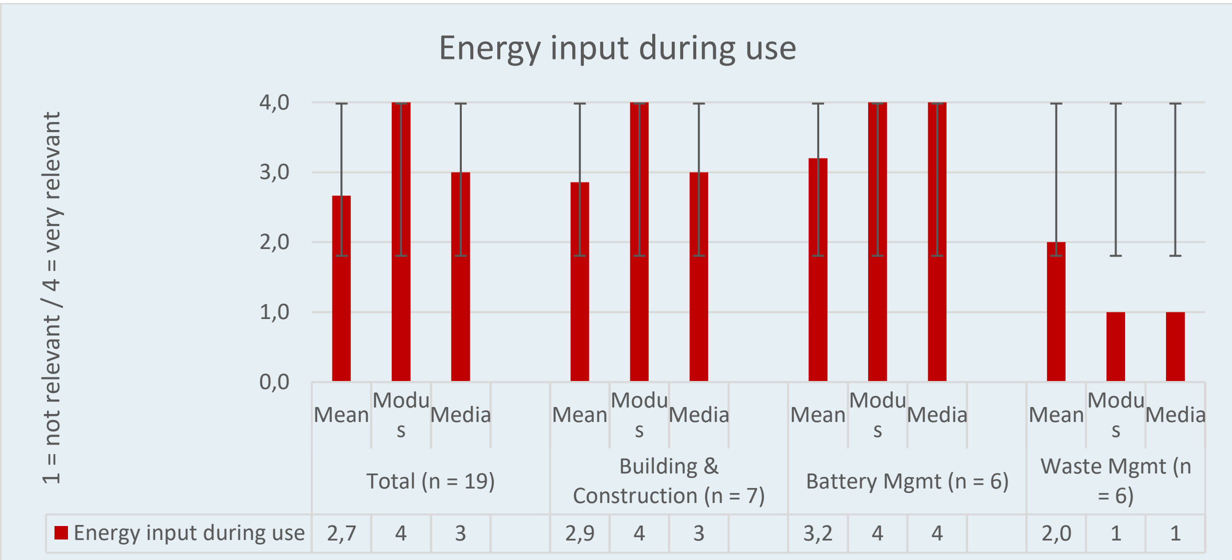


Figure 44: Energy input during use

Observation: The building and construction sector and the battery manufacturing sector assign relatively high scores to this information category as energy input during the usage phase holds significant importance, particularly for marketing purposes related to energy efficiency and the opportunity costs that consumers consider when choosing among different products. Conversely, for the waste sector, this information bears little importance.

Compliance with social standards
Information concerning compliance with social standards during manufacturing ranks as the lowest among all information categories, with variations observed across sectors.

In the building and construction sector, this information category still holds a relatively high degree of relevance. This is primarily due to the significant number of construction product manufacturers who will soon face heightened documentation standards resulting from supply chain due diligence. Consequently, upcoming regulations will impose obligations on manufacturers to ensure compliance.

In contrast, the relevance of this information category diminishes in the battery manufacturing sector and the waste management sector. This decline is expected in the waste management sector, as the importance of this information diminishes during the end-of-life phase. However, the low scores for the battery manufacturing sector should be attributed to the fact that the participating companies have very little capabilities to obtain this information beyond self-declared procurement standards. The results are depicted in Figure 31.

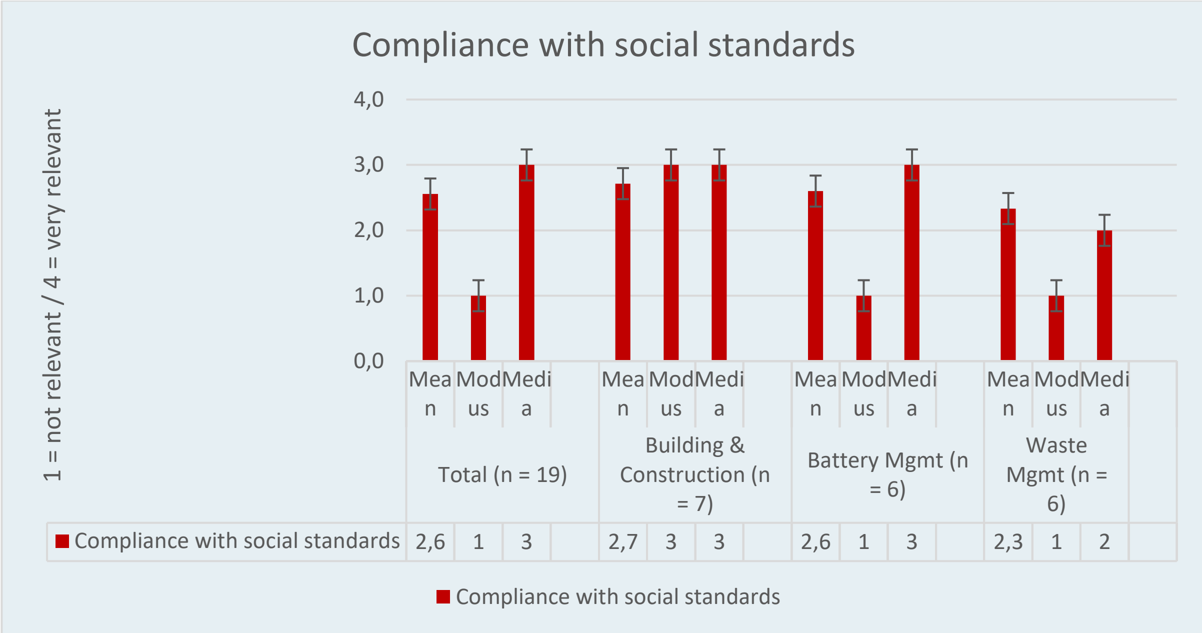


Figure 45: Compliance with social standards

Observation: In the building and construction sector, this information category still holds a relatively high degree of relevance due to upcoming obligations on manufacturers to ensure compliance with social and safety standards. In contrast, the relevance of this information category diminishes in the battery manufacturing sector and the waste management sector. While this is obvious for the waste management sector, the low scores for the battery manufacturing sector should be attributed to the fact that the participating companies have very little capabilities to obtain this information beyond self-declared procurement standards.

Benefits of a DPP

The following section examines the numerous benefits associated with a DPP. These benefits have been drawn from literature research, encompassing both policy objectives and the indirect effects resulting from improved access to product-related information. Figure 32 provides a comprehensive overview of the collective responses obtained from all participants.

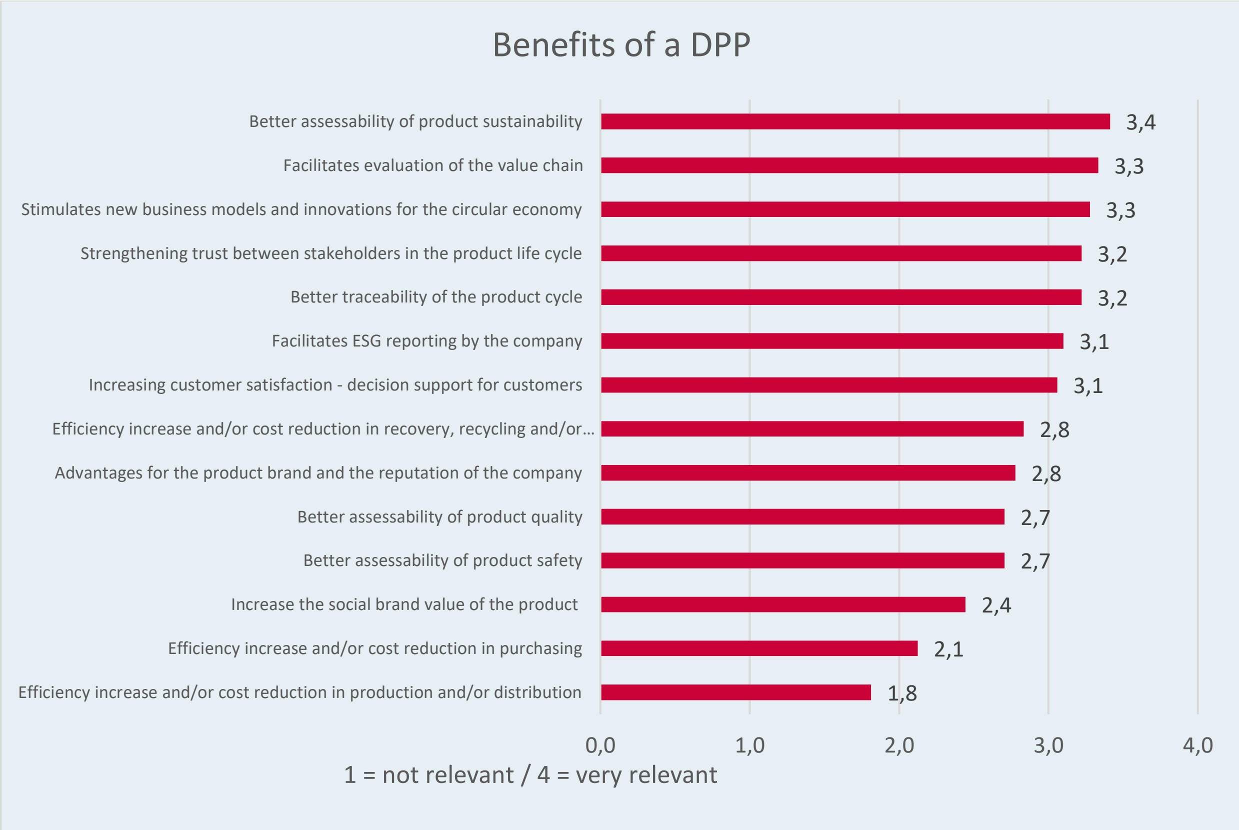


Figure 46: Benefits of a DPP

When ranking the benefits, participants highlighted the following top three advantages of a DPP:

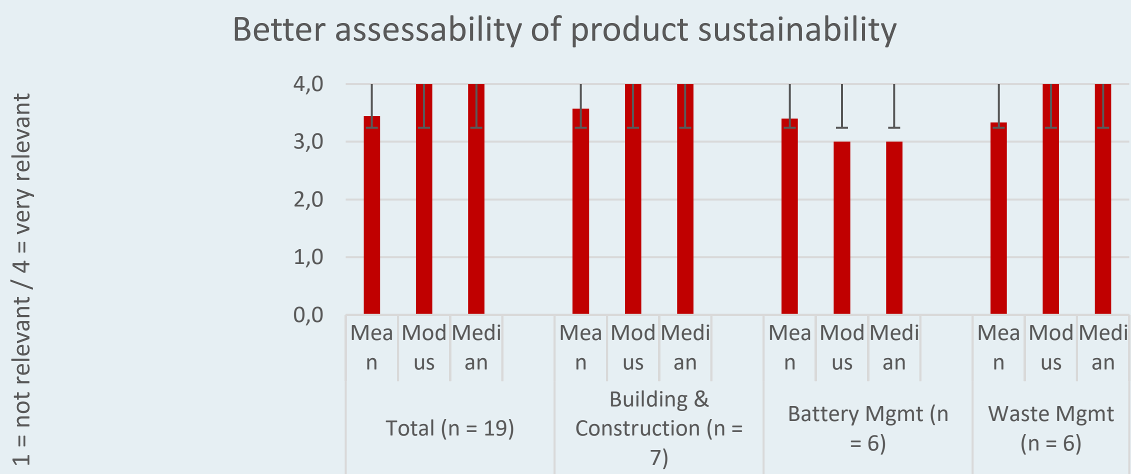
- Enhanced sustainability assessment: A DPP enables a more comprehensive evaluation of a product's sustainability, empowering consumers and businesses to make informed choices.
- Improved assessment of the product's value chain: Participants recognized that a DPP facilitates a deeper understanding of a product's entire value chain, promoting transparency and accountability.
- Encouragement of circular business models and innovation: A DPP can serve as a catalyst for the adoption of circular business practices and inspires the development of innovative solutions that support sustainability goals.

On the other hand, participants did not anticipate any efficiency gains or cost reductions in the areas of 1) production or distribution, 2) procurement and purchase of products, or 3) positive effects on a product's brand value. Additionally, several participants raised concerns that the benefits derived from a DPP strongly coincide with the appropriate presentation and visualization of information in accordance with the stakeholders’ contextual knowledge and willingness to learn. It this respect it will be crucial to provide various entry levels to product-related information and differing degrees of complexity that ideally combine simple labelling approaches (such as a nutria score) with more informative and nuanced explanations of product characteristics and their impact on specific stakeholders. In the subsequent sections, we delve into a detailed analysis of the obtained results.

Observation: A DPP can be a catalyst for transparent manufacturing, the adoption of circular business practices and inspires the development of innovative solutions that support sustainability goals, but it is not expected to lead to cost savings or efficiency gains. Nevertheless, various abstraction levels of product information shall be provided to serve specific needs of various stakeholders along the product life cycle.

Better assessability of product sustainability

As previously discussed, a DPP plays a pivotal role in facilitating a holistic assessment of a product's sustainability, thereby empowering both consumers and businesses to make well-informed decisions prior to, or during, a transaction. This objective stands as a cornerstone of DPP policy implementation and holds significant relevance across diverse sectors, albeit with slightly diminished ratings in the battery industry. These encouraging findings demonstrate that a DPP is widely recognized as an effective means of equipping stakeholders with comprehensive sustainability information pertaining to a product. The results are depicted in Figure 33.



	Total (n = 19)			Building & Construction (n = 7)			Battery Mgmt (n = 6)			Waste Mgmt (n = 6)		
	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median
Better assessability of product sustainability	3,4	4	4	3,6	4	4	3,4	3	3	3,3	4	4

Figure 47: Better assessability of product sustainability

Observation: Among the participants a DPP is recognized as an effective means of equipping stakeholders with comprehensive sustainability information pertaining to a product.

Facilitates evaluation of the value chain

The growing heterogeneity and complexity of value chains present significant challenges for businesses and consumers in comprehending the intricate interconnections within a product's entirety. However, a Digital Product Passport (DPP) is regarded as a practical solution to enhance transparency and foster accountability. It is acknowledged as an effective tool for illuminating value chains, enabling stakeholders to make informed assessments regarding the economic relevance of different entities and market players. By fulfilling this objective, a DPP aligns with a fundamental policy goal of promoting market transparency and nurturing a dynamic demand-driven economy, which is especially relevant for the building and construction sector and its customers' environmental concerns. The results are depicted in Figure 34.

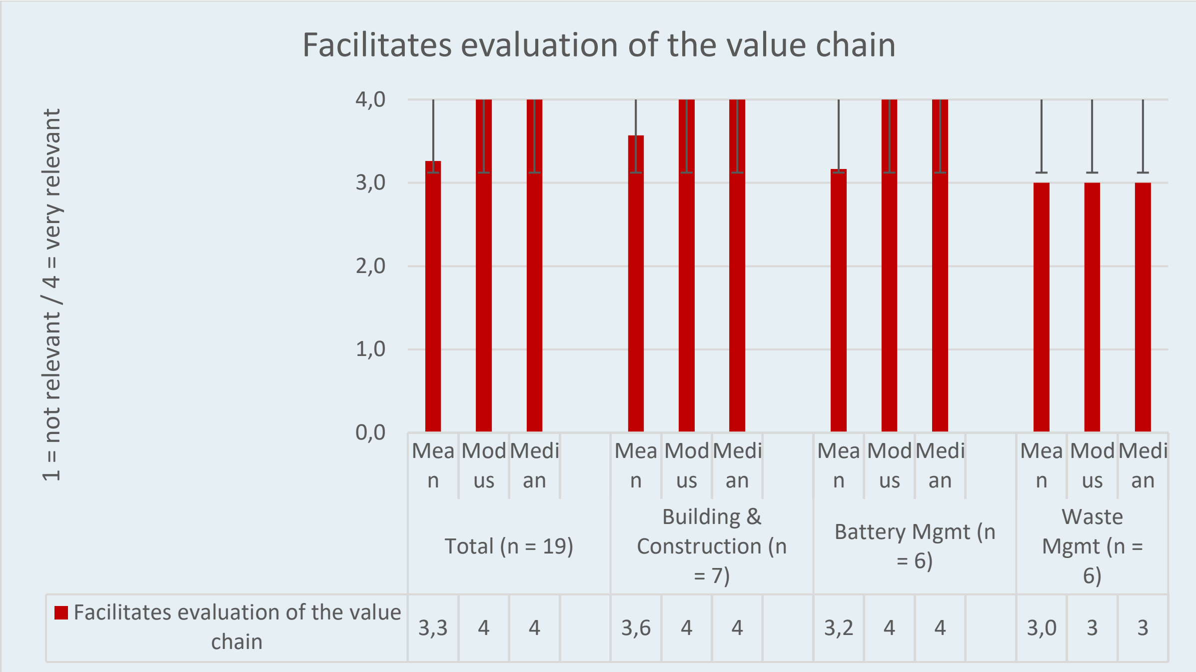


Figure 48: Facilitates evaluation of the value chain

Observation: A DPP aligns with a fundamental policy goal of promoting market transparency and nurturing a dynamic demand-driven economy, which is especially relevant for the building and construction sector and its customers' increasing environmental concerns.

Stimulates new business models and innovations for the circular economy

While it may not be an explicit policy objective, most participants believe that a DPP has the potential to emerge as a significant driver for fostering circular business models and encouraging innovations aligned with the principles of the circular economy.

Nevertheless, a DPP can play a crucial role as a catalyst, facilitating the adoption of circular practices by businesses and inspiring the creation of innovative solutions that contribute to sustainability objectives. This perspective holds true across all sectors, although some participants raised serious concerns that this effect is overstated, especially in the context of international supply chains. The results are depicted in Figure 35.

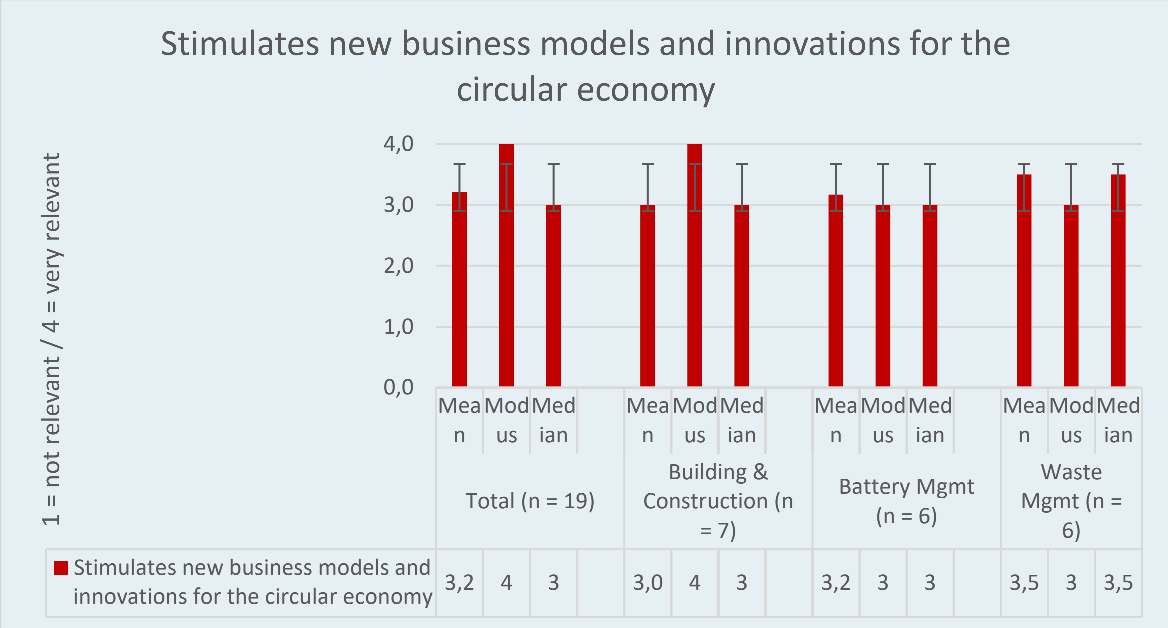


Figure 49: Stimulates business models and innovations for the circular economy

Observation: A DPP can play a crucial role as a catalyst, facilitating the adoption of circular practices by businesses and inspiring the creation of innovative solutions that contribute to sustainability objectives. Nevertheless, some participants raised serious concerns that this effect is overstated, especially in the context of international supply chains.

Strengthening trust between stakeholders in the product life cycle

Closely tied to the emergence of new business models is the issue of trust-building among the various actors involved in the product lifecycle. Most participants express a firm belief in the substantial trust-building potential of a DPP, even though the precise mechanisms through which this effect occurs are not yet clearly discernible. Some participants raised doubts about the trust-enhancing mechanism of a DPP given the fragile mechanisms involved in establishing trust and reputation within complex social settings such as supply chains. Accordingly, participants especially from the battery manufacturing sector raise concerns about the trust enhancing effects of a DPP along a product’s life cycle. The results are depicted in Figure 36.

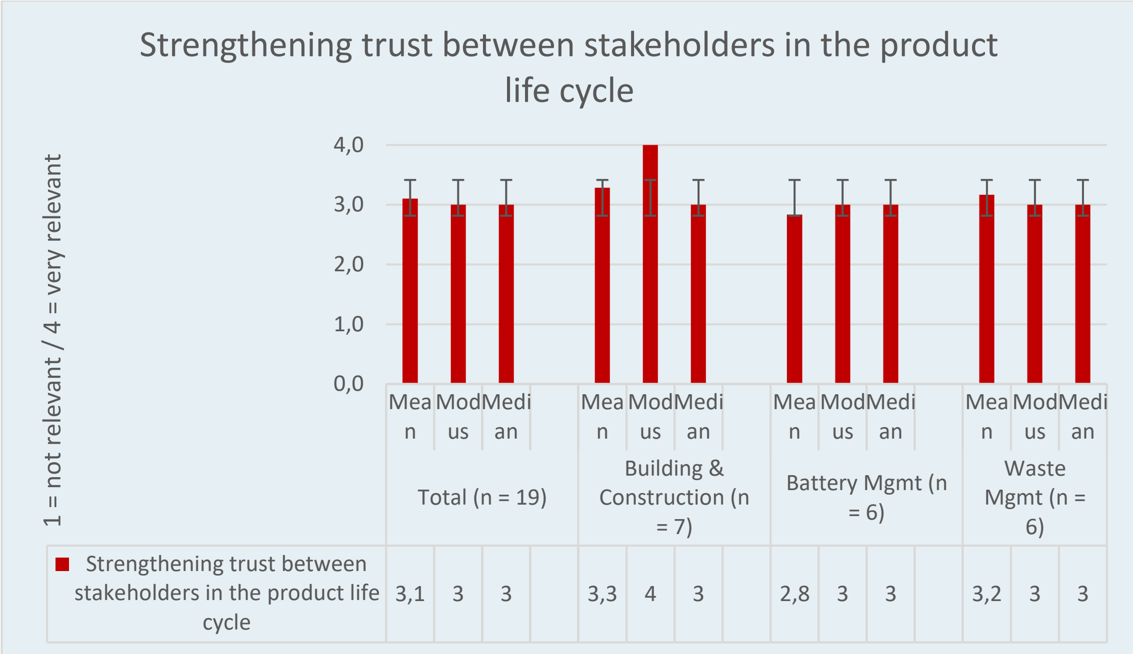


Figure 50: Strengthening trust between stakeholders in the product life cycle

Observation: Most participants express a firm belief in the substantial trust-building potential of a DPP, even though the precise mechanisms through which this effect occurs are not yet clearly discernible.

Better traceability of the product cycle

The participants also recognize the advantages of enhanced traceability throughout a product's lifecycle. Notably, this attribute receives higher ratings from respondents in the building and construction sector as well as the battery manufacturing sector, in comparison to the waste management sector. The lower scores in the waste management sector can be attributed to the decreased emphasis on traceability during the end-of-life phase, where factors like repairability, reuse, and proper disposal take precedence over the need for complete cycle traceability. The results are depicted in Figure 37.

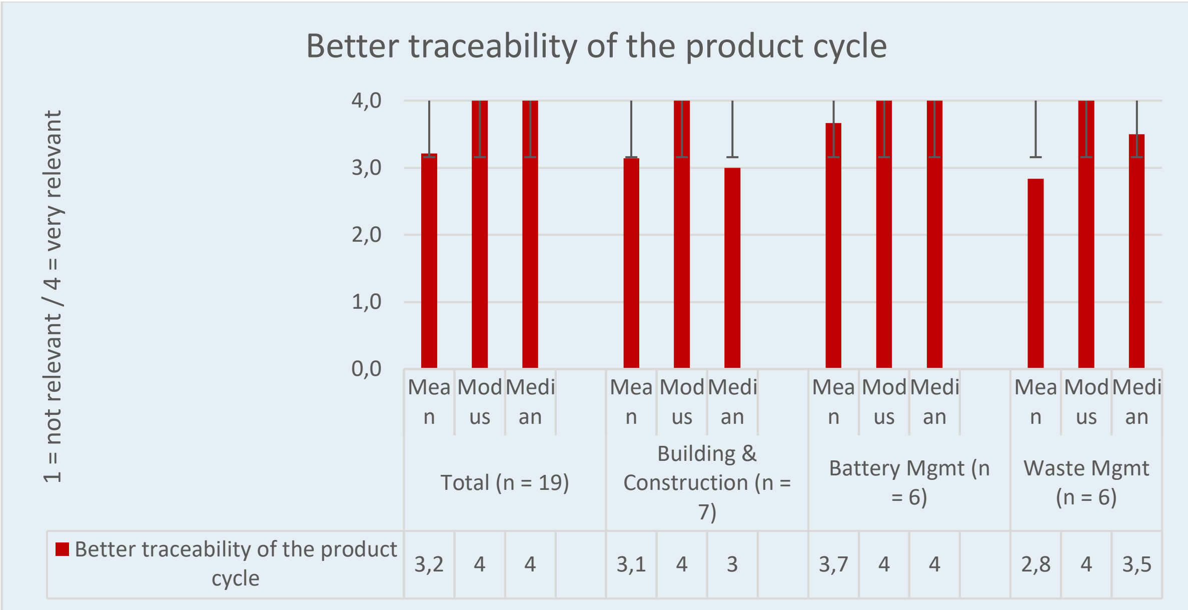


Figure 51: Better traceability of the product cycle

Observation: Enhanced traceability throughout a product's lifecycle receives higher ratings from respondents in the building and construction sector as well as the battery manufacturing sector, while for the waste management sector the traceability of products diminishes during the end-of-life phase.

Facilitates ESG reporting by the company

Disclosing information on environmental, social, and economic sustainability of economic activities is intricately linked to ESG (Environmental, Social, and Corporate Governance) management, which is already a mandatory component of non-financial reporting obligations for large enterprises and will become mandatory in attenuated form for smaller companies as well as the implementation of the Corporate Sustainability Reporting Directive (European Commission, 2022b) will extend these requirements to encompass smaller enterprises as well. Considering this, participants especially from the building and construction sector and the waste management sector anticipate that a DPP could serve as a valuable asset in their ESG reporting endeavors, although not as a facilitator of ESG management but rather as an additional format to serve various stakeholders and the public with product-related ESG-information. The results are depicted in Figure 38.

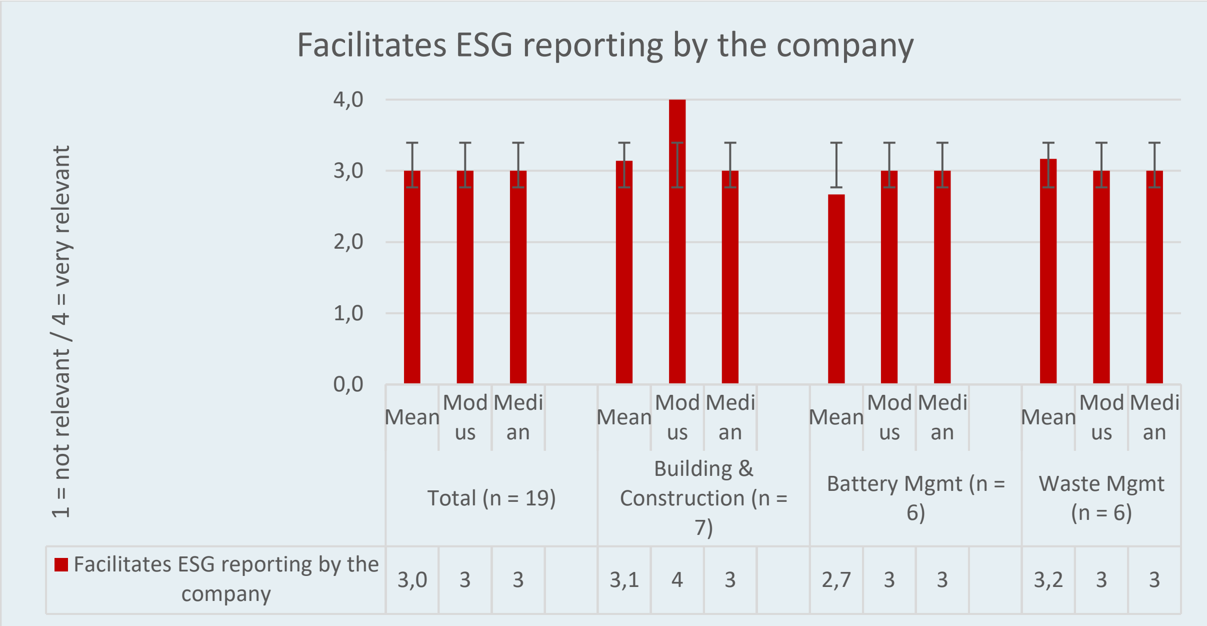


Figure 52: Facilitates ESG reporting by the company

Observation: Participants especially from the building and construction sector and the waste management sector anticipate that a DPP could serve as a valuable asset in their ESG reporting endeavors, although not as a facilitator of ESG management but rather as an additional format to serve various stakeholders and the public with product-related ESG-information.

Increasing customer satisfaction - decision support for customers

The participants from the building and construction sector and the battery manufacturing sector believe that providing comprehensive and accessible information via a DPP empowers customers to make more informed purchasing decisions. According to some statements, customers can gain a better understanding of the product's quality, environmental impact, ethical considerations, and social responsibility, aligning their values with their purchasing choices. This can enhance customer satisfaction by reducing uncertainty, increasing trust, and ensuring that the product meets their expectations. Nevertheless, some participants especially from the waste management sector are slightly more skeptical about these effects, referring to the problem information visualization and the loss of important information to convenient labelling and scoring approaches. The results are depicted in Figure 39.

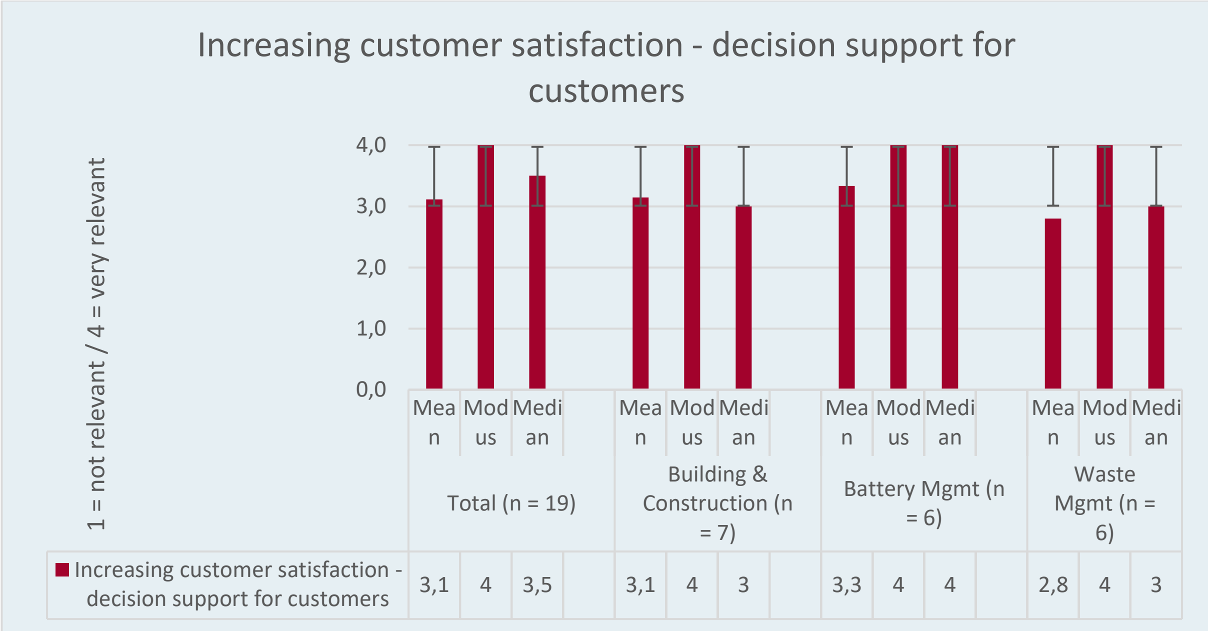


Figure 53: Increasing customer satisfaction - decision support for customers

Observation: Most participants believe that providing comprehensive and accessible information via a DPP empowers customers to make more informed purchasing decisions. Nevertheless, convenient scoring and labelling techniques can be misleading due to the loss of nuanced information.

Efficiency increase and/or cost reduction in recovery, recycling and/or disposal

Participants from the battery manufacturing sector believe that a DPP has the huge potential to contribute to efficiency increases and cost reductions in recovery, recycling, and disposal processes. To a lesser degree, this notion is also shared by the waste management sector. By providing detailed information about a product's composition, materials, and recyclability, a DPP can streamline the recovery and recycling processes by facilitating proper sorting and handling of materials. Additionally, a DPP can enable more accurate and effective disposal practices by providing guidance on proper disposal methods, such as identifying hazardous materials that require special treatment. This can help prevent improper disposal, which can be costly and environmentally damaging. Furthermore, a DPP can support the development of more efficient and cost-effective recycling technologies and infrastructure.

The participants also mentioned that these effects depend on factors such as the implementation of supporting infrastructure, collaboration among stakeholders, and the adoption of standardized practices across the industry. These constraints have been mainly mentioned by participants from the building and construction sector, explaining their low scores on this topic. The results are depicted in Figure 40.

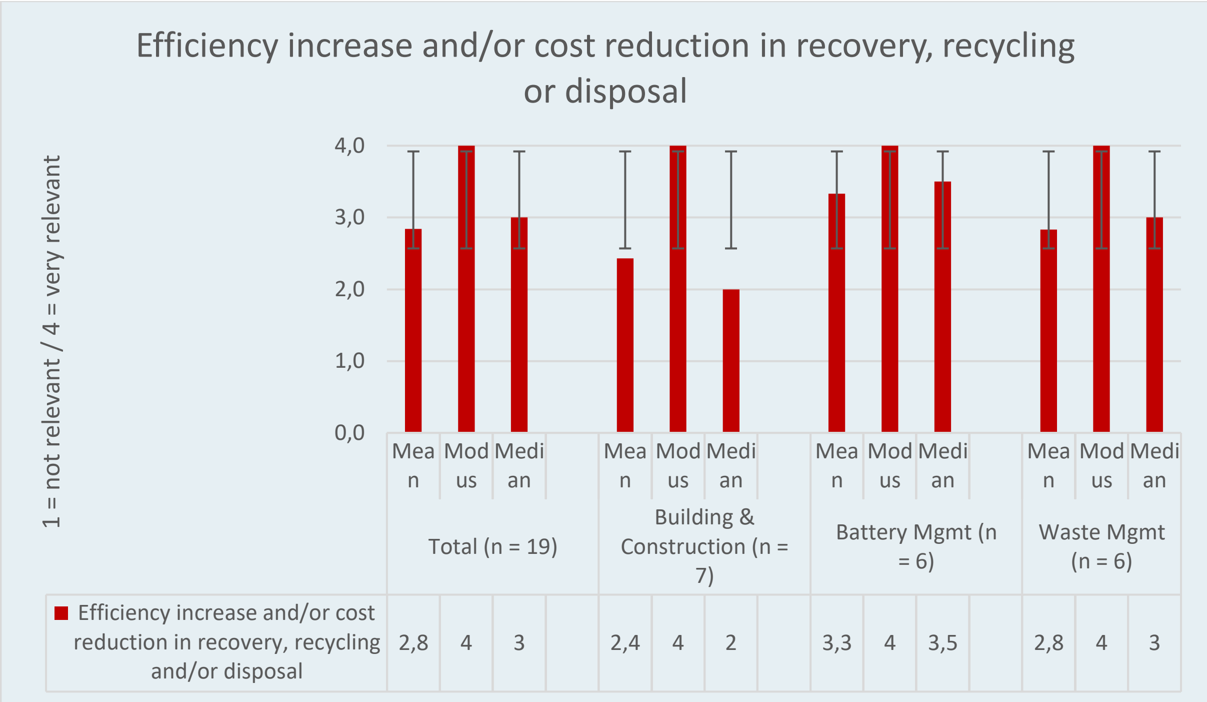


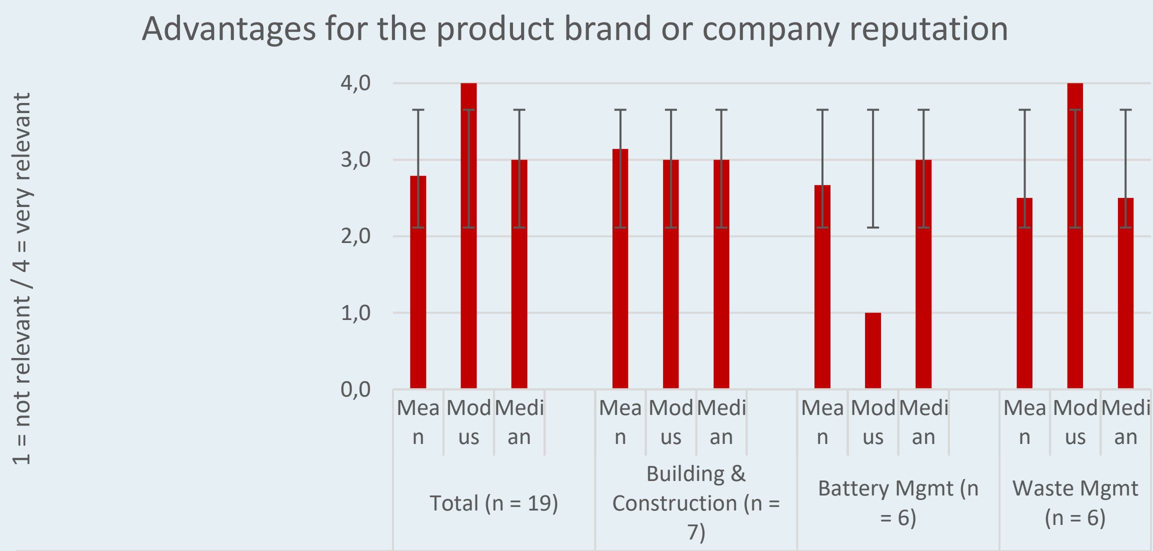
Figure 54: Efficiency increase / cost reduction in recovery, recycling or disposal

Observation: While participants from the battery manufacturing sector believe that a DPP has the huge potential to contribute to efficiency increases and cost reductions in recovery, recycling, and disposal processes, participants from the building and construction sector stated that such effects heavily depend on factors such as the implementation of supporting infrastructure, collaboration among stakeholders, and the adoption of standardized practices across the industry.

Advantages for the product brand and the reputation of the company

Especially participants from the building and construction sector believe that a DPP can generate advantages for the product brand and the reputation of the company. Several interview partners mentioned that customers increasingly demand sustainability and ethical considerations when making purchasing decisions. According to some statements a DPP can demonstrate a company's commitment to transparency and responsible practices, which can positively impact brand perception and customer loyalty. Moreover, a DPP can help companies highlight their sustainability efforts and initiatives, showcasing their commitment to environmental stewardship, social responsibility, and ethical business practices. This can lead to improved brand positioning and a competitive advantage in the market and is already exercised by one participant. Additionally, a DPP can facilitate communication and engagement with customers, allowing them to interact with the brand on a deeper level.

Representatives from the battery manufacturing and waste management sector do not necessarily share this notion and are more skeptical about it as a DPP will be mandatory for most products with limited options for differentiation from competitors. The results are depicted in Figure 41.



	Total (n = 19)			Building & Construction (n = 7)			Battery Mgmt (n = 6)			Waste Mgmt (n = 6)		
	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median
Advantages for the product brand and the reputation of the company	2,8	4	3	3,1	3	3	2,7	1	3	2,5	4	2,5

Figure 55: Advantages for the product brand or reputation of the company

Observation: Participants within the building and construction sector maintain the belief that a DPP serves as a vehicle to showcase a company's dedication to transparency and ethical conduct, thereby potentially enhancing brand reputation and fostering customer allegiance. In contrast, representatives from the battery manufacturing and waste management sectors exhibit a more cautious stance, displaying skepticism towards this notion due to lack of differentiation between competitors.

Better assessability of product quality

While representatives from the building and construction sector and the waste management sector believe that a DPP can contribute to a better assessability of product quality by offering transparency and accessibility to product information that may not be readily available through traditional means, this is not shared by representatives from the battery manufacturing sector due to the technical nature of the product and existing warranty obligations.

Generally, it is well understood that consumers can use the DPP to verify the quality claims made by the manufacturer or retailer, allowing them to assess whether the product meets their desired quality standards. Furthermore, a DPP can facilitate user feedback and reviews, providing additional insights into the product's quality from other consumers who have purchased and used it. This collective feedback can help potential buyers make more accurate assessments of the product's quality before making a purchase decision. The results are depicted in Figure 42.

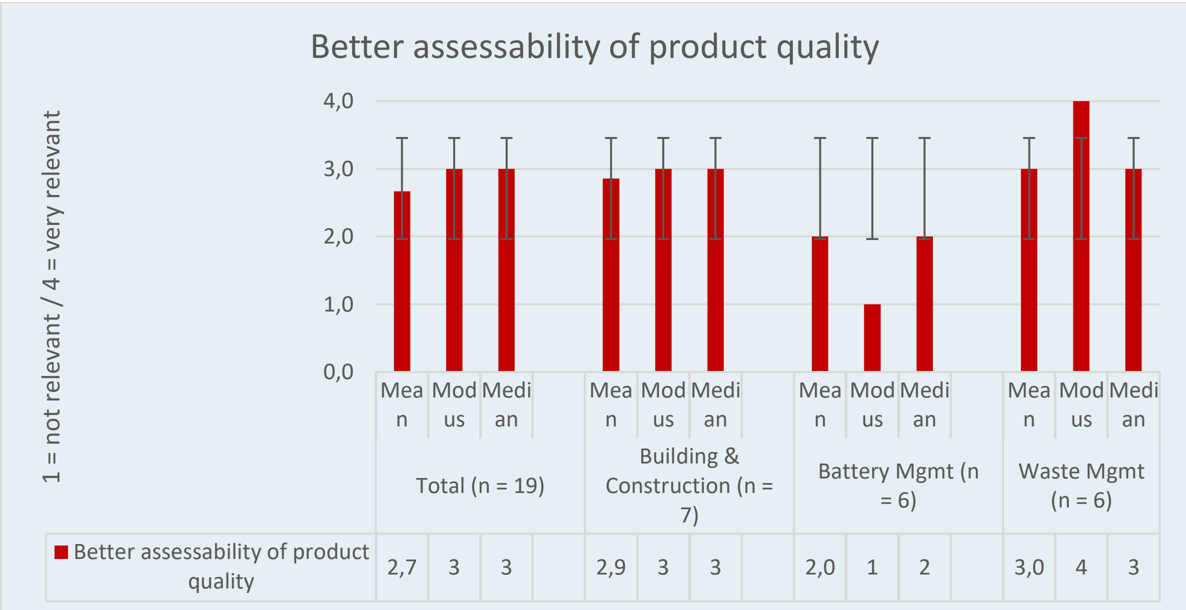


Figure 56: Better assessability of product quality

Observation: While representatives from the building and construction sector and the waste management sector believe that a DPP can contribute to a better assessability of product quality, this notion is not shared by representatives from the battery manufacturing sector.

Better assessability of product safety

While participants from the waste management sector believe that a DPP can contribute to a better assessability of product safety, this notion is not necessarily shared by representatives from the other sectors unless such information is explicitly provided. One participant mentioned the idea that by including details about safety testing, hazard warnings, usage instructions, and safety-related recalls or incidents associated with the product, this information will help consumers to assess the safety aspects of a product before making a purchase. Hence, a DPP could provide access to safety-related data and certifications from trusted sources, giving consumers confidence in the product's safety claims. This can be particularly crucial when purchasing products that have potential safety implications, such as electrical appliances, children's toys, or personal care items. The results are depicted in Figure 43.

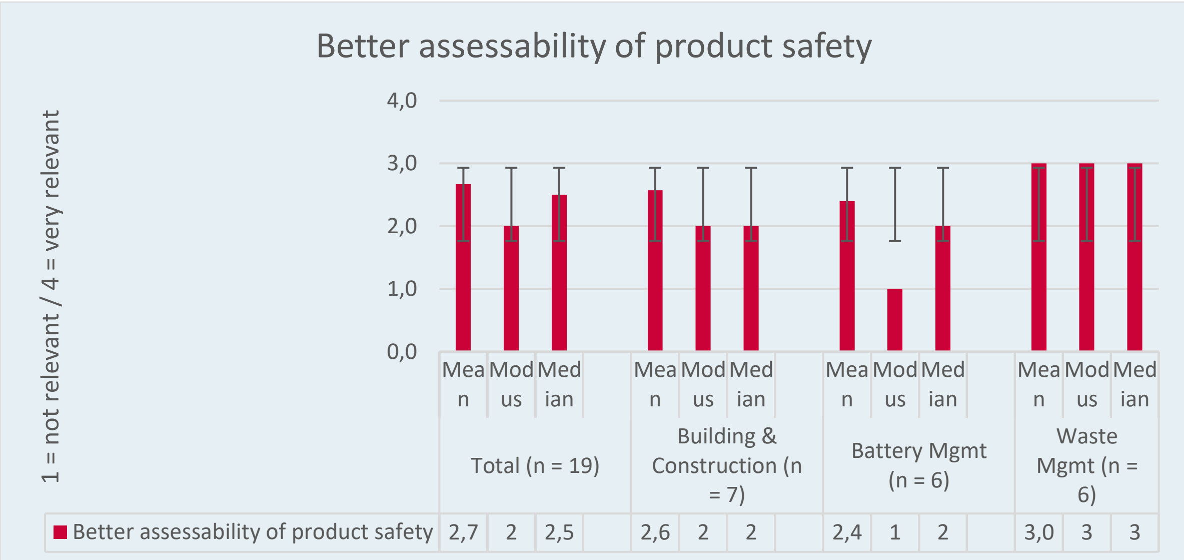


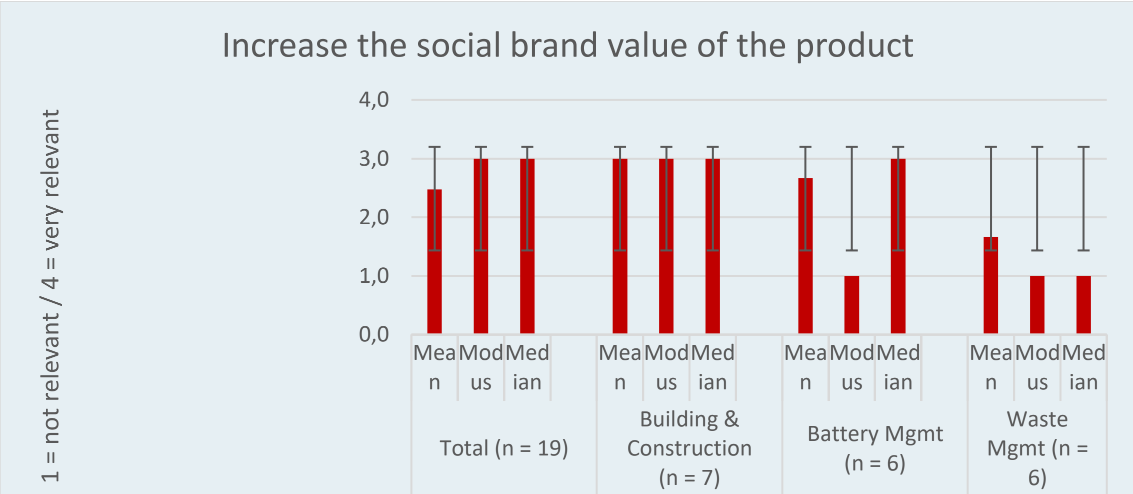
Figure 57: Better assessability of product safety

Observation: While participants from the waste management sector believe that a DPP can contribute to a better assessability of product safety, this notion is not necessarily shared by representatives from the other sectors unless information such as results from safety tests, hazard warnings, or safety-related recalls is explicitly provided.

Increase the social brand value of the product

As consumers are increasingly concerned about the social and ethical aspects of the products they purchase, a DPP can showcase a brand's efforts to address social issues such as fair labor practices, human rights, community engagement, and sustainable sourcing. This transparency and commitment to social values can enhance the social brand value of a product. This notion is mostly shared by representatives from the building and construction sector and the battery manufacturing sector but is not confirmed by responses from the waste management sector.

In theory participants confirm that a DPP allows consumers to access information about a product's social initiatives, certifications, and partnerships that promote positive social impact, providing evidence of a brand's social claims. In practice, they are rather skeptical about this assumption, given the difficulties of acquiring and assessing such information along the supply chain. The results are depicted in Figure 44.



	Total (n = 19)			Building & Construction (n = 7)			Battery Mgmt (n = 6)			Waste Mgmt (n = 6)		
	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median
Increase the social brand value of the product	2,5	3	3	3,0	3	3	2,7	1	3	1,7	1	1

Figure 58: Increase the social brand value of the product

Observation: The notion that a DPP can showcase a brand's efforts to address social issues such as fair labor practices, human rights, community engagement, and sustainable sourcing is moderately shared by representatives from the building and construction sector and the battery manufacturing sector but is not confirmed by responses from the waste management sector.

Efficiency increase and/or cost reduction in purchasing

According to the participants the contribution of a DPP to efficiency gains or costs reductions during the purchasing phase such as lower efforts in product selection through higher transparency and comparability is rather limited, despite the fact that the ability to assess products in a standardized manner reduces the need for extensive research or manual data collection, resulting in improved efficiency.

While the transparency provided by a DPP can improve communication and collaboration between purchasers and suppliers, it also puts pressure in the company negatively impacting existing marketing and sales strategies. By having access to standardized product information, purchasers can engage in more critical discussions with suppliers and even negotiate better terms which can result in improved efficiency, reduced lead times, and potential cost savings. Finally, a DPP can help mitigate risks associated with purchasing decisions by providing information about product quality, safety, and compliance.

While the extent of efficiency gains and cost reductions may vary depending on the implementation and adoption of DPPs, the availability of accurate and standardized product information can undoubtedly contribute to streamlining purchasing processes, reducing the time, effort, and costs involved, which is especially relevant during procurement decisions. The results are depicted in Figure 45.

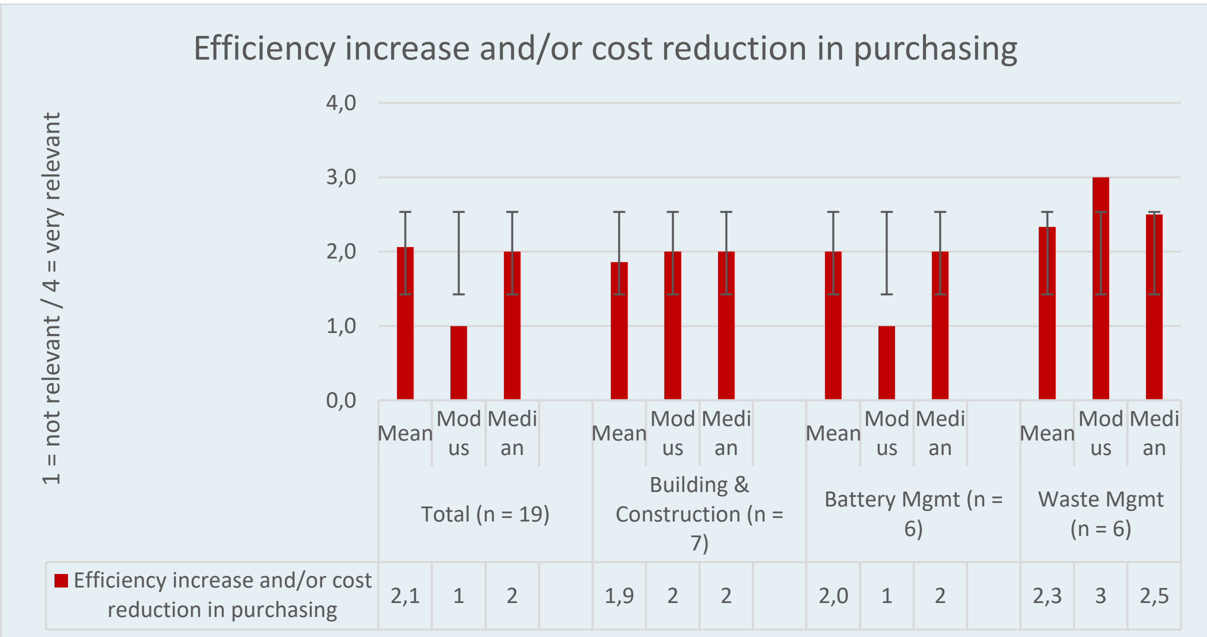


Figure 59: Efficiency increase and/or cost reduction in purchasing

> **Observation:** According to the participants the contribution of a DPP to efficiency gains or costs reductions during the purchasing phase such as lower efforts in product selection through higher transparency and comparability is rather limited.

Efficiency increase and/or cost reduction in production and/or distribution

The literature mentions various positive impacts of a DPP on increased efficiency and cost reduction in production or distribution processes. Among these are enhanced supply chain visibility, improved inventory management, streamlined production processes, better supplier collaboration.

While participants generally agree with these effects, they are skeptical that such gains can be accomplished in practice through the implementation and adoption of a DPP. This would require close coordination and cooperation among various stakeholders which is difficult to incentivize, especially with respect to voluntary data disclosure. The results are depicted in Figure 46.

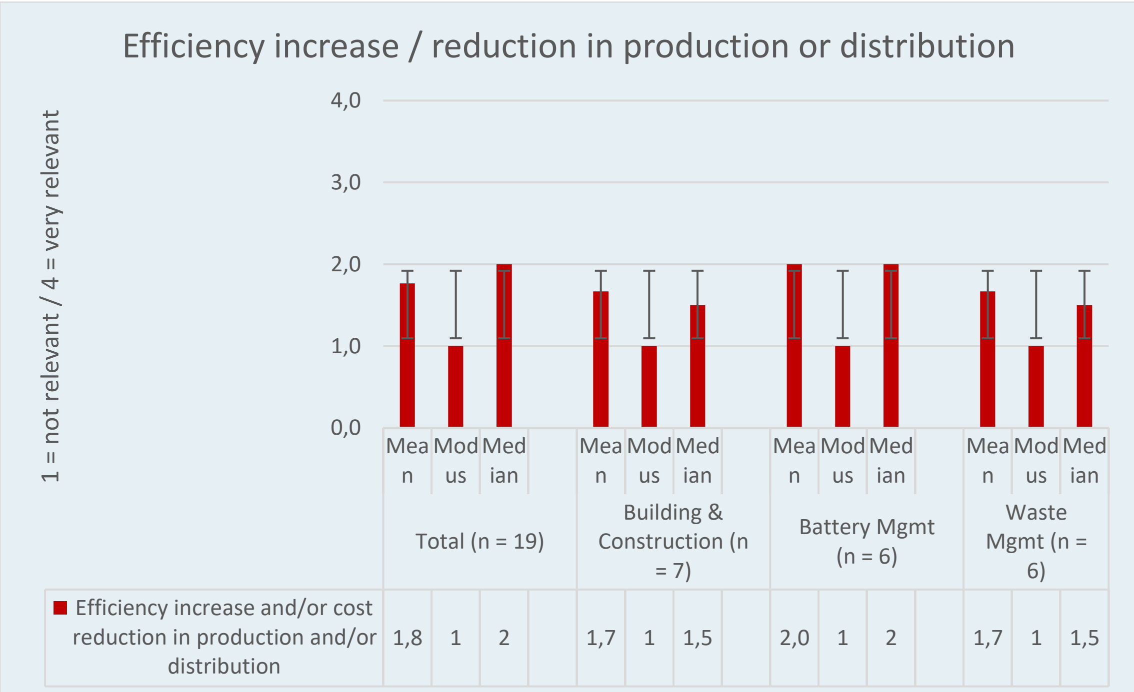


Figure 60: Efficiency increase / cost reduction in production or distribution

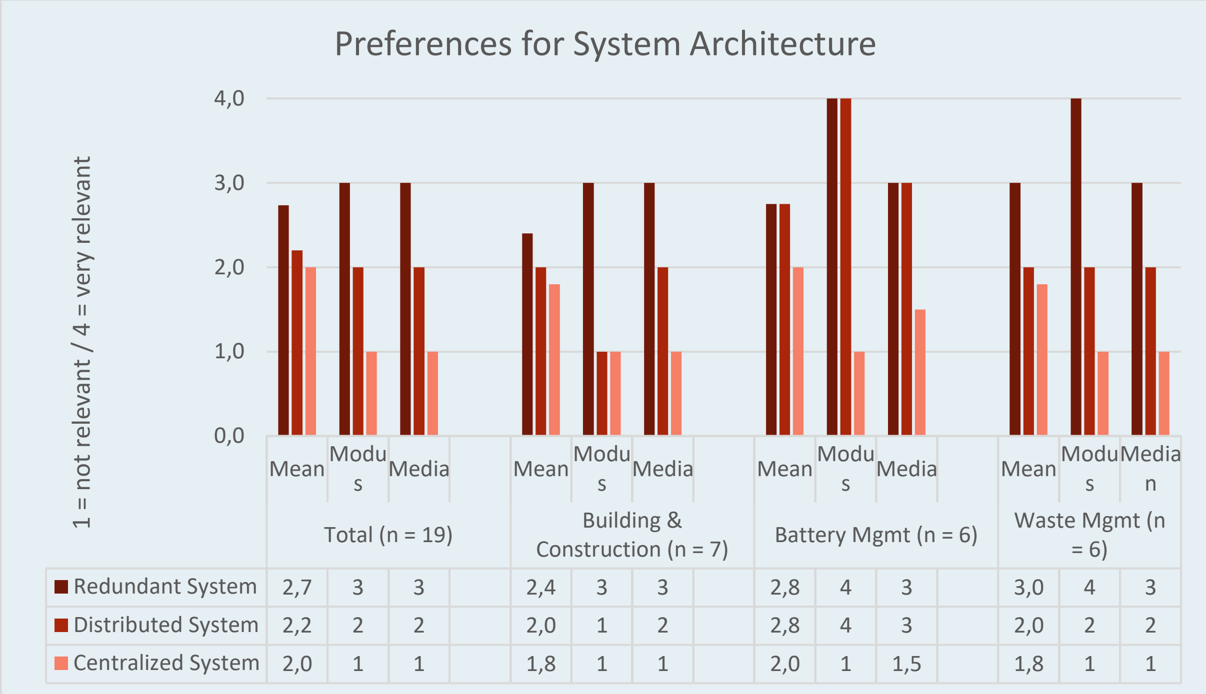
Observation: While participants in theory agree that a DPP can increase efficiency and cost reduction in production or distribution processes, they are skeptical that such gains can be accomplished in practice through the implementation and adoption of a DPP as this would require closer coordination and cooperation among various stakeholders which is difficult to incentivize.

Preferences for System Architecture

A DPP necessitates a robust and extensive data infrastructure capable of collecting, processing, and maintaining pertinent product information over extended periods with high availability. Such infrastructures can encompass diverse architectures that impact data management and the distribution of responsibilities and efforts among contributors to the infrastructure. In this respect it is important to consider factors such as low administrative efforts, cost-effective legal compliance, and companies' interests in providing differentiated access and usage control to data, particularly when it possesses inherent business value.

The results depicted in Figure 47 reveal that companies exhibit clear preferences for a redundant IT architecture that enables them to manage a digital twin of their data sets internally, while retaining specific data through stringent access controls. Conversely, preference scores for a distributed system or a central system are significantly lower.

It should be noted that the survey results reflect the preferences of the interviewees, some of whom may have lacked a deep understanding of the distinctions between the three architecture options and may not have fully considered the associated efforts and costs. Nonetheless, the results demonstrate a distinct concern regarding the necessity to share and disclose data on one hand, and the imperative to maintain control over such data on the other.



	Total (n = 19)				Building & Construction (n = 7)				Battery Mgmt (n = 6)				Waste Mgmt (n = 6)		
	Mean	Modus	Median		Mean	Modus	Median		Mean	Modus	Median		Mean	Modus	Median
Redundant System	2,7	3	3		2,4	3	3		2,8	4	3		3,0	4	3
Distributed System	2,2	2	2		2,0	1	2		2,8	4	3		2,0	2	2
Centralized System	2,0	1	1		1,8	1	1		2,0	1	1,5		1,8	1	1

Figure 61: Preferences for system architecture

Observation: There is a clear preference for a system architecture that allows redundancies in data storage to solve conflicts of interest between data disclosure and retaining control over it.

Legal Impacts of a DPP

We addressed the participants' views on potential interdependencies between a DPP and various legislative aspects that might be influenced by such a large-scale data infrastructure. These aspects include competition issues, liabilities, and privacy concerns. The results revealed a relatively consistent perception among participants, highlighting the following key points:

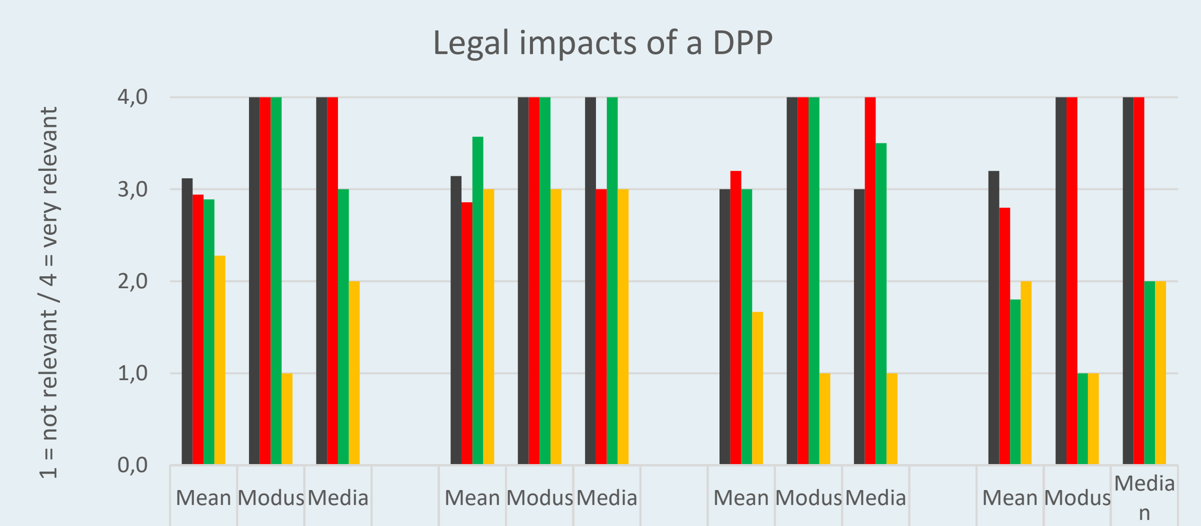
- concerns regarding data disclosure impacting secrecy and confidentiality,
- potential negative effects on intellectual property rights (IPR) strategies,
- heightened obligations related to warranties, and
- specific privacy management challenges.

Notably, variations in perspectives emerged across different sectors.

While concerns regarding reduced confidentiality were significant across all sectors, differences surfaced in the building and construction sector. Here, warranty concerns primarily stemmed from higher documentation standards and the longer availability of information about construction materials. Privacy concerns, on the other hand, were primarily driven by the increased availability and utilization of sensor data, which has the potential to be highly intrusive. These privacy concerns were also present in the battery manufacturing sector, though to a lesser extent.

These findings illustrate the challenge of developing a DPP that equally caters to all affected sectors. Careful steps need to be taken to thoroughly understand the data being collected and shared, as well as how these new practices may conflict with existing business and compliance practices.

In summary, the results depicted in Figure 48 emphasize the importance of addressing concerns related to data confidentiality, intellectual property, warranties, and privacy in the design and implementation of a DPP. Taking sector-specific considerations into account and navigating potential conflicts with established practices will be crucial to ensure successful integration and adoption of the DPP.



	Total (n = 18)			Building & Construction (n = 7)			Battery Mgmt (n = 5)			Waste Mgmt (n = 6)		
	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median	Mean	Modus	Median
Secrecy	3,1	4	4	3,1	4	4	3,0	4	3	3,2	4	4
IPR	2,9	4	4	2,9	4	3	3,2	4	4	2,8	4	4
Warranty	2,9	4	3	3,6	4	4	3,0	4	3,5	1,8	1	2
GDPR	2,3	1	2	3,0	3	3	1,7	1	1	2,0	1	2

Figure 62: Legal impacts of a DPP

Observation: There are sector specific differences about the wider legal impacts of a DPP. While a loss of secrecy is of high concern to all participants, the building and construction sector is worried about stricter warranty obligations.

Syntheses of the results

Chapter 4 of this report investigated the company perspective on a DPP under special consideration of actors from the sectors building and construction, battery manufacturing, and waste management. We conducted a series of in-depth interviews shedding light on organizational, technological, and legal aspects of a DPP and how they might be affected by it.

General Findings

The survey revealed that the participants can make sense on the concept DPP but lack substantial knowledge about its impact on their business. They generally feel well prepared for a DPP from an organizational, technological, and legal perspective, with slight differences between the various sectors. All participants acknowledge the interdisciplinary nature of such an endeavor and organizational challenges deriving thereof, such as that domain experts will become more important under conditions of a DPP which might become a serious issue especially in the building & construction sector. Nevertheless, just one third of participants already provides DPP-related trainings to their workforce, while the rest is still on hold, as a DPP'S impact on daily routines is not yet clear to them.

When it comes to data storage, the participants express a clear preference for a system architecture that allows redundancies in data storage to solve conflicts of interest between data disclosure and retaining control over it.

There are sector specific differences about the wider legal impacts of a DPP. While a loss of secrecy is of high concern to all participants, the building and construction sector is worried about stricter warranty obligations.

Challenges and Concerns

The participants mentioned various concerns and challenges associated with the implementation and maintenance of a DPP.

The building & construction sector, along with the waste management sector, face the potential of a significant skill shortage among IT experts which could prove to be a serious issue. Additionally, the maintenance costs of a DPP could become a burden for them.

The lack of harmonization between the various legal and industry initiatives and its specific (technological) approaches towards product information management (i.e., product pass vs. battery pass vs. material pass) is perceived as a serious obstacle which could lead to regulatory overburdening and the risk of compliance failure. Participants raising this issue fear that this might have a negative impact on the policy objectives associated with a DPP.

Ensuring syntactic and semantic interoperability in the collection and exchange of product data along (international) supply chains will become a key issue to ensure validity and reliability of provided data and the trustworthiness of applications making use of them. This also concerns the harmonization of methodologies to operationalize specific ESG-benchmarks.

All participants understand that a DPP requires a good coordination between technical and domain experts to serve the informational objectives of a DPP. But especially medium and small enterprises face challenges in tackling the resulting complexity arising from this, either because of the lack of resources and the overburdening of existing staff with new compliance obligations. In addition, nearly all participants criticize a lack of economic incentives and / or appropriate compensation models for disclosing product related data beyond existing legal obligations.

Relevance of DPP-information

Companies perceive the relevance of information provided by a DPP very similarly with product composition being of highest relevance, followed by product health impact and ecological footprint. Herein, information about the health impact of products is perceived to be an important feature of a DPP which is especially relevant for building and construction materials during their usage and end-of-life phase. Additionally, a DPP can be a viable technique to document the ecological footprint of products and making it publicly available to various stakeholders along the supply chain. Nevertheless, it must be acknowledged that ESG-reporting and documentation standards differ in accordance with company size which might make it difficult to establish a coherent and seamless stream of data, especially if SMEs are involved in the supply chain.

The inclusion of repairability and disposal instructions into a DPP is highly reasonable, especially for high value products such as batteries. Additionally, such information would be highly useful for the appropriate handling of products during the end-of-life phase, especially when building and construction material is concerned.

Differences exist about the perceived usefulness of product durability information in a DPP. This information is of high relevance to the building and construction sector as well as the waste management sector. In the context of battery life cycle management concerns have been raised if such information should be documented within a DPP.

Information about the degree of wear of products are highly relevant to the building and construction sector and the waste management sector as they contribute to operational efficiency. Participants from the battery manufacturing sector raised concerns if this information should be documented within a DPP.

Survey participants emphasize that the relevance of supply chain information in a DPP varies based on product type, transportation sensitivity, and company localization. Hence, the building and construction sector downrate the relevance of this information due to local ties and shorter transport routes, while the battery manufacturing and waste management sectors prioritize it for international distribution and substance management.

While it is difficult to operationalize the concept of "origin" in general, the building and construction sector, characterized by higher local embeddedness, is more capable of providing and utilizing origin information compared to the other sectors. The difficulty of assigning a specific origin to a product is most pronounced in the battery manufacturing sector, which typically has globally distributed supply chains and products with a high degree of compositional complexity.

Gaining a better understanding of the energy input during the production phase can help companies from the building and construction sector and the battery manufacturing sector to better estimate the resource intensity and environmental impact of a product, facilitating the improvement of resource management efficiency. Obviously, this information is of minor importance to the waste management sector.

The building and construction sector and the battery manufacturing sector assign relatively high scores to information on energy input during the usage phase, particularly for marketing purposes related to energy efficiency and the opportunity costs that consumers consider when choosing among different suppliers. Conversely, for the waste sector, this information bears little importance.

Compliance with social and labor standards plays a minor role – at least under given regulations, especially in the waste management sector. While this is obvious for the waste management sector, the low scores for the battery manufacturing sector should be attributed to the fact that the participating companies have very little capabilities to obtain this information beyond self-declared procurement standards. Some participants raised concerns about the complexity and feasibility of collecting such information throughout the supply chain, especially when various tiers of manufacturing and processing of secondary materials are concerned.

Perceived Benefits of a DPP

A DPP can be a catalyst for transparent manufacturing, the adoption of circular business practices and inspires the development of innovative solutions that support sustainability goals, but it is not expected to lead to cost savings or efficiency gains. Nevertheless, various abstraction levels of product information shall be provided to serve specific needs of various stakeholders along the product life cycle. Some participants raised serious concerns that this effect is overstated, especially in the context of international supply chains.

Among the participants a DPP is recognized as an effective means of equipping stakeholders with comprehensive and transparent sustainability information pertaining to a product. Accordingly, participants especially from the building and construction sector and the waste management sector anticipate that a DPP could serve as an asset in their ESG reporting endeavors, although not as a facilitator of ESG management but rather as an additional format to serve various stakeholders and the public with product-related ESG-information. Bedside that most participants express a firm belief in the substantial trust-building potential of a DPP, even though the precise mechanisms through which this effect occurs are not yet clearly discernible.

Most participants believe that providing comprehensive and accessible information via a DPP empowers customers to make more informed purchasing decisions. Nevertheless, some participants raised concerns that convenient scoring and labelling techniques can be misleading due to the loss of nuanced information.

Participants within the building and construction sector maintain the belief that a DPP serves as a vehicle to showcase a company's dedication to transparency and ethical conduct, thereby potentially enhancing brand reputation and fostering customer allegiance. In contrast, representatives from the battery manufacturing and waste management sectors exhibit a more cautious stance, displaying skepticism towards this notion due to lack of differentiation between competitors, once a DPP becomes mandatory.

While representatives from the building and construction sector and the waste management sector believe that a DPP can contribute to a better assessability of product quality and safety, this notion is not shared by representatives from the battery manufacturing sector unless information from safety tests, hazard warnings, or safety-related recalls is explicitly provided via a DPP.

DPP - Consumer Perspective

This chapter presents a quantitative online survey among the Austrian population, focusing on the following aspects:

- Consumers' information-gathering behavior: The survey aims to understand how consumers gather information about specific product groups before or during purchase decisions.
- Perceived relevance of DPP information: The survey investigates how consumers perceive the relevance of information provided by a DPP when making purchase decisions.
- Willingness to share usage data: The survey explores consumers' willingness to share their usage data as a contribution to a DPP.

In today's rapidly evolving climate and environmental crisis, consumers have become increasingly conscious of the environmental and social impact of the products they purchase. With growing awareness of environmental issues and social injustices, a growing number of consumers want to make informed decisions that align with their values and contribute to a more sustainable world. A DPP is a promising contribution for enabling consumers to access essential information relevant for purchase decisions. A DPP can serve as a comparison scorecard, providing consumers with transparency on sustainability and social indicators, such as sustainability indicators and social hotspots analysis (Koppelaar et al., 2023).

Consumers increasingly seek more transparency from companies and demand information about product origins, environmental impact, and labor conditions. Therefore, introducing a DPP for products presents an opportunity to address these concerns. By providing detailed information about a product's lifecycle, from sourcing to disposal, the DPP enables consumers to make informed choices and supports the transition towards a circular economy (Adisorn et al., 2021; Ospital et al., 2022).

Therefore, product passports are commonly seen as instruments to shape consumer behavior towards sustainable purchasing and responsible product ownership (King et al., 2023; Munaro and Tavares, 2021). However, consumer surveys about the usage relevance of product information are scarce, which makes it challenging to understand how consumers interact with DPPs and the impact of the information provided on their decision-making process. The following section is a contribution to closing this gap.

Methodology

General remarks: This section presents a comprehensive overview of the methodology employed to conduct a quantitative online survey among the Austrian population, with a targeted sample size of 2000 participants. The survey took place between May 30 and June 14, 2023. The research aimed to gather insights into 1) a consumer's actual information gathering behavior related to specific product groups before or during a purchase decision, 2) the consumer's perceived relevance of information provided by a DPP for the purpose of informed purchase decisions as well as 3) the willingness to share usage data as a contribution to a DPP. These variables were analyzed against a set of independent control variables, namely 1) socio-demographic characteristics (i.e., gender, age, income, level of education, 2) technological affinity, 3) lifestyle typologies, and 4) beliefs towards climate change and 5) a sustainable lifestyle.

Sampling Strategy: To ensure a representative sample of the Austrian population, a stratified random sampling technique was employed. Initially, Austria was divided into different strata based on key demographic variables such as age, gender, and geographic location (urban, suburban, and rural areas). The sample size for each stratum was determined proportionally to its population size. Consequently, participants were randomly selected from each stratum, providing a diverse and representative sample.

Survey Instrument Development: To collect data, an online questionnaire was developed. It comprised a series of structured questions designed to explore the specific variables of interest mostly applying a four-level Likert scale. The questionnaire included both closed-ended questions with predefined response options and open-ended questions to allow participants to provide additional insights. The survey instrument was thoroughly reviewed, and pilot tested with a small group of participants to ensure clarity, relevance, and appropriateness.

Data Collection Procedure: The online survey was caried out and administered by the market research company FOCUS Institut Marketing Research Ges.m.b.H. using a reputable survey platform (LimeSurvey) that ensured data security and confidentiality. Survey participants were recruited from an existing panel. The survey was conducted in German to accommodate participants' language preferences. Participants were provided with a clear explanation of the research objectives, the investigated concepts and informed consent procedures before beginning the survey.

Data Analysis: Upon completion of the data collection phase, the responses were aggregated and securely stored for further analysis. The data were carefully cleaned and checked for accuracy, and any missing or inconsistent responses were addressed resulting in slight variations of the actual sample size between 1184 and 2009 completed responses. Subsequently, descriptive statistical analyses were conducted to summarize the data, including (where appropriate) frequencies, means, and standard deviations. Inferential statistical techniques were employed to identify relationships and patterns within the dataset.

Ethical Considerations: Throughout the research process, ethical guidelines were strictly adhered to. Participants' anonymity and confidentiality were maintained by ensuring that no personally identifiable information was collected. Additionally, participants were informed about their rights, including the option to withdraw from the survey at any point without penalty.

Limitations: It is important to acknowledge certain limitations of the research. Firstly, the survey relies on self-reported data to a topic that carries an inherently positive connotation, which is subject to potential response biases. Secondly, the survey was designed for people with limited knowledge on product information which made it necessary to reduce the complexity of the subject matter potentially leading to fuzzy outcomes or biases. Thirdly, the online survey format may have excluded individuals without internet access or those who are less inclined to participate in online surveys. Finally, the presented findings have been compiled from an exploratory analysis with the purpose to identify patterns and dependencies between the investigated sample. A more sophisticated testing is currently being performed but due to timely constraints did not make it into this report.

Data Model and Sample Description

Data Model

We developed the following data model to test interactions between our set of variables. Table 17 and 18 depict the data model.

Dependent Variables:	
Information search behavior per product category (Cronbach's α = 0,89)	7 product categories divided into 16 items: Electronics: Consumer electronics, IT, Household appliances Goods for daily needs: Food products, Sanitary products, Cleaning and detergent products) Building and construction materials Textiles: Fashion / Clothing, Everyday textiles Batteries: Household batteries, Storage batteries, Rechargeable batteries Packaging Plastics: Plastic toys, Plastic Dishes & Containers, Plastic decorations
Relevance of DPP information per product category (Cronbach's α = 0,88)	7 product categories and 11 items: Lifetime / Durability Reusability / repairability Energy consumption during use Disposal instructions Health impact Origin of the product Materials, Ingredients & Product Composition Environmental friendliness / ecological footprint Compliance with social standards in manufacturing Energy consumption during production Supply Chain & Transportation
Willingness to share data	2 item scale (1 = do not agree; 4 = strongly agree) Item 1: Would you be willing to voluntarily provide your usage data in a Digital Product Passport provided your privacy is protected? Item 2: Would monetary incentives or perks (coupons, bonus points, or similar) increase your willingness to share usage data?

Table 3: Data model of the consumer survey

Independent Variables:	
Gender	1 = male; 2 = female; 3 = diverse (n = 2009)
Age	Population between 15 – 75 years of age (n = 2009)
Household Income	Self-declared average income per month (n = 1384)
Education	1 = Completed elementary, secondary school; 2 = Completed vocational school/apprenticeship; 3 = Secondary school without Matura degree; 4 = Secondary school with Matura degree; 5 = Completed university, technical college; 6 = Not specified (n = 1994)
Affinity for technology (Cronbach's α = 0,746)	4 item version of the Affinity for Technology Interaction (ATI) scale (1= do not agree; 4 = highly agree) Item 1: "I like to look more closely at technical systems." (n = 1980) Item 2: "I like to try out the functions of new technical systems." (n = 1989) Item 3: "It is enough for me that a technical system works, I don't care how or why." (n = 1987) Item 4: "It is enough for me to know the basic functions of a technical system." (n = 1992)
Attitude towards sustainable purchasing (Cronbach's α = 0,59)	3 item scale (1= do not agree; 4 = highly agree) Item 1: "I make conscious choices about sustainable products in my daily purchases." (n = 1976) Item 2: "I would like to reach for sustainable products more often, but I can't afford it." (n = 1959) Item 3: "It's easy for me to determine the sustainability of a product." (n = 1964)
Attitude towards climate change (Cronbach's α = 0,661)	4 item scale (1= do not agree; 4 = highly agree) Item 1: "I'm very concerned about climate change." (n = 1980) Item 2: "I find the media coverage of climate change to be exaggerated." (n = 1962) Item 3: "I can make a contribution to climate protection with my purchasing behavior." (n = 1973) Item 4: "I trust environmental seals of approval and certifications." (n = 1972)
Lifestyle typology (Cronbach's α = 0,741)	Münsteraner Lifestyle Typology (14 item scale) (1= do not agree; 4 = highly agree) Item1: “I live a simple, modest life.” (n = 1981) Item 2: “I attach great importance to being thoroughly informed in order to better understand backgrounds and contexts.” (n = 1987) Item 3: “I'm very wait-and-see when it comes to new things.” (n = 1981) Item 4: “I save a fixed amount every month.” (n = 1949) Item 5: “I have ambitious plans and goals, I want to get ahead in life.” (n = 1963) Item 6: “Good food and drink play a big role in my life.” (n = 1994) Item 7: “I like to afford expensive things.” (n = 1966)

	Item 8: "I am a rather steady person, attached to habits and familiar things." (n = 1977) Item 9: "What I want is fun, variety and entertainment." (n = 1975) Item 10: "I love conversations about art and philosophy." (n = 1985) Item 11: "For furniture and furnishings I pay special attention to high-quality materials and exclusive design." (n = 1968) Item 12: " I am disciplined and conscientious." (n = 1983) Item 13: „In life, I am always open to new opportunities and challenges." (n = 1985) Item 14: „I often have the urge to experience something strong and new." (n = 1968)
Disabilities (physical / cognitive)	1 item scale (1 = yes; 2 = no) Item: "Are you dependent on barrier-free offerings when using online content due to health or age-related limitations?" (n = 1925)

Table 4: Data model of the consumer survey (continued)

Descriptive Statistics

In the following sections we present the descriptive statistics of our consumer survey.

Gender and Age

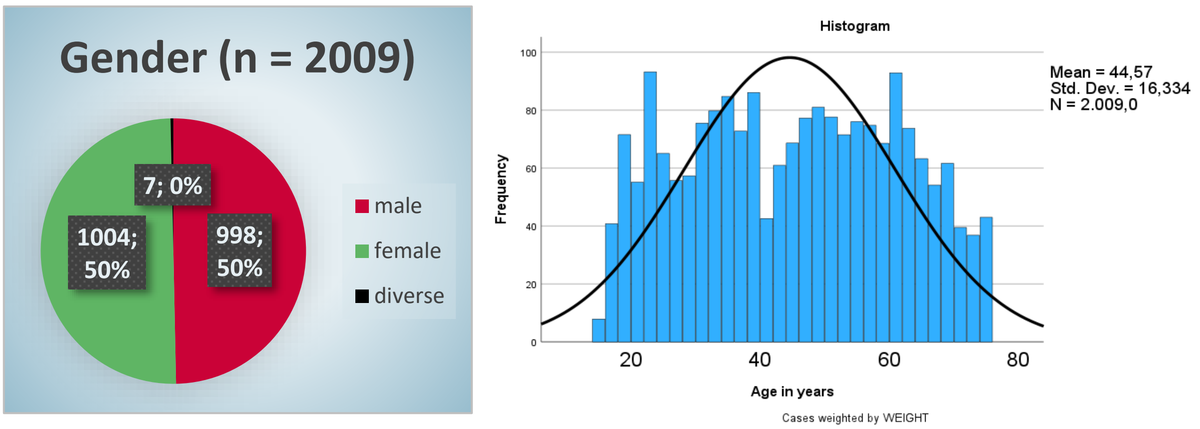


Figure 63: Gender and age distribution of the sample

49,7% of all participants declared to be male, 50% declared to be female. Just 0,3% of the participants declared a different gender. The investigated population was between 15 and 75 years of age, with an average age of 44,57 years. The results are depicted in Figure 50.

Education and Household Income

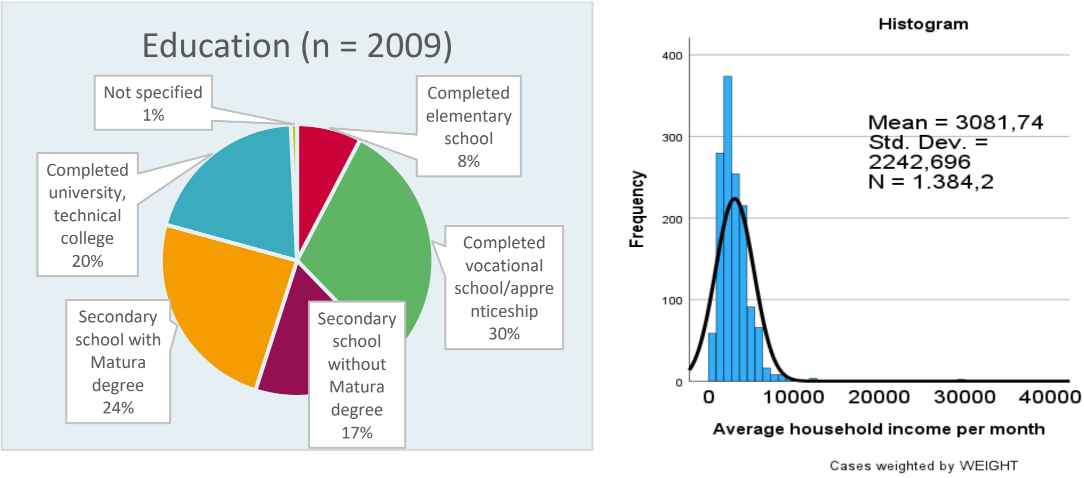


Figure 64: Education and Household Income

The distribution of the highest completed education is as follows: 8% have completed elementary school, 30% completed some sort of vocational school, 17% hold a degree from a secondary school without a maturity diploma[24], 24% completed a secondary school with a maturity diploma, 20% completed a university or an equivalent thereof, and 1% did not specify its formal educational achievements.

The average household income per month is 3082 Euro with strong deviations in both directions. The minimum amount was reported at 0 Euro, while the reported maximum amount was 30000 Euro per month. The results are depicted in Figure 50.

Affinity of Technology Interaction (ATI) scale

In the survey we used the Affinity Technology Interaction (ATI) scale developed by Franke et al., (2019). It basically measures the tendency of a person "to actively engage in intensive technology interaction, as a key personal resource for coping with technology" (ibid.). The original scale consists of nine items with a 6-point Likert scale, but the authors also offer a short version consisting of 4 items with a 4-point Likert scale. To lower the cognitive burden for the survey participants, we decided for the short ATI scale. Figure 51

[24] In various European countries the „Matura degree" (such as in Austria) or "Abitur degree" (such as in Germany) is equivalent to a "maturity diploma" that qualifies for entering higher education facilities such as universities or other educational measures leading to an academic degree.

illustrates the mean values of the study participants' responses, which were condensed into an index value for further analyses.

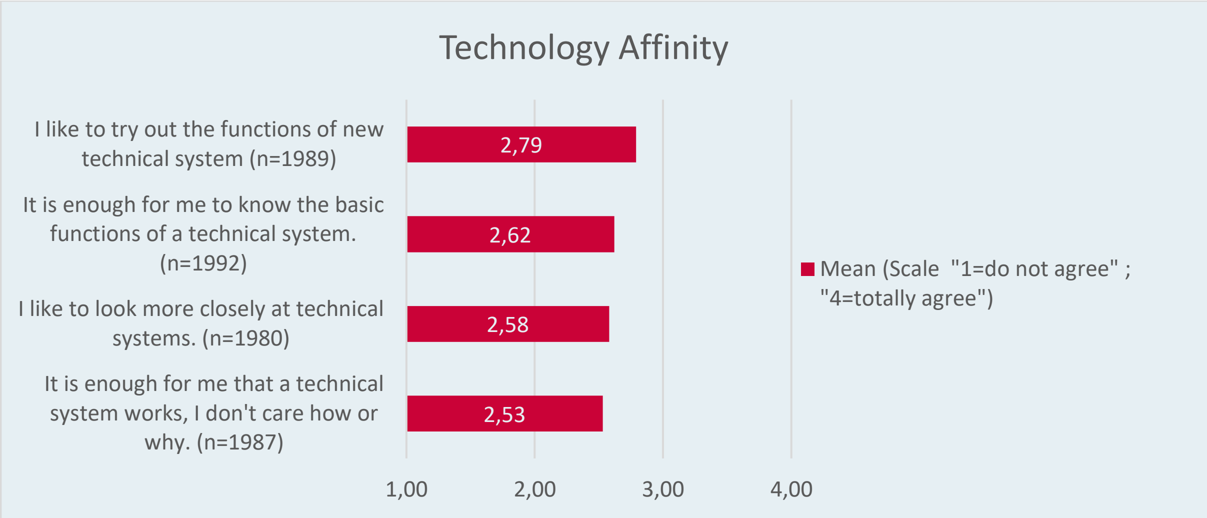


Figure 65:Technology affinity

Attitude towards sustainable purchasing

The gain a better understanding about the influence of various attitudes towards sustainable purchasing we developed an ad-hoc scale consisting of three items and a 4-point Likert scale related to consumption behavior of sustainable products. Due to timely constraints the scale has not been tested beyond the pretest level. But given the promising results of a Cronbach's Alpha of 0,59 we decided to include it into the data model. Figure 52 illustrates the mean values of the study participants' responses, which were condensed into an index value for further analyses.

Figure 66: Attitude towards sustainable purchasing

Attitude towards climate change

We also wanted to test, whether the attitude towards climate change influences the perception and notion of a DPP. Hence, we developed an ad-hoc scale consisting of four items and a 4-point Likert scale related to personal attitudinal aspects of climate change and environmental issues. As in the previous case, due to timely constraints the scale has not been tested beyond the pretest phase. Nevertheless, we decided to include it into the data model. Figure 53 illustrates the mean values of the study participants' responses, which were condensed into an index value for further analyses.

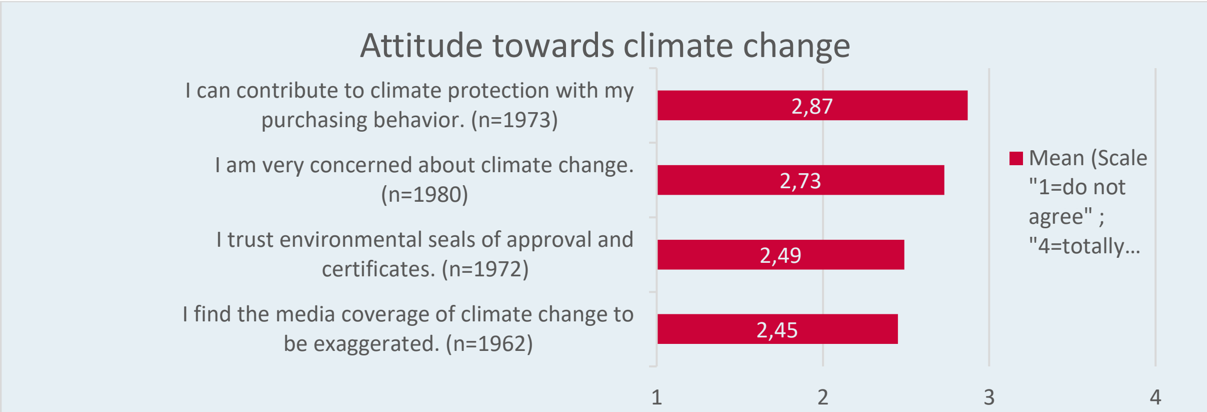


Figure 67: Attitude towards climate change

Lifestyle typology

The Münster Lifestyle Typology is an established method for surveying and classifying lifestyles. It builds on the concept of social structure analysis, has been continuously developed over recent years, and has been tested for validity in a variety of studies (Stelzer and Heyse, 2023). We used it to test the influence of lifestyles on the usage behavior of product information and the perceived relevance of information provided by a DPP. Due to timely constraints, only a condensed index value is included in further analysis making it only possible to distinguish between lower-level and higher-level lifestyles. Herein, lower-level lifestyles indicate people with less socio-economic and cultural capital, compared to higher-level lifestyles of people with a richer set of socio-economic and cultural capital. The in-depth analysis of interactions with product information as a function of distinguished lifestyle typologies derived from a factor analysis will be conducted at a later stage. The question set consists of 14 items along a 4-point Likert scale. Figure 54 illustrates the mean values of the study participants' responses.

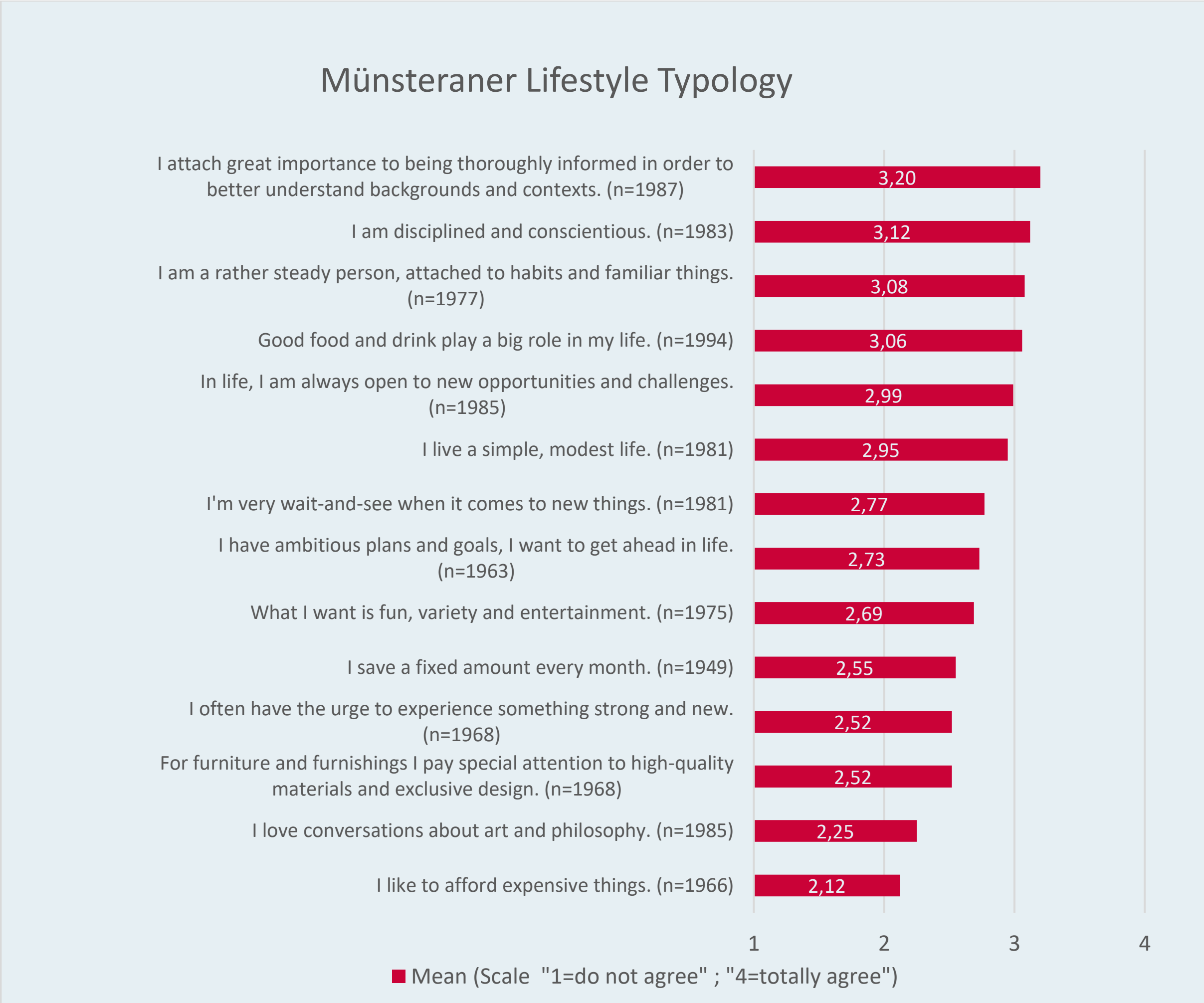


Figure 68: Münsteraner Lifestyle Typology

Disability

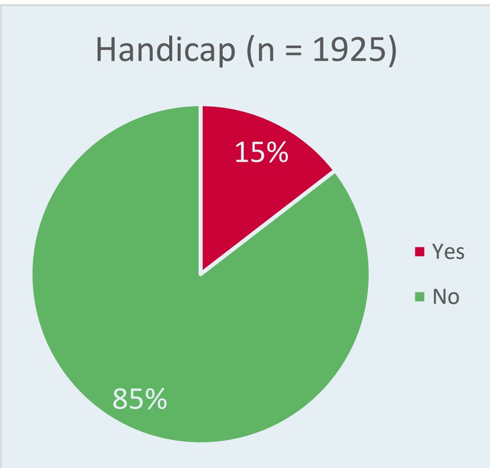


Figure 69: Disability

Finally, we asked the participants if they are dependent on barrier-free offerings resulting from age or other physical or cognitive impairments when using online content which allowed us to operationalize some sort of handicap. 15% of the respondents reported that they are dependent on such offerings compared to 85% who can consume online content without any impairments, as depicted in Figure 55.

Inferences and Interpretation

In the following sections we present the results of the statistical inferences performed on the reported data mainly by linear regression, where ** indicates a p-value of 0,05 < p < 0,001 and *** p < 0,001. The findings are a first exploratory step to gain a better understanding about dependencies and interactions within the data model and derive conclusions from the behavioral and attitudinal factors influencing information search behavior, the perception of relevance of product information provided by a DPP and the willingness to share product usage data with respect to a distinct set of product categories.

Information Search Behavior by Product Category

The survey participants were asked to indicate for which product groups they specifically search for product information before or during a purchase decision. The results look as follows:

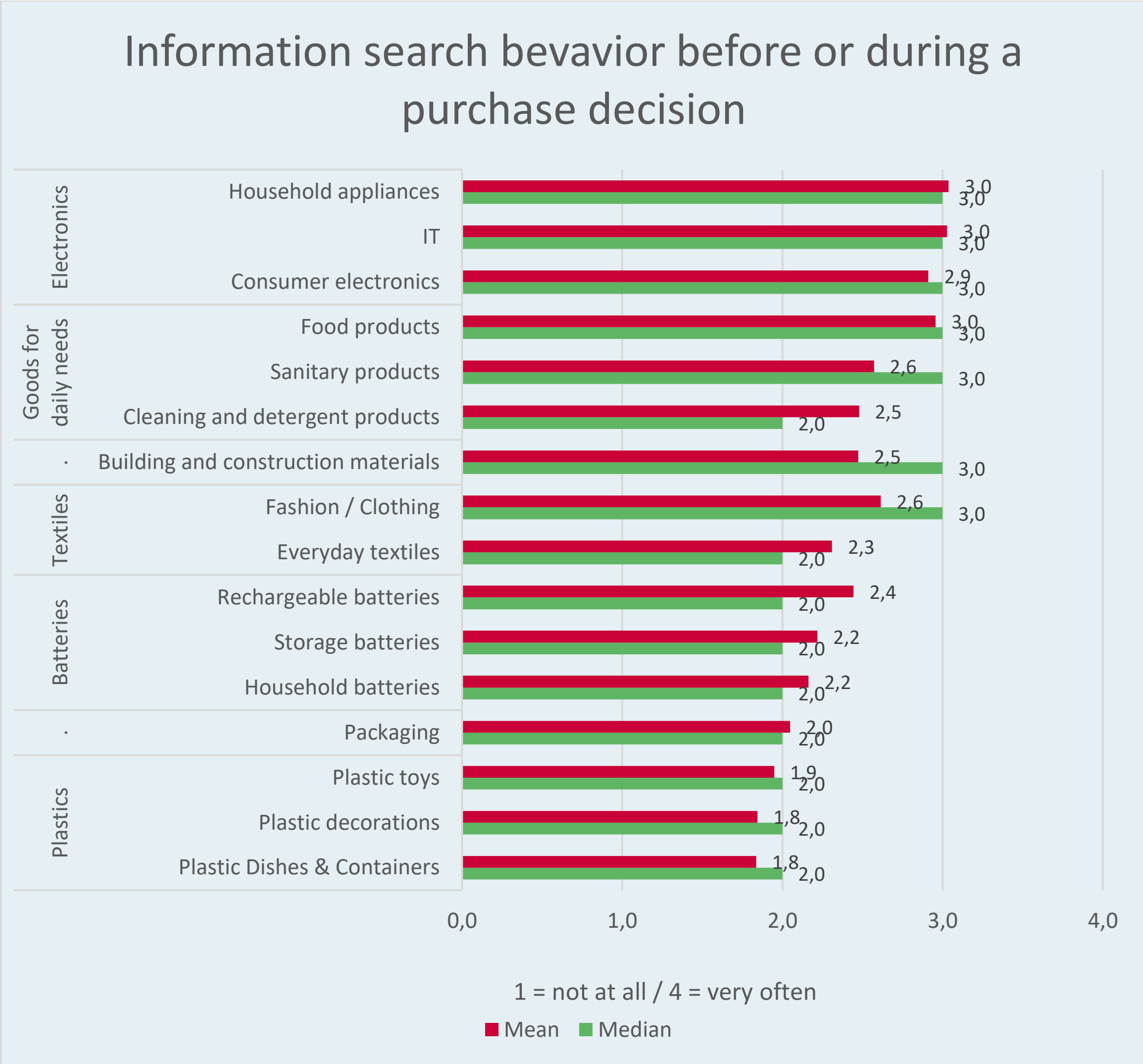


Figure 70: Information search before or during a purchase

Figure 56 illustrates that there are clear preferences in information search in relation to specific product categories. While electronics and goods for daily needs score highest among the list with specific outliers for building and construction materials as well as clothing, the interest in other product categories is declining with plastics producing the lowest scores.

Factors influencing information search behavior

		Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	R2	n
Electronics	Household appliances		0,003**	0,164***		0,116***	0,474***	0,197**	0,041**	0,000**	0,111***	1234
	IT	-0,135**		0,359***		0,138***	0,322***	0,155**	0,085***		0,179***	1228
	Consumer electronics	-0,193***	-0,005**	0,362***		0,128***	0,294***				0,166***	1229
Goods for daily needs	Food products	0,099**		0,113**	0,210***	0,197***	0,486***				0,131***	1232
	Sanitary products	0,236***	-0,010***	0,095**	0,219***	0,157***	0,574***		-0,066**		0,174***	1233
	Cleaning and detergent products	0,306***		0,061**	0,207***	0,189***	0,527***	-0,185**			0,151***	1230
.	Building and construction materials	-0,236***		0,274***			0,378***			0,000**	0,139***	1222
Textiles	Fashion / Clothing	0,283***	-0,006**	0,096**	0,192***	0,209***	0,626***	-0,142*			0,206***	1229
	Everyday textiles	0,218***	-0,006***	0,098**	0,163**	0,170***	0,513***	-0,243**			0,149***	1228
Batteries	Rechargeable batteries	-0,220***		0,341***	0,212***	0,141**	0,407***	-0,195**			0,205***	1217
	Storage batteries	-0,316***		0,278***	0,243***	0,113**	0,408***	-0,307***			0,198***	1205
	Household batteries	-0,124**		0,224***	0,286***	0,089**	0,454***	-0,354***			0,184***	1230
.	Packaging		-0,008***	0,075**	0,331***	0,117**	0,436***	-0,290***			0,167***	1229
Plastics	Plastic toys	0,207***	-0,017***	0,108**		0,157***	0,386***	-0,219**			0,157***	1193
	Plastic decorations	0,217***	-0,011***	0,187***	0,112**	0,090**	0,512***	-0,498***	-0,076***		0,227***	1207
	Plastic Dishes & Containers	0,203***	-0,010***	0,105**	0,186***	0,135***	0,464***	-0,453***			0,198***	1208

Table 5: Factors influencing information search behavior

The results illustrated in Table 19 are discussed below:

- **Gender:** Information on technical products such as electronics, batteries and building and construction material is more likely searched by males, goods for daily needs, textiles and plastics show a clear female bias. Gender does not have an influence on packaging.
- **Age:** There is a slight tendency that the search for product information decreases with age, except for household appliances.
- **Technology Affinity:** People which show a higher technological affinity seem to search for product information more intensely, especially when technical products are concerned.
- **Attitude towards sustainable purchasing:** People with a higher attituded towards sustainable purchasing show a higher interest in product information, except for electronics and building and construction materials, and plastic toys.
- **Attitude towards climate change:** People that are more concerned about climate change and environmental issues tend to search for more product information.

- **Lifestyle typology:** We observe a very strong trend across all product categories that people with a higher degree of socio-economic and cultural capital show a higher interest in product information compared to people with lower socio-economic and cultural capital.
- **Disabilities:** People with disabilities have a higher interest in product information on electronics such as household appliances and IT, with an inverse trend for all other product categories. No specific patterns have been found for consumer electronics, food and sanitary products, and building and construction material.
- **Education:** Education does mot have a major impact on product information search, unless for household appliances and IT, which shows a low tendency towards people with higher education, and inversely sanitary products and plastic decorations that show a low tendency towards people with lower education.
- **Income:** Income does not seem to have an impact on information search behavior.

Observation: We can observe differing patterns in information search behavior with respect to specific product categories and gender. People with higher socio-economic and cultural capital, a higher technology affinity, a higher attitude towards a sustainable purchasing, and who are more concerned about climate show a higher interest in product information. Education and income do not seem to have an effect.

In the subsequent sections we take a closer look at the relevance of DPP information by product category divided into specific product types. The participants were provided with a standardized list of information that is likely to be provided in a DPP and were asked to indicate their personal relevance for this information. The order of appearance indicates which information is perceived to be of higher relevance for a specific product type.

Relevance of DPP Information – Electronics

Household appliances (e.g., refrigerator, dishwasher, vacuum cleaner)

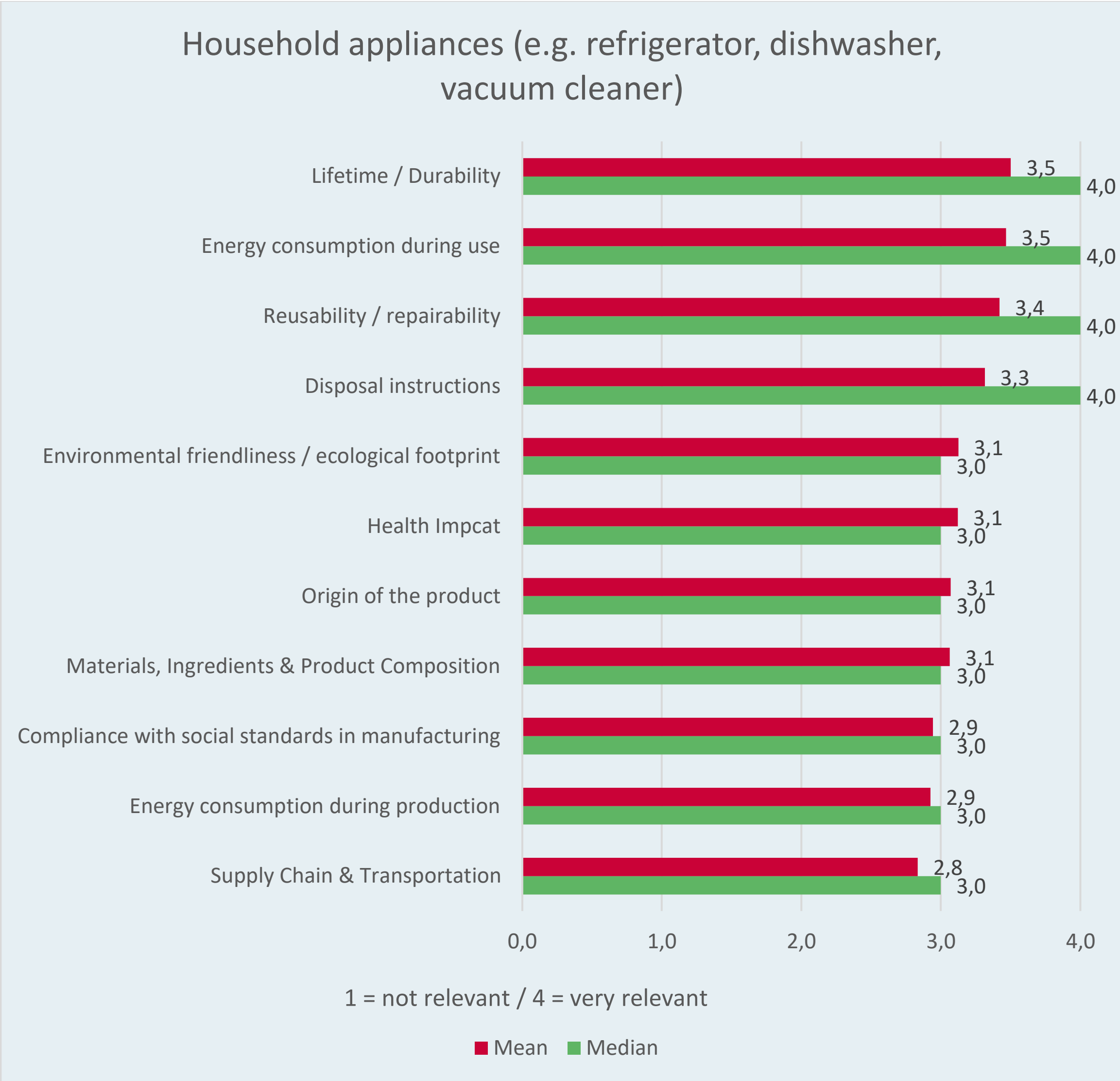


Figure 71: Relevance of DPP-information for household appliances

Figure 57 illustrates that with respect to household appliances information on durability, energy consumption during use, repairability and disposal instructions generate the highest relevancy scores among the participants, while a product's compliance with social standards during manufacturing, energy consumption during production and supply chain and transportation are of minor interest.

Factors influencing the relevance of information for household appliances

Household appliances (e.g. refrigerator, dishwasher, vacuum cleaner)	**Gender**	**Age**	**Tech Aff.**	**Att. Sust. Purch.**	**Att. Clim. Change**	**Lifestyle**	**Disab.**	**Educ.**	**Income**	**corr. R2**	**n**
Lifetime / Durability	0,083**	**0,006*** **		-0,109**	**0,131*** **	**0,368*** **	**0,388*** **	0,050**		0,114***	1228
Energy consumption during use	0,114**	**0,008*** **			**0,220*** **	**0,316*** **	**0,343*** **			0,140***	1227
Reusability / repairability		**0,007*** **			**0,226*** **	**0,369*** **	**0,393*** **			0,135***	1225
Disposal instructions	0,143**	**0,007*** **			**0,341*** **	**0,422*** **	**0,324*** **			0,176***	1225
Environmental friendliness / ecological footprint	0,143**				**0,501*** **	**0,421*** **	**0,225*** **			0,252***	1224
Health Impcat	0,101**	0,004**			**0,256*** **	**0,517*** **	0,166**			0,114***	1223
Origin of the product		**0,006*** **		0,111**	**0,333*** **	**0,461*** **	0,146**	-0,045**		0,167***	1223
Materials, Ingredients & Product Composition	0,119**	0,003**		0,105**	**0,283*** **	**0,559*** **	0,231**		0,000**	0,163***	1226
Compliance with social standards in manufacturing	0,154**			0,117**	**0,439*** **	**0,398*** **				0,193***	1222
Energy consumption during production	0,145**			0,140**	**0,413*** **	**0,466*** **	0,180**			0,190***	1225
Supply Chain & Transportation	0,127**			**0,168*** **	**0,429*** **	**0,465*** **				0,210***	1226

Table 6: Factors influencing the relevance of information for household appliances

The results illustrated in Table 20 are discussed below:

- **Gender:** Female or diverse participants show a higher interest in DPPs related to household appliances compared to male participants, except for information on repairability and reusability and the origin of a product.
- **Age:** There is a low tendency that the interest in specific information provided by DPPs rises with increasing age.
- **Technology Affinity:** Technology Affinity does not have an impact on the perceived relevance of DPP-information which indicates that no difference exists between preferences for DPP information in accordance with one's technology affinity.
- **Attitude towards sustainable purchasing:** Counterintuitively, people with a lower attitude towards sustainable purchasing show a higher interest in durability information, while participants with a higher attitude are more concerned about information with lower relevancy scores.
- **Attitude towards climate change:** Participants that are more concerned about climate show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Information on durability, energy consumption during use, repairability and disposal instructions of household appliances show the highest relevancy, while the interest in DPP information is higher among female and diverse participants, people with higher attitudes towards climate change and sustainable purchasing, as well as higher socio-economic and cultural capital. Also, people with disabilities have a higher interest in DPP information, while education and income does not seem to make a difference.

IT (e.g., smartphones, laptops, tablets)

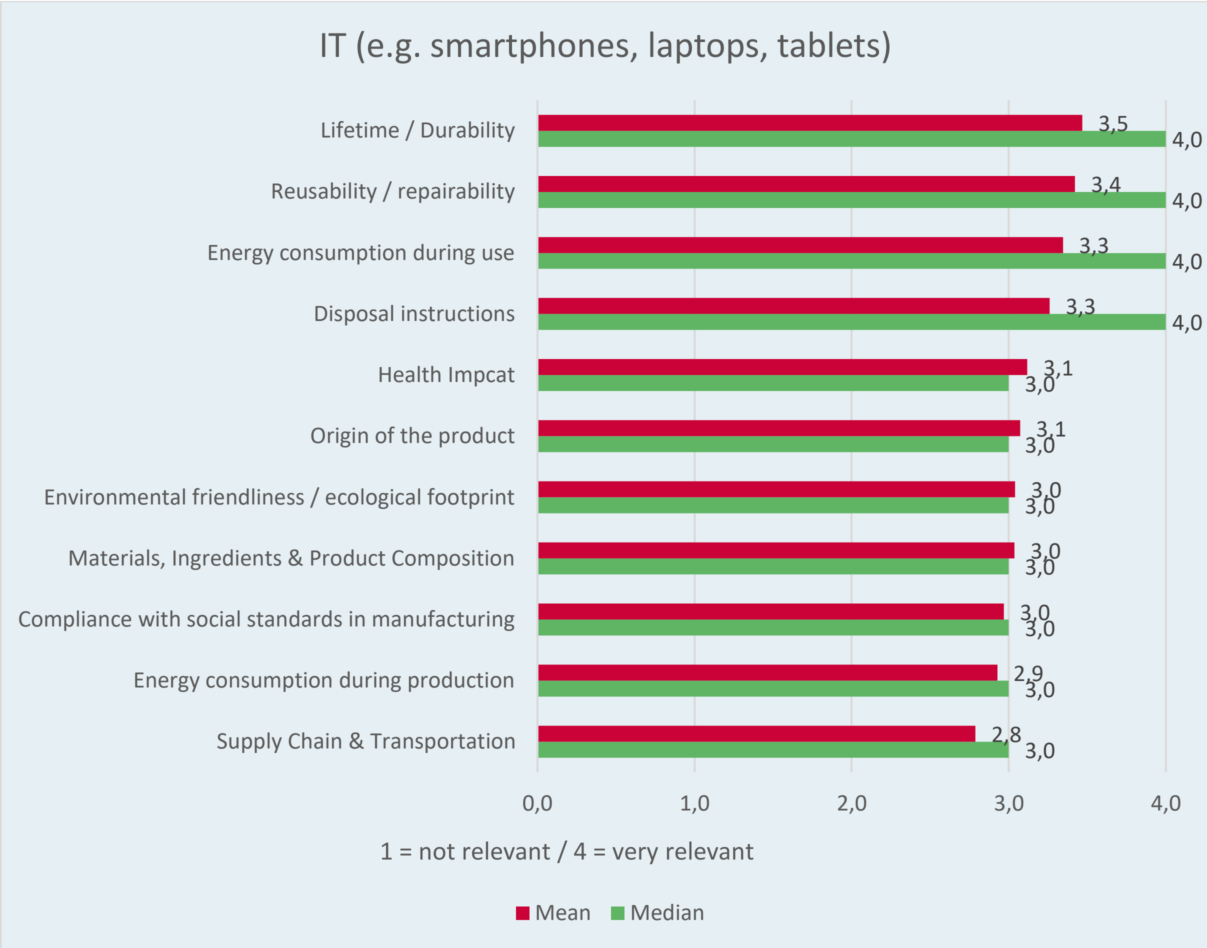


Figure 72: Relevance of DPP-information for IT

Figure 58 illustrates a very similar pattern to household appliances with a slight difference in the relevance of repairability, which is higher for this product type. With respect to IT information on durability, energy consumption during use, repairability and disposal instructions generate the highest relevancy scores among the participants, while a product's compliance with social standards during manufacturing, energy consumption during production and supply chain and transportation are of minor interest.

Factors influencing the relevance of information for IT

IT (e.g. smartphones, laptops, tablets)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Lifetime / Durability	0,089**	0,007***		-0,097**	0,101**	0,342***	0,191**	0,050**		0,076***	1222
Reusability / repairability		0,003**			0,257***	0,352***	0,266***			0,116***	1221
Energy consumption during use	0,112**	0,006***			0,266***	0,423***	0,325***			0,144***	1224
Disposal instructions		0,006***			0,376***	0,477***	0,259***			0,166***	1225
Health Impcat		0,005**			0,234***	0,578***				0,105***	1219
Origin of the product		0,005**			0,360***	0,412***		-0,039**		0,140***	1222
Environmental friendliness / ecological footprint	0,106**			0,108**	0,557***	0,482***				0,286***	1221
Materials, Ingredients & Product Composition					0,317***	0,534***				0,143***	1222
Compliance with social standards in manufacturing	0,203***			0,100**	0,458***	0,427***				0,201***	1217
Energy consumption during production	0,132**				0,466***	0,472***	0,176**			0,187***	1223
Supply Chain & Transportation				0,206***	0,434***	0,507***			0,000**	0,217***	1222

Table 7: Factors influencing the relevance of information for IT

Concerning the importance of DPP-information, a similar pattern occurs between IT products and household appliances. The results illustrated in Table 21 are discussed below:

- **Gender:** Female or diverse participants show a higher interest in DPPs related to household appliances compared to male participants, except for information on repairability and reusability and the origin of a product.
- **Age:** There is a low tendency that the interest in specific information provided by DPPs rises with increasing age.
- **Technology Affinity:** Technology Affinity does not have an impact on the perceived relevance of DPP-information which indicates that no difference exists between preferences for DPP information in accordance with one’s technology affinity.
- **Attitude towards sustainable purchasing:** Counterintuitively, people with a lower attitude towards sustainable purchasing show a higher interest in durability information, while participants with a higher attitude are more concerned about information with lower relevancy scores.
- **Attitude towards climate change:** Participants that are more concerned about climate show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information.

- **Education:** Education does not seem to have a major impact on the assigned relevance of DPP information.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Information on durability, energy consumption during use, repairability and disposal instructions of IT products show the highest relevancy, while the interest in DPP information is higher among female and diverse participants, people with higher attitudes towards climate change and sustainable purchasing, as well as higher socio-economic and cultural capital. Also, people with disabilities have a higher interest in DPP information, while education and income does not seem to make a difference.

Consumer electronics (e.g., TV set, game console, stereo system)

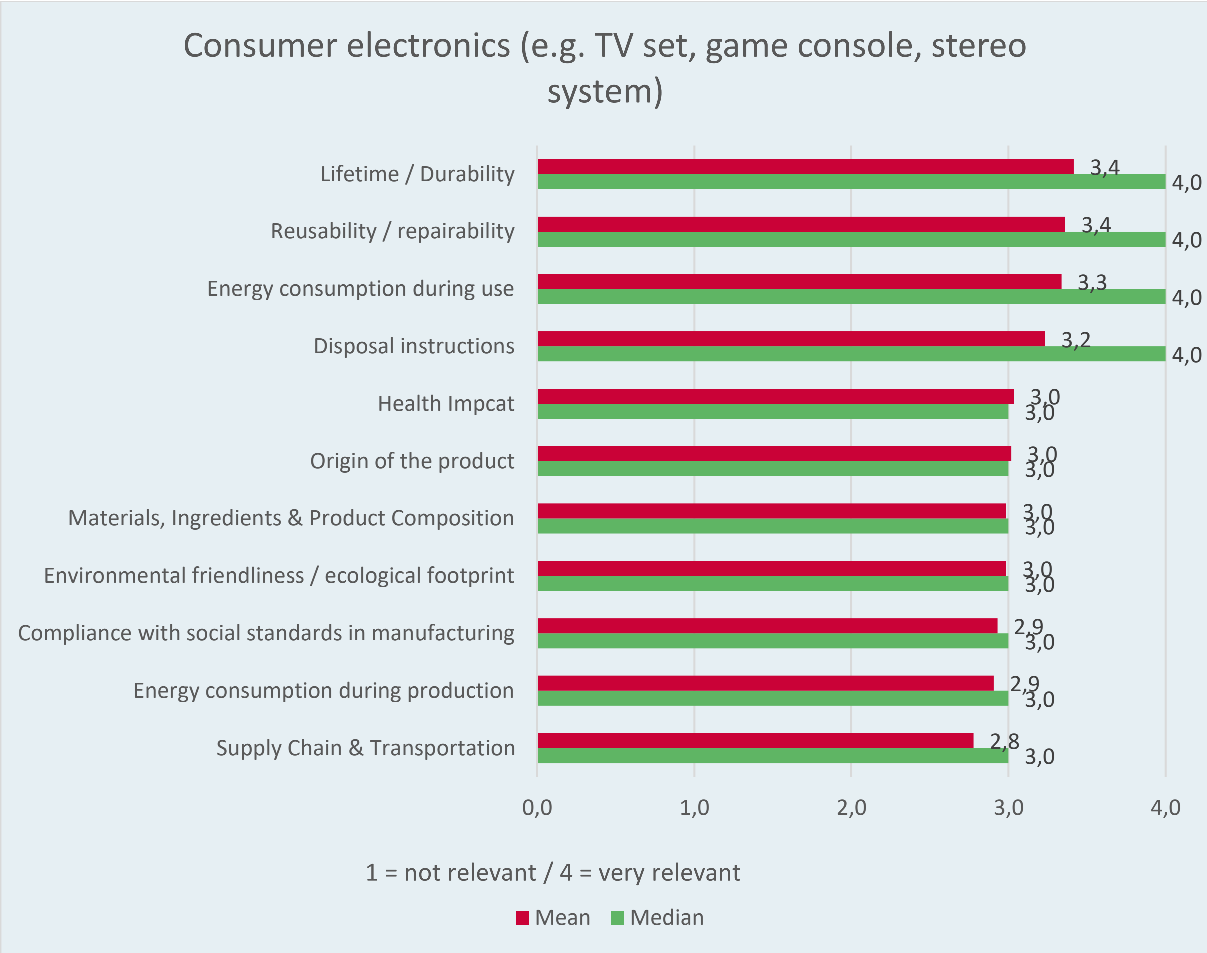


Figure 73: Relevance of DPP-information for consumer electronics

Figure 59 illustrates an identical pattern to IT. With respect to consumer electronics information on durability, energy consumption during use, repairability and disposal instructions generate the highest relevancy scores among the participants, while a product's compliance with social standards during manufacturing, energy consumption during production and supply chain and transportation are of minor interest.

Factors influencing the relevance of information for consumer electronics

Consumer electronics (e.g. TV set, game console, stereo system)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Lifetime / Durability		0,006***		-0,093**	0,124***	0,349***	0,250***			0,061***	1219
Reusability / repairability		0,006***	0,063**		0,250***	0,341***	0,293***			0,108***	1220
Energy consumption during use		0,006***			0,302***	0,383***	0,315***			0,135***	1221
Disposal instructions		0,005***			0,395***	0,491***	0,371***			0,183***	1220
Health Impcat		0,004**			0,214***	0,508***				0,082***	1217
Origin of the product					0,367***	0,451***	0,236***	-0,066***		0,154***	1217
Materials, Ingredients & Product Composition				0,148**	0,310***	0,483***				0,148***	1221
Environmental friendliness / ecological footprint				0,142**	0,519***	0,362***				0,230***	1221
Compliance with social standards in manufacturing	0,152**			0,117**	0,433***	0,463***		-0,062**		0,204***	1219
Energy consumption during production				0,164***	0,426***	0,412***				0,178***	1222
Supply Chain & Transportation				0,180***	0,364***	0,482***		-0,046**		0,167***	1215

Table 8: Factors influencing the relevance of information for consumer electronics

Concerning the importance of DPP-information, a slightly different patterns occurs when asked about the relevance of DPP information. The results illustrated in Table 22 are discussed below:

- **Gender:** Gender does not have an impact on relevance, except for compliance with social standards which is of higher relevance to female and diverse participants.
- **Age:** There is a low tendency that the interest in specific information provided by DPPs rises with increasing age.
- **Technology Affinity:** People with higher technology affinity show a higher interest in repairability information.
- **Attitude towards sustainable purchasing:** Counterintuitively, people with a lower attitude towards sustainable purchasing show a higher interest in durability information, while participants with a higher attitude are more concerned about information with lower relevancy scores.
- **Attitude towards climate change:** Participants that are more concerned about climate show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information.
- **Education:** Participants with lower education are more interested in the origin of a product, the compliance with social standards during manufacturing, and supply chain information.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: While the relevancy scores for DPP information on consumer electronic are identical to IT, we can observe slight differences compared to other electronics products. While gender does not seem to make a difference, people with higher attitudes towards climate change and sustainable purchasing, as well as higher socio-economic and cultural capital. Also, people with disabilities have a higher interest in DPP information. Also, people with lower education report higher interest in the origin of a product, the compliance with social standards during manufacturing, and supply chain information. Income does not seem to make a difference.

Relevance of DPP Information – Goods for daily needs

Disclaimer: Although the EU Commission does not plan to introduce a DPP for goods of daily needs we included this product category into the survey as most consumers have experience with related product information, especially with respect to food products.

Food products

Figure 74: Relevance of DPP-information for food products

Figure 60 illustrates that information on health impact, origin, ingredients, and durability receive the highest relevancy scores, while compliance with social standards in manufacturing, energy consumption during production, and disposal instructions are of lesser importance to the participants.

Factors influencing the relevance of information for food products

Food products	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat		0,007***		-0,094**	0,123***	0,424***	0,281***			0,110***	1229
Origin of the product	0,106**	0,007***			0,243***	0,401***	0,362***			0,152***	1230
Materials, Ingredients & Product Composition	0,157***	0,006***	0,079**		0,192***	0,407***	0,350***			0,148***	1225
Lifetime / Durability		0,005***		-0,095**	0,124***	0,408***	0,313***			0,083***	1227
Environmental friendliness / ecological footprint					0,507***	0,424***	0,220***			0,254***	1226
Supply Chain & Transportation	0,154**				0,375***	0,435***	0,236***			0,162***	1227
Compliance with social standards in manufacturing					0,422***	0,469***				0,178***	1226
Energy consumption during production	0,159**			0,169***	0,404***	0,476***	0,233**			0,194***	1228
Disposal instructions				0,118**	0,283***	0,673***		-0,057**	0,000**	0,149***	1221

Table 9: Factors influencing the relevance of information for food products

The results illustrated in Table 23 are discussed below:

- **Gender:** Female and diverse participants expose a higher interest in the origin of a food product, its ingredients, supply chain, and energy consumption during production.
- **Age:** Participants with higher age are more interested in food's health impact, its origin, its ingredients, and its durability.
- **Technology Affinity:** Participants with higher technology affinity show a higher interest in ingredients.
- **Attitude towards sustainable purchasing:** People with a lower attitude towards sustainable purchasing show a higher interest in food' s health impact and its durability, while participants with higher attitudes are more interested in energy consumption during **production and disposal instructions.**
- **Attitude towards climate change:** Participants that are more concerned about climate show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information.
- **Education:** Participants with lower education are more interested in the origin of a product, the compliance with social standards during manufacturing, and supply chain information.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Information about health impact, product origin of food products has the highest relevancy scores. Female and diverse participants show a slightly higher interest in food related product information compared to male participants, while the interest in specific information rises with age. Slight differences exist in accordance with the attitude towards sustainable purchasing. Participants with higher attitudes towards climate change and higher socio-economic and cultural capital assign higher relevancy scores to all information provided by a DPP, which can also be observed to a slightly lesser degree for participants with disabilities. Education and income do not seem to make a difference.

Sanitary products

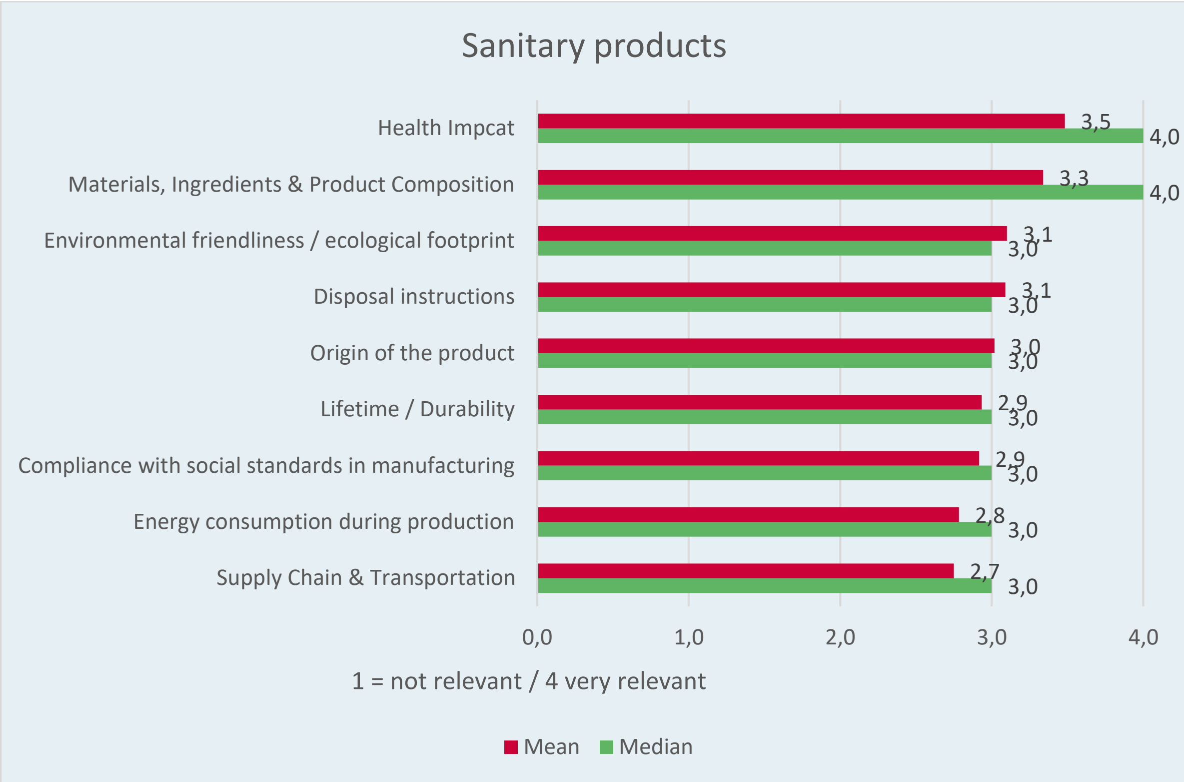


Figure 75: Relevance of DPP-information for sanitary products

Figure 61 illustrates that for sanitary products information on health impact, ingredients, the product's ecological footprint, as well as disposal instructions receive the highest relevancy scores, while compliance with social standards during manufacturing, energy consumption during production and supply chain information score very low.

Factors influencing the relevance of information for sanitary products

Sanitary products	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat	0,134**	**0,008*****	0,078**	-0,082**	**0,133*****	**0,389*****	**0,378*****			0,121***	1224
Materials, Ingredients & Product Composition	**0,178*****	0,004**			**0,228*****	**0,473*****	**0,318*****			0,142***	1225
Environmental friendliness / ecological footprint	0,143**			**0,144*****	**0,518*****	**0,466*****	0,155**			0,269***	1225
Disposal instructions					**0,325*****	**0,562*****	**0,262*****			0,137***	1223
Origin of the product	0,142**			**0,167*****	**0,288*****	**0,481*****		-0,040**	0,000**	0,154***	1225
Lifetime / Durability		-0,005**	0,081**		0,094**	**0,659*****	0,214**			0,107***	1221
Compliance with social standards in manufacturing	0,103**			**0,183*****	**0,402*****	**0,472*****		-0,051**		0,200***	1222
Energy consumption during production	0,131**			**0,243*****	**0,374*****	**0,440*****		-0,040**		0,183***	1221
Supply Chain & Transportation				**0,204*****	**0,391*****	**0,499*****		-0,042**	0,000**	0,190***	1221

Table 10: Factors influencing the relevance of information for sanitary products

The results illustrated in Table 24 are discussed below:

Gender: Female and diverse participants expose a higher interest in various information with the health impact of sanitary products, its ingredients, ecological footprint and origin being of highest relevance.

- **Age:** Participants with higher age are more interested in sanitary products' health impact and ingredients, while preference for their durability are more relevant to younger participants.
- **Technology Affinity:** Participants with higher technology affinity show an interest in health impact and durability.
- **Attitude towards sustainable purchasing:** People with a lower attitude towards sustainable purchasing show a higher interest in health impact, while participants with higher attitudes are more interested in the ecological footprint, the origin, compliance with social standards and supply chain information on sanitary products.
- **Attitude towards climate change:** Participants that are more concerned about climate change show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information related to health impact, ingredients, ecological footprint, disposal instructions, and durability.

- **Education:** Participants with lower education show a higher interest in information on origin, compliance with social standards, energy consumption during production and supply chain information.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Health impact, ingredients and environmental friendliness score highest on the relevance list. Female and diverse participants show a slightly higher interest in information related to sanitary products compared to male participants, while the interest rises with age. Slight differences exist in accordance with the attitude towards sustainable purchasing. Participants with higher attitudes towards climate change and higher socio-economic and cultural capital assign higher relevancy scores to all information provided by a DPP, which can also be observed to a slightly lesser degree for participants with disabilities. Participants with lower education show a higher interest in information on origin, compliance with social standards, energy consumption during production and supply chain information. Income do not seem to make a difference.

Cleaning and detergent products

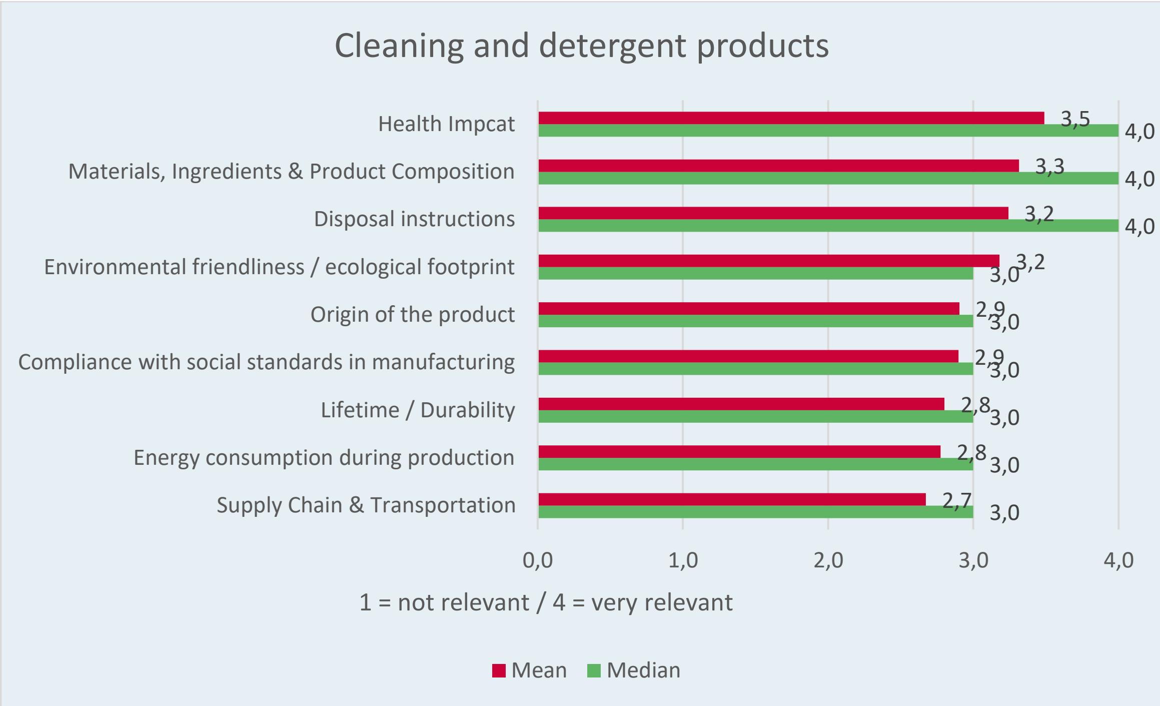


Figure 76: Relevance of DPP-information for cleaning and detergent products

Figure 62 illustrates a similar pattern compared to sanitary products, where information on health impact, ingredients, the product's ecological footprint, as well as disposal instructions receive the highest relevancy scores. Nevertheless, slight differences appear at the bottom of the list where compliance with social standards during manufacturing, durability, energy consumption during production and supply chain information score very low.

Factors influencing the relevance of information for cleaning and detergent products

Cleaning and detergent products	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat		0,008***			0,212***	0,376***	0,465***			0,167***	1225
Materials, Ingredients & Product Composition	0,155***	0,004**			0,277***	0,448***	0,218***		0,000**	0,162***	1224
Disposal instructions		0,007***			0,283***	0,429***	0,378***			0,136***	1222
Environmental friendliness / ecological footprint	0,149**	0,003**			0,498***	0,414***	0,219**			0,244***	1224
Origin of the product		0,004**		0,141**	0,366***	0,469***				0,166***	1223
Compliance with social standards in manufacturing	0,186***	-0,003**		0,185***	0,425***	0,404***		-0,050**		0,199***	1220
Lifetime / Durability					0,159***	0,672***				0,097***	1220
Energy consumption during production	0,136**			0,189***	0,399***	0,497***				0,210***	1225
Supply Chain & Transportation				0,266***	0,380***	0,458***		-0,045**		0,195***	1222

Table 11: Factors influencing the relevance of information for cleaning and detergent products

The results illustrated in Table 25 are discussed below:

- **Gender:** Female and diverse participants expose a higher interest in various information with ingredients, ecological footprint, compliance with social standards, and energy consumption during production being of highest relevance.
- **Age:** Participants with higher age show a higher interest in detergent products' health impact and ingredients, disposal instructions, ecological footprint, and origin.
- **Technology Affinity:** Technology affinity does not seem to have an impact.
- **Attitude towards sustainable purchasing:** People with a higher attitude towards sustainable purchasing show a higher interest in origin, compliance with social standards, energy consumption during production, and supply chain information on detergent products.
- **Attitude towards climate change:** Participants that are more concerned about climate change show strong tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show strong tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher interest in DPP information related to health impact, ingredients, ecological footprint, and disposal instructions.
- **Education:** Participants with lower education show a higher interest in compliance with **social standards and supply chain information.**
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Female and diverse participants show a slightly higher interest in information related to detergent products compared to male participants, while the interest in particular information rises with age. People with a higher attitude towards sustainable purchasing show a higher interest in origin, compliance with social standards, energy consumption during production, and supply chain information on detergent products. Participants with higher attitudes towards climate change, and higher socio-economic and cultural capital assign higher relevancy scores to all information provided by a DPP, which can also be observed to a slightly lesser degree for participants with disabilities. Participants with lower education show a higher interest in compliance with social standards and supply chain information. Income do not seem to make a difference.

Relevance of DPP Information – Building and construction materials

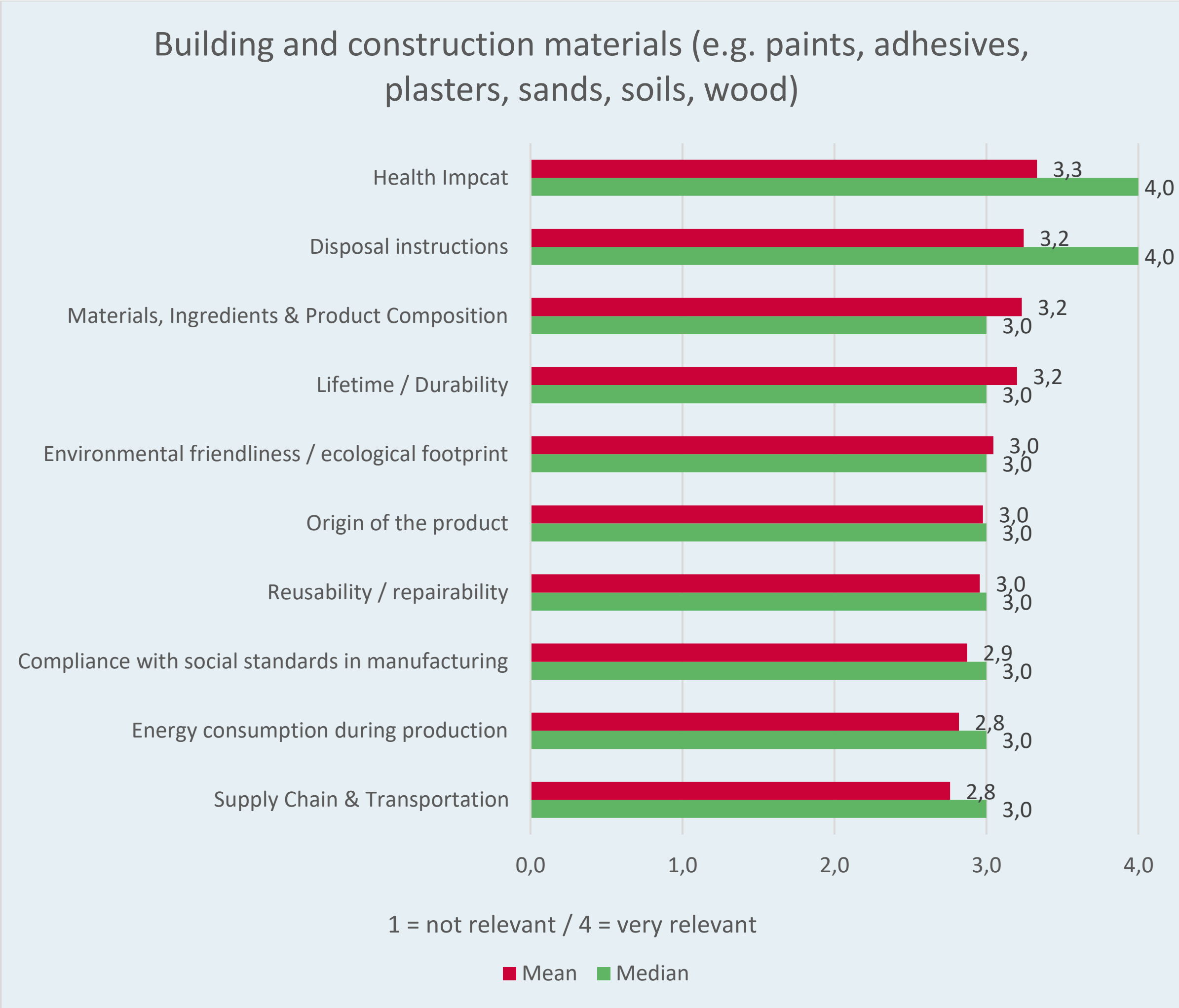


Figure 77: Relevance of DPP-information for building and construction materials

Figure 63 illustrates that information on health impact, disposal instructions, material composition and durability receive the highest relevancy scores when it comes to building and construction material, while *information on compliance with social standards, energy consumption during production, and supply chain information score very low.

Factors influencing the relevance of information for building and construction materials

Building and construction materials (e.g. paints, adhesives, plasters, sands, soils, wood)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat	0,098**	0,008***		-0,104**	0,265***	0,440***	0,252***			0,131***	1219
Disposal instructions		0,005**			0,277***	0,370***	0,313***			0,122***	1220
Materials, Ingredients & Product Composition		0,004**	0,089**		0,210***	0,388***	0,341***	0,053**		0,130***	1218
Lifetime / Durability		0,005**			0,149***	0,465***	0,262***			0,076***	1216
Environmental friendliness / ecological footprint		0,004**		0,125**	0,499***	0,454***	0,280***		0,000**	0,249***	1219
Origin of the product		0,004**		0,149**	0,320***	0,575***	0,228**			0,185***	1219
Reusability / repairability					0,185***	0,560***	0,257**			0,095***	1213
Compliance with social standards in manufacturing	0,126**			0,174***	0,409***	0,487***				0,196***	1216
Energy consumption during production				0,181***	0,381***	0,580***	0,176**			0,202***	1217
Supply Chain & Transportation				0,172***	0,364***	0,422***				0,165***	1216

Table 12: Factors influencing the relevance of information for building and construction materials

The results illustrated in Table 26 are discussed below:

- **Gender:** Gender is of minor importance for this product category, although female and diverse participants show a higher interest in information on health impact and compliance with social standards.
- **Age:** Participants with higher age show a higher interest in the products' health impact, disposal instructions, composition, durability, ecological footprint, and origin.
- **Technology Affinity:** Participants with higher technology affinity are more interested in the composition of building and construction materials.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in the ecological footprint, origin, compliance with social standards, and supply chain information, while participants with lower attitudes are more interested in the health impact.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
-
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy score across all DPP information, except for compliance with social standards and supply chain information.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Health impact, disposal instructions, and product composition rank as the most relevant aspects. While gender has a minor impact on the relevancy scores assigned to information on building and construction materials, differences exist with respect to age, with older participants reporting higher relevancy scores. Differences also exist with respect to attitudes towards sustainable purchasing, climate change and lifestyles, generally indicating that with higher attitudes the relevance of information increases. This is also the case for people with disabilities, while education and income do not seem to have an impact.

Relevance of DPP Information – Textiles

Fashion & Clothing

Figure 78: Relevance of DPP-information for fashion and clothing

Figure 64 illustrates that product composition, health impact, and origin rank highest among the list, while information about energy consumption during production, supply chain and disposal instructions are of least relevance.

Factors influencing the relevance of information for fashion and clothing

Fashion / Clothing	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Materials, Ingredients & Product Composition	**0,160*** **				**0,255*** **	**0,402*** **	**0,267*** **			0,146***	1221
Health Impcat		**0,006*** **			**0,182*** **	**0,450*** **	**0,250*** **	0,036**		0,108***	1224
Origin of the product	0,116**	0,004**			**0,351*** **	**0,496*** **	**0,275*** **			0,173***	1223
Environmental friendliness / ecological footprint	0,111**			0,126**	**0,520*** **	**0,424*** **	0,139**			0,267***	1220
Compliance with social standards in manufacturing	0,100**			0,143**	**0,435*** **	**0,420*** **				0,196***	1218
Lifetime / Durability			0,091**		0,131**	**0,554*** **				0,080***	1218
Reusability / repairability	0,155**				**0,285*** **	**0,567*** **				0,138***	1224
Energy consumption during production	0,120**			**0,180*** **	**0,429*** **	**0,437*** **				0,190***	1223
Supply Chain & Transportation				**0,200*** **	**0,414*** **	**0,471*** **				0,205***	1221
Disposal instructions				0,145**	**0,311*** **	**0,568*** **				0,141***	1223

Table 13: Factors influencing the relevance of information for fashion and clothing

The results illustrated in Table 27 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in information related to clothing and fashion, especially with respect to product composition, origin, ecological footprint, compliance with social standards, repairability and energy consumption during production.
- **Age:** Age does not seem to have a major influence, despite a low tendency of older participants assigning higher relevance to health impact and origin.
- **Technology Affinity:** Technology affinity does not have an impact, except for lifetime and durability that is more relevant for people with higher affinity to technology.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in the ecological footprint, compliance with social standards, energy consumption during production, supply chain information, and disposal instructions.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy score for product composition, health impact, origin, and ecological footprint.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information, except for health impact which is of higher relevance to more educated people.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: Product composition, health impact and origin are the most relevant information types on fashion and clothing. While clothing information is more relevant to female participants, age technology affinity and education just have a minor influence. Instead, strong attitudes towards sustainable purchasing, climate change and participants with higher lifestyles assign high relevance to information on clothing and fashion. Income does not have an impact.

Everyday textiles (e.g. towels, table linen, bed linen)

Figure 79: Relevance of DPP-information for everyday textiles

Figure 65 illustrates that product composition, health impact and ecological footprint rank highest among the list, while repairability, energy consumption during production, and supply chain information rank lowest.

Factors influencing the relevance of information for everyday textiles

Everyday textiles (towels, table linen, bed linen)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2
Materials, Ingredients & Product Composition	0,149**	0,006***			0,231***	0,483***	0,242***	0,039**		0,151***
Health Impcat	0,097**	0,007***			0,220***	0,479***	0,325***			0,133***
Environmental friendliness / ecological footprint	0,122**			0,110**	0,504***	0,453***				0,246***
Origin of the product					0,319***	0,482***				0,142***
Lifetime / Durability					0,118***	0,487***				0,061***
Compliance with social standards in manufacturing	0,151**			0,136**	0,364***	0,427***	0,156**			0,156***
Disposal instructions				0,146**	0,290***	0,436***				0,104***
Reusability / repairability		-0,006**		0,139**	0,207***	0,603***			0,000**	0,120***
Energy consumption during production	0,119**			0,184***	0,454***	0,452***				0,205***
Supply Chain & Transportation				0,284***	0,399***	0,373***				0,198***

Table 14: Factors influencing the relevance of information for everyday textiles

The results illustrated in Table 28 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in information related to clothing and fashion, especially with respect to product composition, health impact, ecological footprint, compliance with social standards, and energy consumption during production.
- **Age:** Age does not seem to have a major influence, despite a low tendency of older participants assigning higher relevance to product composition and health impact, and younger participants towards repairability.
- **Technology Affinity:** Technology affinity does not have an impact.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in the ecological footprint, compliance with social standards, disposal instructions, repairability, energy consumption during production, and supply chain information.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy score for product composition, health impact, and compliance with social standards.

- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information, except for product compositions which is of higher relevance to more educated people.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: When it comes to everyday textiles, participants are most interested in product composition, health impact and ecological footprint, while female participants expose a higher interest, participants with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Technology affinity, education and income do not have an impact.

Relevance of DPP Information – Batteries

Rechargeable batteries (e.g. mobile, ebike, escooter)

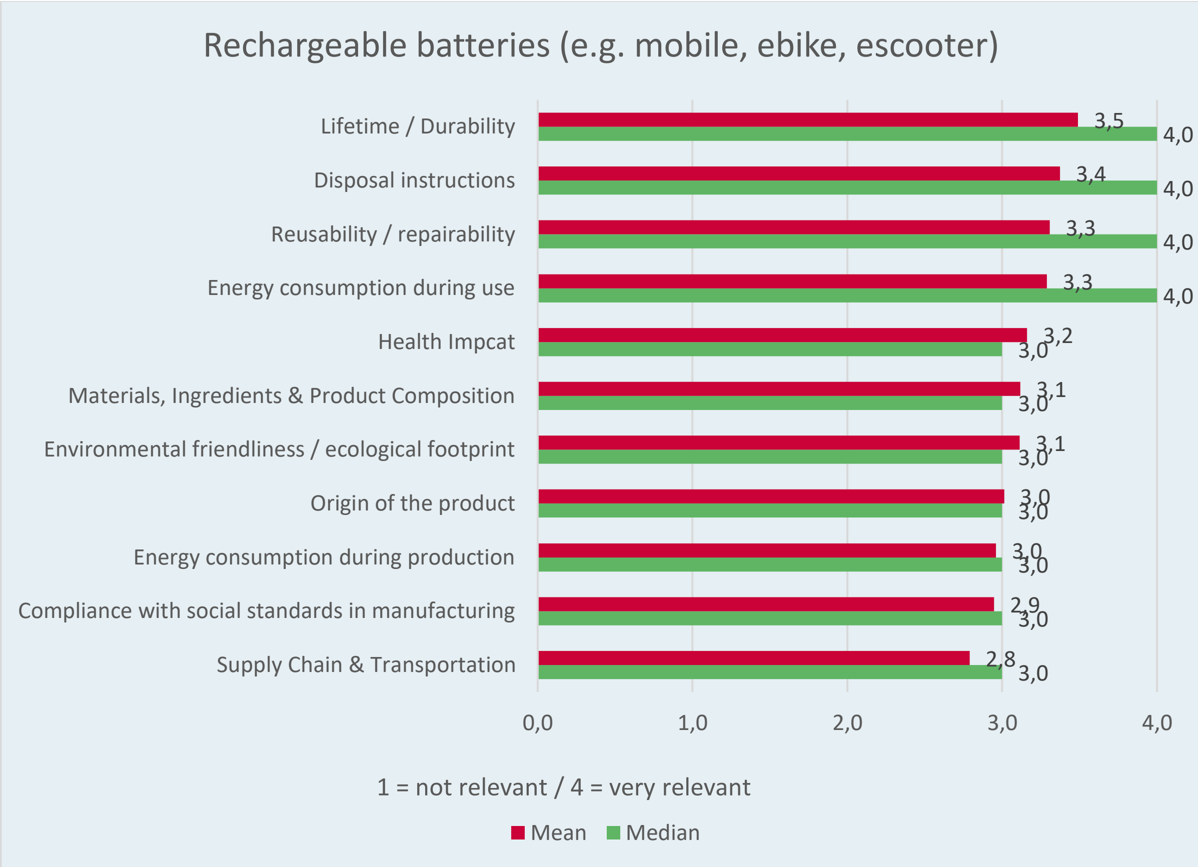


Figure 80: Relevance of DPP-information for rechargeable batteries

Figure 66 illustrates that durability, disposal instructions, and reusability show the highest relevancy score for rechargeable batteries, while information energy consumption during production, compliance with social standards, and supply chain information have the lowest scores.

Factors influencing the relevance of information for rechargeable batteries

Rechargeable batteries (e.g. mobile, ebike, escooter)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Lifetime / Durability		0,007***		-0,133***	0,181***	0,350***	0,333***	0,033**		0,115***	1217
Disposal instructions		0,005***			0,296***	0,296***	0,379***			0,139***	1214
Reusability / repairability		0,004**			0,299***	0,384***	0,346***			0,138***	1216
Energy consumption during use	0,150**	0,007***			0,263***	0,390***	0,300***	0,049**		0,141***	1217
Health Impcat	0,143**	0,009***			0,192***	0,464***	0,176**			0,095***	1213
Materials, Ingredients & Product Composition					0,236***	0,523***	0,221**			0,139***	1214
Environmental friendliness / ecological footprint					0,498***	0,375***	0,200**			0,222***	1219
Origin of the product	0,127**	0,004**			0,302***	0,408***				0,123***	1215
Energy consumption during production				0,124**	0,419***	0,507***				0,191***	1217
Compliance with social standards in manufacturing	0,144**			0,100**	0,402***	0,436***				0,173***	1210
Supply Chain & Transportation				0,234***	0,344***	0,487***				0,183***	1216

Table 15: Factors influencing the relevance of information for rechargeable batteries

The results illustrated in Table 29 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in information related to energy consumption during use, health impact, origin, and compliance with social standards.
- **Age:** There is a low tendency that with increasing age the interest in information on durability, disposal instructions, reusability, energy consumption during use, health impact and origin rises.
- **Technology Affinity:** Technology affinity does not have an impact on the relevance of DPP information.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in energy consumption during production, compliance with social standards, and supply chain information, while participants with a lower attitude are more interested in information on durability.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy score for durability, disposal instructions, reusability, energy consumption during use, health impact, product composition and ecological footprint.

- **Education:** Participants with higher education declare higher relevance for durability and energy consumption during use.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: When it comes to rechargeable batteries, participants are most interested in durability, disposal instructions, and reusability, while female participants expose a higher interest, participants with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Technology affinity, education and income do not have an impact.

Storage batteries (e.g., electric car batteries, solar batteries)

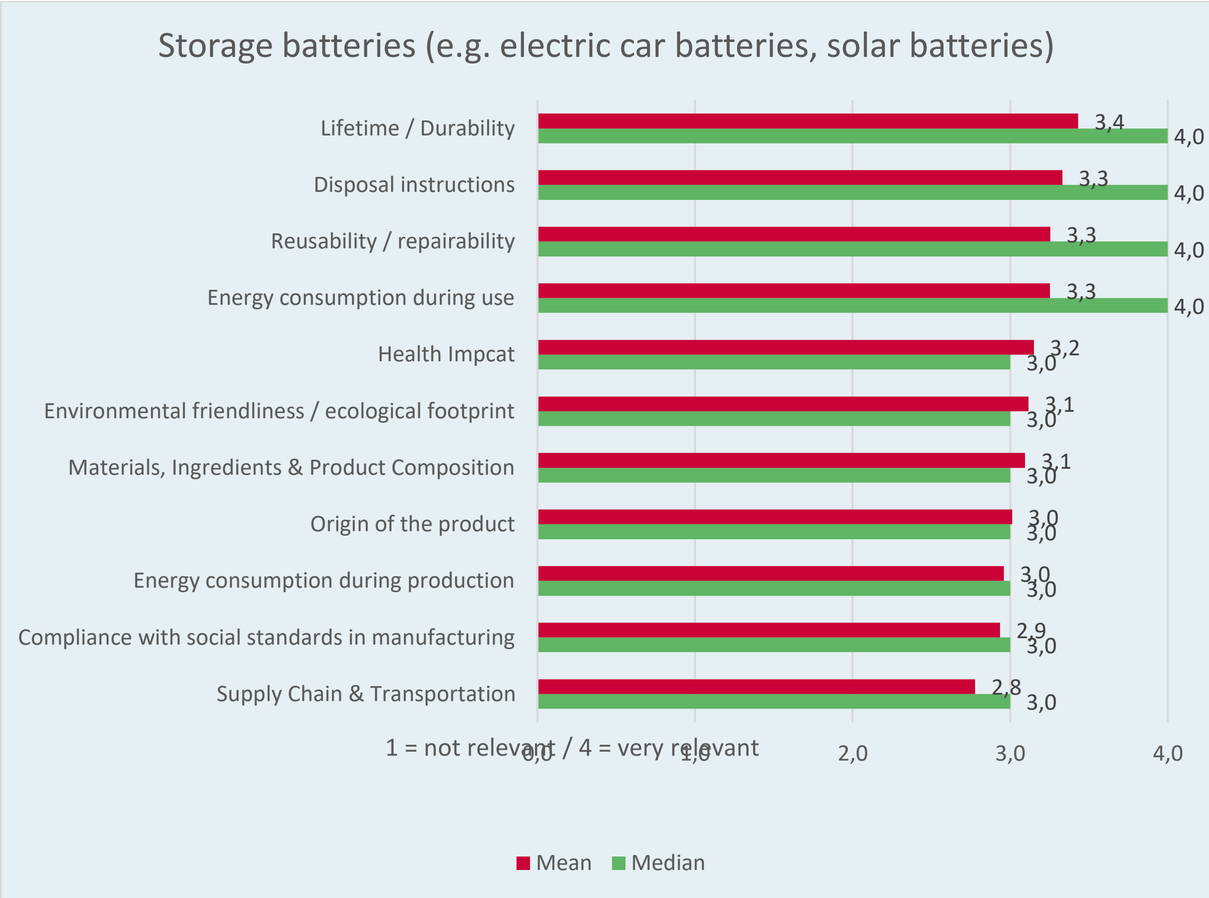


Figure 81: Relevance of DPP-information for storage batteries

Figure 67 illustrates that storage batteries show the same pattern as rechargeable batteries, with durability, disposal instructions, and reusability receiving the highest relevancy score for rechargeable batteries, while information energy consumption during production, compliance with social standards, and supply chain information have the lowest scores.

Factors influencing the relevance of information for storage batteries

Storage batteries (e.g. electric car batteries, solar batteries)	**Gender**	**Age**	**Tech Aff.**	**Att. Sust. Purch.**	**Att. Clim. Change**	**Lifestyle**	**Disab.**	**Educ.**	**Income**	**corr. R2**	**n**
Lifetime / Durability		**0,009*****	0,068**	**-0,110*****	**0,204*****	**0,321*****	**0,331*****			0,116***	1212
Disposal instructions		**0,011*****			**0,328*****	**0,325*****	**0,419*****			0,167***	1212
Reusability / repairability					**0,321*****	**0,351*****	**0,272*****			0,106***	1210
Energy consumption during use	0,120**	**0,007*****			**0,265*****	**0,439**	**0,276*****			0,133***	1211
Health Impcat		**0,008*****			**0,205*****	**0,520*****	0,180**			0,098***	1204
Environmental friendliness / ecological footprint	0,103**				**0,495*****	**0,402*****	0,200**			0,210***	1209
Materials, Ingredients & Product Composition			0,067**		**0,279*****	**0,435*****	**0,248*****			0,122***	1211
Origin of the product				0,116**	**0,333*****	**0,411*****	0,159**			0,135***	1209
Energy consumption during production		0,004**		**0,131*****	**0,442*****	**0,392*****				0,173***	1212
Compliance with social standards in manufacturing				**0,173*****	**0,407*****	**0,484*****		-0,062**		0,188***	1208
Supply Chain & Transportation				**0,267*****	**0,370*****	**0,454*****			0,000**	0,185***	1210

Table 16: Factors influencing the relevance of information for storage batteries

The results illustrated in Table 30 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in information related to energy consumption during use, and ecological footprint.
- **Age:** There is a low tendency that with increasing age the interest in information on durability, disposal instructions, energy consumption during use, health impact, and energy consumption during production rises.
- **Technology Affinity:** Participants with higher technology affinity show a higher interest in information on durability and product composition.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in origin, energy consumption during production, compliance with social standards, and supply chain information, while participants with a lower attitude are more interested in information on durability.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy scores over all categories, except for energy consumption during use, compliance with social standards, and supply chain.
- **Education:** Participants with lower education declare higher relevance for information on compliance with social standards.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: When it comes to storage batteries, participants are most interested in durability, disposal instructions, and reusability, while older participants expose a higher interest in this product type, participants with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested. Also, disabilities have an impact on the perceived relevance. Gender plays a minor role. Technology affinity, education and income do not have an impact.

Household batteries (e.g. button batteries, "Duracell" batteries, flashlight batteries)

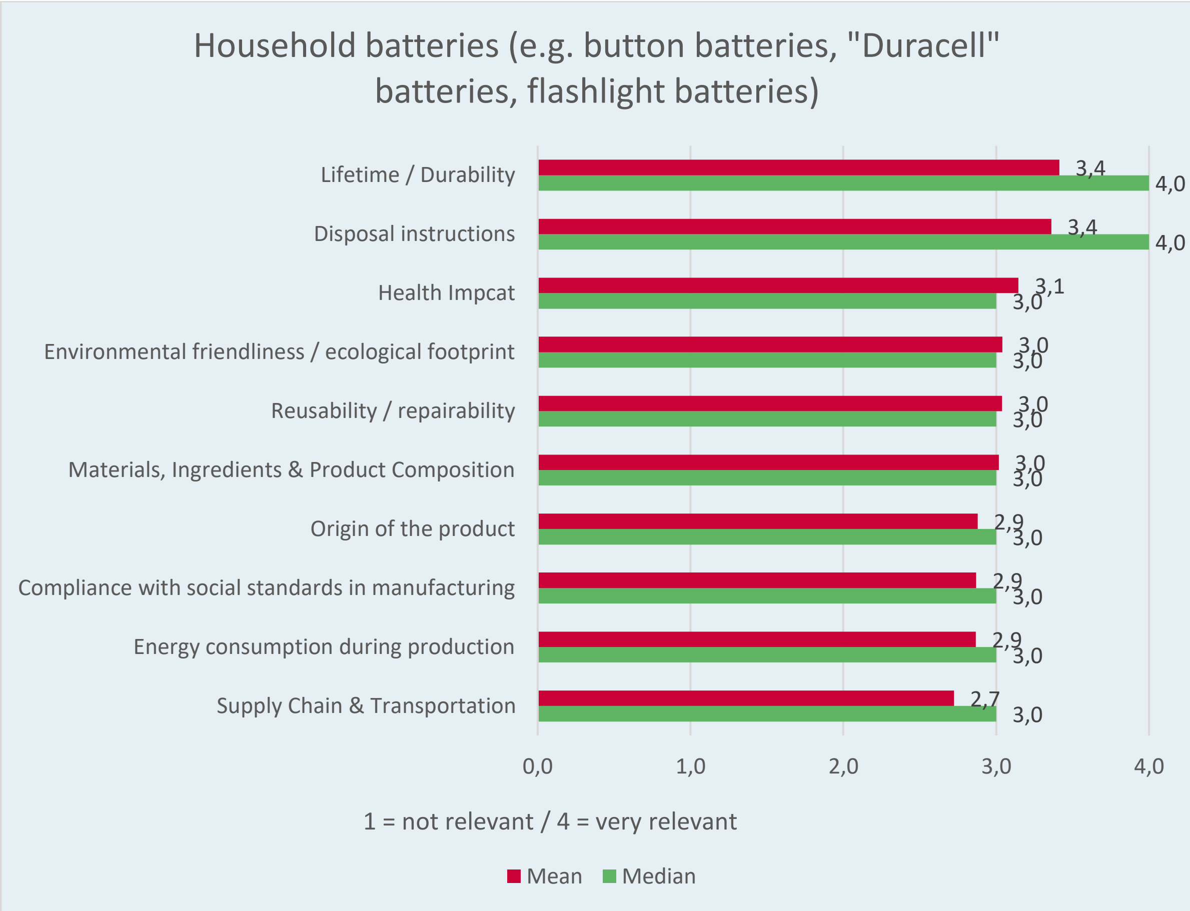


Figure 82: Relevance of DPP-information for household batteries

Figure 68 shows slight diverging patterns from the other battery types, with durability, disposal in strictions and health impact exposing the highest relevance scores, while compliance with social standards, energy consumption during production, and supply chain information rank lowest.

Factors influencing the relevance of information for household batteries

Household batteries (e.g. button batteries, "Duracell" batteries, flashlight batteries)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Lifetime / Durability		0,005***			0,159***	0,431***	0,299***			0,096***	1222
Disposal instructions		0,007***			0,292***	0,327***	0,264***			0,127***	1225
Health Impcat		0,006***			0,254***	0,449***	0,267***			0,096***	1218
Environmental friendliness / ecological footprint	0,110**			0,112**	0,508***	0,432***				0,237***	1224
Reusability / repairability	0,160**	-0,005**			0,220***	0,611***	0,192**			0,110***	1220
Materials, Ingredients & Product Composition					0,298***	0,581***	0,223**			0,145***	1221
Origin of the product				0,124**	0,346***	0,534***		-0,043**		0,155***	1223
Compliance with social standards in manufacturing	0,122**			0,175***	0,434***	0,467***		-0,040**		0,201***	1218
Energy consumption during production				0,173***	0,433***	0,486***				0,193***	1222
Supply Chain & Transportation				0,218***	0,373***	0,520***		-0,047**		0,191***	1221

Table 17: Factors influencing the relevance of information for household batteries

The results illustrated in Table 31 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in information related to ecological footprint, reusability, and compliance with social standards.
- **Age:** There is a low tendency that with increasing age the interest in information on durability, disposal instructions, and health impact rises, while younger partticipants are more concerned about reusability.
- **Technology Affinity:** Technology affinity does not seem to have an impact.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in environmental friendliness, origin, compliance with social standards, energy consumption during production, and supply chain information.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy scores for durability, disposal instructions, health impact reusability, and product composition.
- **Education:** Participants with lower education declare higher relevance for information on origin, compliance with social standards, and supply chain information.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: When it comes to household batteries, participants are most interested in durability, disposal instructions, and health impact, while older participants expose a higher interest in this product type, participants with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested. Also, disabilities have an impact on the perceived relevance. Gender and education play a minor role. Technology affinity and income do not have an impact.

Relevance of DPP Information – Plastics

Plastic toys (e.g., stuffed animals, sand toys, Lego, Playmobil)

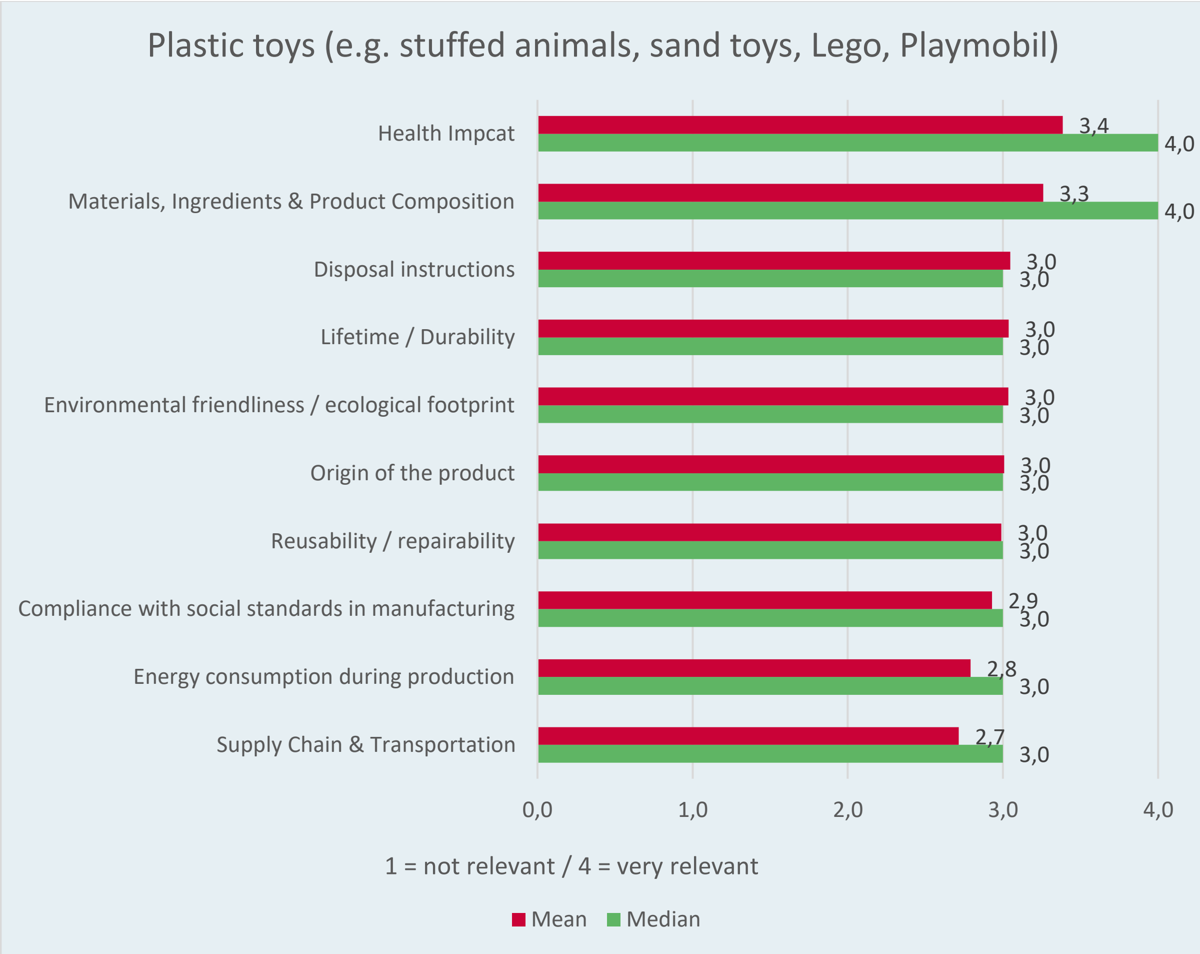


Figure 83: Relevance of DPP-information for plastic toys

Figure 69 shows that when it comes to plastic toys health impact, product composition, and disposal instructions are of highest relevance, while compliance with social standards, energy consumption during production, and supply chain information have the lowest ranks.

Factors influencing the relevance of information for plastic toys

Plastic toys (e.g. stuffed animals, sand toys, Lego, Playmobil)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat	0,109**	0,009***			0,217***	0,364***	0,346***			0,116***	1186
Materials, Ingredients & Product Composition	0,226***	0,004**	0,104**		0,283***	0,429***	0,240***			0,142***	1189
Disposal instructions	0,144**	0,006***			0,368***	0,408***				0,138***	1185
Lifetime / Durability			0,094**		0,179***	0,435***	0,238**			0,070***	1184
Environmental friendliness / ecological footprint	0,143**				0,541***	0,406***				0,238***	1188
Origin of the product	0,180***	0,004**	0,077**	0,105**	0,317***	0,440***				0,142***	1186
Reusability / repairability	0,144**				0,246***	0,424***				0,087***	1187
Compliance with social standards in manufacturing	0,131**			0,105**	0,428***	0,460***				0,182***	1185
Energy consumption during production	0,163**			0,158**	0,418***	0,389***				0,169***	1186
Supply Chain & Transportation	0,142**		0,079**	0,186***	0,453***	0,427***				0,201***	1186

Table 18: Factors influencing the relevance of information for plastic toys

The results illustrated in Table 32 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in nearly all information related to plastic toys, except for durability.
- **Age:** There is a low tendency that with increasing age the interest in information on health impact, product composition, disposal instructions, and origin rises.
- **Technology Affinity:** Participants with higher technology affinity assign higher relevance to information about product composition, durability, origin, and supply chain information.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in origin, compliance with social standards, energy consumption during production, and supply chain information.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy scores for health impact reusability, product composition, and durability.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information.
- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information.

Observation: When it comes to plastic toys, participants are most interested in health impact, product composition, and disposal instructions, while female participants expose a higher interest in nearly all information categories, participants with higher technology affinity and stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Education and income do not have an impact.

Plastic decoration (e.g., flowers, wall & garden decoration)

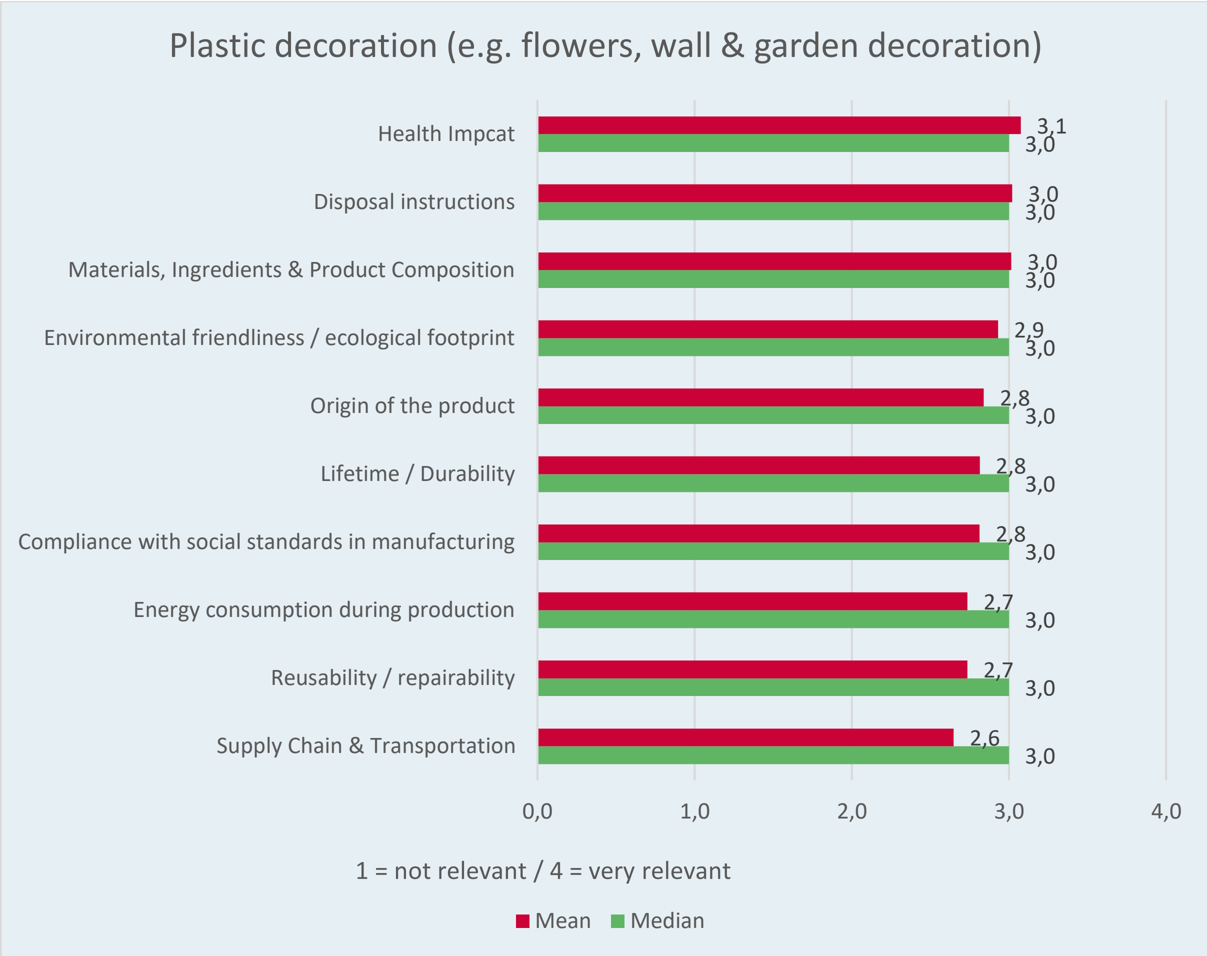


Figure 84: Relevance of DPP-information for plastic decoration

Figure 70 shows that when it comes to plastic decorations health impact, disposal instructions, and product composition are of highest relevance, while energy consumption during production, repairability, and supply chain information have the lowest ranks.

Factors influencing the relevance of information for plastic decoration

Plastic decoration (e.g. flowers, wall & garden decoration)	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Health Impcat		0,004**			0,250***	0,483***	0,169**			0,094***	1188
Disposal instructions					0,399***	0,486***				0.148***	1187
Materials, Ingredients & Product Composition			0,080**		0,313***	0,420***				0,114***	1192
Environmental friendliness / ecological footprint	0,138**			0,109**	0,548***	0,382***				0,234***	1195
Origin of the product				0,176***	0,358***	0,421***				0,147***	1192
Lifetime / Durability					0,154***	0,499***			0,000**	0,077***	1191
Compliance with social standards in manufacturing				0,153**	0,474***	0,442***		-0,068***	0,000**	0,207***	1191
Energy consumption during production				0,167***	0,452***	0,445***				0,193***	1193
Reusability / repairability	0,125**	-0,007***		0,123**	0,231***	0,540***				0,111***	1187
Supply Chain & Transportation			0,097**	0,208***	0,376***	0,460***		-0,060**		0,180***	1192

Table 19: Factors influencing the relevance of information for plastic decoration

The results illustrated in Table 19 are discussed below:

- **Gender:** Gender does not seem to have a major impact, except for female and diverse participants showing a higher interest in environmental friendliness and reusability information.
- **Age:** The influence of age is also limited, with older participants being slightly more interested in health impact and younger participants in reusability.
- **Technology Affinity:** Participants with higher technology affinity assign higher relevance to information about product composition, and supply chain information.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in environmental friendliness, origin, compliance with social standards, energy consumption during production, reusability, and supply chain information.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a higher relevancy interest in health impact.
-
- **Education:** Participants with lower education are more interested in compliance with social standards and supply chain information.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information, although we can observe unspecific interactions.

Observation: When it comes to plastic decorations, participants are most interested in health impact, product composition, and disposal instructions, while female participants expose a higher interest in nearly all information categories, participants with higher technology affinity and stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Education and income do not have an impact.

Plastic Dishes & Containers

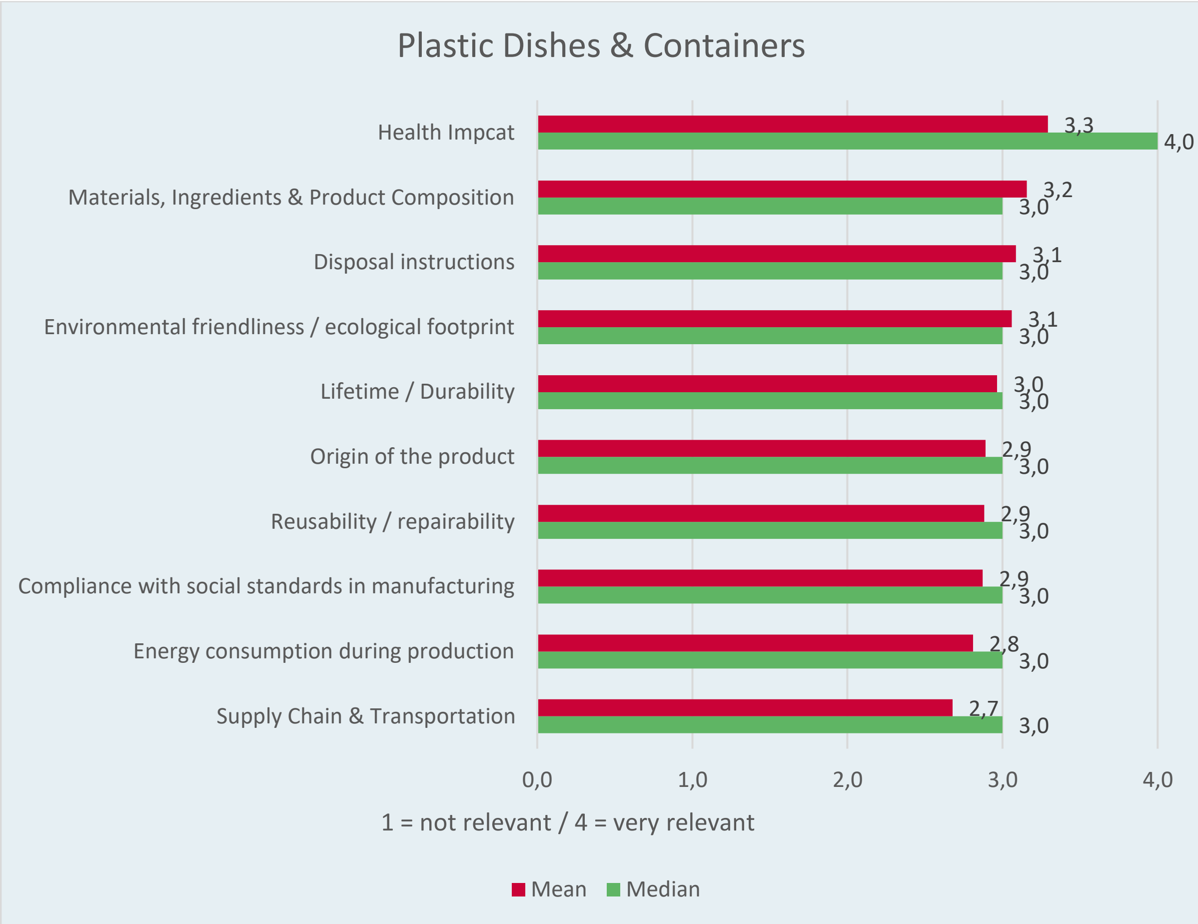


Figure 85: Relevance of DPP-information for plastic dishes and containers

Figure 71 shows that when it comes to plastic toys health impact, product composition, and disposal instructions are of highest relevance, while compliance with social standards, energy consumption during production, and supply chain information have the lowest ranks.

Factors influencing the relevance of information for plastic dishes and containers

Plastic Dishes & Containers	**Gender**	**Age**	**Tech Aff.**	**Att. Sust. Purch.**	**Att. Clim. Change**	**Lifestyle**	**Disab.**	**Educ.**	**Income**	**corr. R2**	**n**
Health Impcat		**0,008*** **			**0,194*** **	**0,488*** **	**0,252*** **			0,111***	1204
Materials, Ingredients & Product Composition		**0,006*** **			**0,331*** **	**0,433*** **	0,195**			0,143***	1206
Disposal instructions		0,004**			**0,395*** **	**0,496*** **	0,168**			0,162***	1206
Environmental friendliness / ecological footprint	0,111**				**0,522*** **	**0,366*** **	0,167**		0,000**	0,222***	1204
Lifetime / Durability	0,157**	0,005**	0,096**		**0,176*** **	**0,429*** **			0,000**	0,067***	1205
Origin of the product	0,127**	0,004**	0,072**		**0,353*** **	**0,486*** **				0,152***	1205
Reusability / repairability		-0,005**			**0,258*** **	**0,491*** **				0,096***	1204
Compliance with social standards in manufacturing	0,132**			0,154**	**0,439*** **	**0,439*** **		-0,052**		0,196***	1202
Energy consumption during production	0,116**			0,144**	**0,421*** **	**0,477*** **			0,000**	0,187***	1203
Supply Chain & Transportation				**0,241*** **	**0,372*** **	**0,533*** **				0,202***	1205

Table 20: Factors influencing the relevance of information for plastic dishes and containers

The results illustrated in Table 34 are discussed below:

- **Gender:** Female and diverse participants show a higher interest in environmental friendliness, durability, origin, compliance with social standards, and energy consumption during production.
- **Age:** There is a low tendency that with increasing age the interest in information on health impact, product composition, disposal instructions, durability, and origin rises, while younger participants show higher interest in reusability.
- **Technology Affinity:** Participants with higher technology affinity assign higher relevance to information about durability and origin.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in compliance with social standards, energy consumption during production, and supply chain information.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy scores across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy scores for health impact reusability, product composition, durability, and environmental friendliness.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information, excepts for compliance with social standards which is of higher interest to lower educated participants.

- **Income:** Income does not seem to have an impact on the assigned relevance of DPP information, although we can observe unspecific interactions.

Observation: When it comes to plastic dishes and containers, participants are most interested in health impact, product composition, and disposal instructions, while female participants expose a higher interest in nearly some information categories, participants with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Technology affinity, education and income just have a minor impact.

Relevance of DPP Information – Packaging

Figure 86: Relevance of DPP-information for packaging

Figure 72 illustrates that information on disposal instructions, health impact, ecological footprint and composition receive the highest relevancy score, while energy consumption during production, origin, and information on supply chain receive the lowest scores.

Factors influencing the relevance of information for packaging

Packaging	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
Disposal instructions	0,112**	0,005**			**0,348******	**0,397******	0,216**			0,138***	1222
Health Impcat		0,005**			**0,289******	**0,552******	**0,251******		0,000**	0,135***	1220
Environmental friendliness / ecological footprint					**0,496******	**0,378******	**0,256******			0,218***	1224
Materials, Ingredients & Product Composition	0,148**				**0,308******	**0,517******	0,205**			0,154***	1225
Reusability / repairability					**0,201******	**0,463******				0,071***	1221
Compliance with social standards in manufacturing	0,146**			0,099**	**0,427******	**0,455******		-0,057**		0,182***	1220
Lifetime / Durability					**0,227******	**0,526******	0,177**				1220
Energy consumption during production				**0,188******	**0,388******	**0,432******				0,172***	1221
Origin of the product	0,122**	0,004**		**0,173******	**0,328******	**0,433******			0,000**	0,136***	1224
Supply Chain & Transportation				**0,255******	**0,349******	**0,499******			0,000**	0,186***	1223

Table 21: Factors influencing the relevance of information for packaging

The results illustrated in Table 35 are discussed below:

- **Gender:** Gender is of minor importance for this product category, although female and diverse participants show a higher interest in disposal instructions, composition, compliance with social standards, and origin of the product.
- **Age:** Participants with higher age show a higher interest in the products' disposal instructions, health impact, and origin.
- **Technology Affinity:** Technology affinity does not seem to have an impact.
- **Attitude towards sustainable purchasing:** Participants with a higher attitude show a stronger interest in compliance with social standards, energy consumption during production, origin, and supply chain information of packaging.
- **Attitude towards climate change:** Participants that are more concerned about climate change show a tendency towards higher relevancy score across all DPP information.
- **Lifestyle typology:** Participants with higher socio-economic and cultural capital show a tendency towards higher relevancy score across all DPP information.
- **Disabilities:** Participants with disabilities show a tendency towards higher relevancy score for disposal instructions, health impact, ecological footprint, composition, and durability.
- **Education:** Education does not seem to have an impact on the assigned relevance of DPP information.
- **Income:** We can observe an effect related to income but without a clear tendency.

Observation: While gender, age, education, and income seem to be of minor importance when understanding the relevance of DPP information on packaging, we can observe strong effects with a higher attitude towards sustainable purchasing, climate change, lifestyles and disabilities.

Willingness to share data

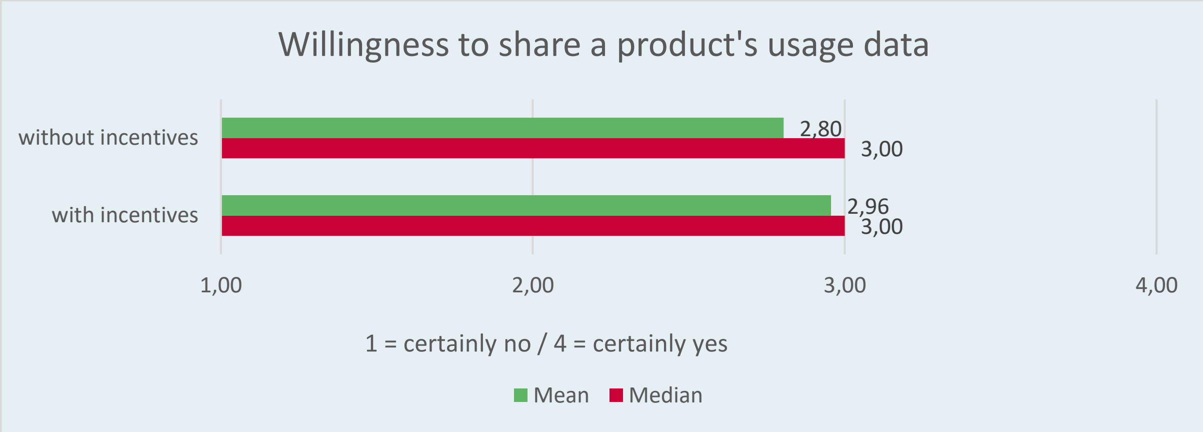


Figure 87: Willingness to share a product's usage data

When asked about the willingness to share usage data 71,2% of the respondents declare to be very willing (18,9%) or willing (53,2%) to share their data without any incentives. These respondents tend to be younger, less affected by disabilities and have a lower educational level. They have a strong attitude towards climate change and possess a richer set of socio-economic and cultural capital.

Influencing factors for willingness to share data

Willingness to share data	Gender	Age	Tech Aff.	Att. Sust. Purch.	Att. Clim. Change	Lifestyle	Disab.	Educ.	Income	corr. R2	n
without incentives		-0,003**			**0,386*** **	**0,326*** **	-0,189**	-0,042**		0,176***	1219
with incentives	-0,139**	**-0,008*** **		**-0,166*** **	**0,346*** **	**0,212*** **		-0,036**		0,120***	1218

Table 22: Influencing factors for willingness to share data

When asked, if monetary or other kinds of incentives would raise their willingness to share data, 75% of the respondents declare that such incentives would strongly increase (27,3%) or increase (47,7%) their willingness to share data. These respondents tend to be male, of younger age, and with a slightly lower educational level. They seem to be less sensitive to sustainable purchase decisions, although they have a strong attitude towards climate change and posses a rich set of socio-economic and cultural capital.

Observation: 71,2% are willing to share their data, given that their privacy is preserved. And for 75% incentives are viable means to increase this willingness. Respondents from these groups tend to be of younger age, have a lower educational level, have a strong attitude towards climate change and perform lifestyles that a characterized by a richer set of socio-economic and cultural capital.

Syntheses of results

The discoveries we made are just scratching the surface of the subject matter but have allowed us to start delving into a deeper understanding of information preferences linked to a DPP. The patterns that have emerged warrant a more extensive exploration and discussion.

General Findings

The interest in and the perception of relevance of product information highly correlates with attitudinal factors towards sustainable purchasing behavior and climate change, but to a lesser degree with demographic factors such as income, education, or age. Nevertheless, we can observe stereotypical patterns with respect to gender, where technically connotated products such as electronics, batteries and building and construction materials score higher among male participants, while goods for daily needs and plastics score higher among female participants. Interestingly, participants with a higher technology affinity also express a higher interest in product information across all categories. Beside all that, the perception of information relevance is highly dependent on lifestyle with participants owning a richer set of socio-economic and cultural capital assigning higher scores compared to participants with lower capital. Counterintuitively, this does not correlate with income and education, but can be better explained with belief systems, social embeddedness and cultural background of the participants and will be subject of further research.

When investigating the relevance of product information provided by a DPP, we can observe two interesting trends: First, DPP information across all categories is more relevant to female participants, and second, the specific set of information provided by a DPP does not correlate with technology affinity, indicating that the (hypothetical) set of information provided by a DPP is not relevant to people with higher interest in technical matters. Instead, it is again lifestyle, attitudinal factors, and the level of (physical or cognitive) impairment that make a difference.

Information Search behavior

The survey revealed that the majority of participants deliberately and purposefully searches for product information but with clear preferences for specific product categories. While we see a clear preference for electronics, goods for daily needs, and building and construction material, batteries, plastics, and packaging receive significantly lower scores. And in the case of textiles, we observe a profound gap in interest between clothing and everyday textiles. Hence, it is important to step beyond the categorial level and investigate specific types of products. Unsurprisingly, participants search for information on products that come with an investment decision, such as household appliances or construction material, or that directly affect personal well-being such as food and sanitary products, or clothing. Products not bearing these attributes score significantly lower.

Relevance of DPP information

Information that is directly attached to daily routines and well-being receives higher relevancy scores, such as health information on goods of daily needs and plastics, lifetime and energy consumption of electronics, durability of batteries or material composition of textiles. Information on subjects that are out of the scope of consumers' immediate influence (such as compliance with social standards in manufacturing, supply chain and transport or energy consumption during production) receive significantly lower scores unless strong attitudinal factors related to sustainable purchasing or climate change come into play. This trend is recognizable among all product types. But the set of relevant information can differ strongly between consumers, indicating that purchase behaviors are solely ruled by hedonistic motives but also incorporate a specific degree of environmental awareness and reflexivity. This is especially true for participants with higher socio-economic and cultural capital, stronger attitudes towards sustainable purchasing and climate change who show a higher interest in product information, while education and income do not seem to have an effect.

Electronics: Information on durability, energy consumption during use, repairability and disposal instructions of household appliances show the highest relevancy, while the interest in DPP information is higher among female and diverse participants, people with higher attitudes towards climate change and sustainable purchasing, as well as higher socio-economic and cultural capital. Also, people with disabilities have a higher interest in DPP information, while education and income does not seem to make a difference.

Goods for daily needs: Health impact, origin, ingredients, and environmental friendliness receive the highest relevancy score when it comes to goods for daily needs. Female and participants with diverse gender assign higher scores compared to male participants, while the interest in DPP information rises with age. Slight differences exist in accordance with the attitude towards sustainable purchasing. Participants with higher attitudes towards climate change and higher socio-economic and cultural capital assign higher relevancy scores to all information provided by a DPP, which can also be observed to a slightly lesser degree for participants with disabilities. Education and income do not seem to make a major difference, although interestingly participants with lower education express a higher interest in information on origin, compliance with social standards, energy consumption during production and supply chain information.

Building and construction materials: Information on health impact, disposal instructions, material composition and durability receive the highest relevancy scores when it comes to building and construction material. While gender does not exhibit a major effect, differences exist with respect to age with older participants reporting higher relevancy scores. Differences also exist with respect to attitudes towards sustainable purchasing, climate change and lifestyles, generally indicating that with higher attitudes the relevance of information increases. This is also the case for people with disabilities, while education and income do not seem to have an impact.

Textiles: When it comes to textiles, participants are most interested in information about product composition, health impact, origin, and environmental friendliness, although we see a clear difference with higher relevancy scores for clothing and fashion compared to everyday textiles. While information on textiles is more relevant to female participants, age technology affinity and education just have a minor influence. Instead, strong attitudes towards sustainable purchasing, climate change and participants with higher lifestyles assign high relevance to information on clothing and fashion. Income does not have an impact.

Batteries: Participants are most interested in lifetime, energy consumption during use, disposal instructions, and reusability. The impact of gender on perceived relevance declines with batteries, participants of older age and with stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles generally show higher interest. Also, participants with disabilities assign higher relevancy scores to information about batteries. Technology affinity, education and income do not have an impact.

Plastics: When it comes to plastics participants are most interested in health impact, product composition, and disposal instructions, although like textiles, we see a clear difference in relevancy scores between product types with plastic toys receiving the highest relevancy scores. Female participants expose a higher interest in nearly all information categories, participants with higher technology affinity and stronger attitudes towards sustainable purchasing and climate change, and those with higher lifestyles are generally more interested in this product type. Also, disabilities have an impact on the perceived relevance. Education and income do not have an impact.

Packaging: When it comes to packaging participants are most interested in disposal instructions, health impact and environmental friendliness. While gender, age, education, and income seem to be of minor importance when information on packaging is concerned, we can observe strong effects with a higher attitude towards sustainable purchasing, climate change, higher lifestyles and higher degrees of disabilities.

Willingness to share data

71,2% are willing to share their data, given that their privacy is preserved. And for 75% monetary or other kinds of incentives are viable means to increase this willingness. Respondents from these groups tend to be of younger age, have a lower educational level, have a strong attitude towards climate change and perform lifestyles that a characterized by a richer set of socio-economic and cultural capital.

Conclusion and Recommendations

A DPP shall support the transition towards a circular economy in the priority areas defined within the EU Ecodesign Directive, namely electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, and food, water and nutrients. For the purpose of this report, we investigated the areas building and construction, battery life cycle management, and end-of-life / waste management, given that these sectors already exhibit relatively high progress with respect to digital product information management and that these areas are of vital importance in the timely transition towards an environmentally sustainable circular economy. In the subsequent sections we identify research questions from a technological, organizational and legal perspective relevant for these areas as well as the perceptive of consumers.

General Remarks

Although access to reliable information enables consumers to make more sustainable choices, it is not always sufficient to drive behavioral change due to complexities in decision-making, such as established habits, economic, social, and cultural capital, and psychological factors. Achieving sustainable consumption requires a holistic approach beyond information provision, addressing behavioral barriers, and incentives to encourage consumers to adopt more environmentally friendly choices.

Observation: We can observe various activities performed in the three sectoral areas but with different degrees of sophistication and maturity. While the battery manufacturing sector, mainly due to its attachment to the automotive sector, currently offers the most advanced approaches towards a DPP, the general progress is still at a relatively low level of technological maturity. While the general architecture of a DPP is no longer subject to debate, uncertainties stemming from regulatory fuzziness with respect to methodological aspects of capturing, documenting and transforming product data into sustainability KPIs across the supply chain as well as the institutionalization of a DPP infrastructure slow down the level of progress. Additionally, competing conceptions of a DPP in diverse but related policy areas pose challenges to cross-sectoral coordination and standardization efforts.

- **Recommendation 1:** Clarification is needed how a DPP infrastructure shall be institutionalized including the division of responsibilities and accountabilities among the affected sectoral stakeholders with a special focus on the persistent, long-term availability of product data and under special consideration of nuanced disclosure and access control.
- **Recommendation 2:** Clarification is needed about methodological recommendations on capturing, documenting, and processing product data to generate sustainability KPIs in accordance with the specificities of the products concerned under close alliance with the sectoral stakeholders.

Observation: While our sectoral investigations revealed that all respondents feel well prepared for a DPP from a technological, organizational, and legal perspective they acknowledge specific challenges associated with the interdisciplinary nature of a DPP which can be attributed to factors such as company size and corporate culture. Small and medium sized companies are generally more concerned about the administrative effort associated with the implementation and maintenance of a DPP compared to larger organizations. But those companies that already perform and live a corporate culture acknowledging inter- and cross-disciplinarity seem to be less concerned, irrespective of the company size.

- **Recommendation 3:** Easily accessible, comprehensive, and free awareness building and training measures should be offered to companies (especially SMEs) that lack the necessary knowledge and capacities to implement and maintain a DPP.
- **Recommendation 4:** Training material needs to refer to and acknowledge already existing sector-specific disclosure regulations on product information and their relevance for serving an DPP. Herein it is of vital importance to not overburden companies with additional disclosure requirements that are out of their control or that could hamper their legitimate interest in IPR protection or secrecy.
- **Recommendation 5:** Recommendations should be given on licenses and usage rights applied to publicly disclosed data, ideally by applying a uniform license model that does not hamper its reuse especially for business purposes. Herein, permissive

licenses could be more attractive licensing models compared to copy-left licenses that come with specific restrictions when combined with other licenses.

Observation: The technological approaches to develop and implement a DPP are quite universal at the architectural level but can be very diverse when it comes to functional specificities and solutions, especially when syntactic and semantic interoperability a concerned. This is also an effect of the rather fragmented development landscape and the lack of cross-industry coordination, especially when the sector shows a strong local embeddedness (such as building and construction, or waste management compared to more internationalized sectors such as battery manufacturing).

- **Recommendation 6:** To ensure interoperability at the system and data level and to avoid vendor lock-ins it is vital to stick to open standards in the syntactical and semantic description of product-related data in machine-readable form for their exchange and reuse across various systems and applications. Openness needs to be ensured at the level of interfaces (APIs), data models (ontologies and schemas for metadata), as well as the terminologies (controlled vocabularies for product descriptions) and uniform identifiers (universal and persistent resource IDs) to enable automated and context-sensitive data exchange.
- **Recommendation 7:** Open standards do not necessarily interfere with the legitimate interest in protecting and controlling the access to data, although technical solutions to implement both aspects into one environment are still challenging, given that the necessary IT infrastructure is mostly privately controlled. Emerging technological concepts such as distributed ledgers and dataspaces offer viable solutions but are either in an early stage of development (such as dataspaces) and/or require adjustments at the level of corporate IT governance (i.e., when it comes to distributed ledgers), especially when security issues are concerned.
- **Recommendation 8:** The heterogeneity of stakeholders involved in a DPP requires nuanced approaches to documenting and displaying product-related information, especially when this information is meant to provide a basis for informed decisions. Measures need to be taken that investigate appropriate visualization techniques for various levels of interest in and intellectual capabilities to understand and process product information in accordance with the stakeholders' informational needs. This is especially relevant for consumers.

Observation: Information about product composition, health impact, environmental friendliness, and repairability receive the highest relevancy scores across all three sectors, indicating that this data is of highest relevance in serving the policy objectives of a DPP, namely fostering the circular transition and deriving business value from it. Nevertheless, relevancy scores sharply decline when information is not directly linked to established business processes or operational issues of legal compliance which is also reflected in the perceived benefits deriving from the maintenance of a DPP. DPPs facilitate better market insights and stimulate diversification of business models but have little impact on operational efficiency or improved brand value beyond established business practices. Hence, a DPP – although necessary – is not perceived to generate substantial business benefits or be a sufficient game changer in the transition towards a circular economy.

- **Recommendation 9:** DPPs shall be designed to enable better market insights and generate operational efficiency in production workflows across the product's life cycle, especially during the end-of-live phase. This includes a better conceptualization and understanding of circularity for specific product types and a transfer of knowledge between the supply chain actors about desired performance indicators, ideally streamlined with policy objectives on cleaner production.

Observation: When it comes to retaining control over data and its persistent provision via a DPP infrastructure, companies prefer system architectures that allow for the redundant storage of information in a balanced combination of centralized and federated approaches. Nevertheless, a lot of uncertainty exists about the impacts of appropriate technical solutions on existing data management practices and associated efforts.

- **Recommendation 10:** Projects developing and testing technical solutions for persistent data provision and storage for product information should provide sand boxes and experimental environments that allow system stakeholders to gain experience and knowledge about the efforts for and impacts on their established data management practices and workflows under special consideration of issues associated with security, trust and secrecy.

Sector-specific Recommendations

In addition to the general observations described above that following sector-specific challenges should be addressed:

Building and Construction

Recommendations for technological challenges:

- Evaluate and ensure maximum reusability of existing product information contained in product sheets and other documentations provided by manufacturers of building and construction materials.
- Screen existing product registries and repositories for syntactic and semantic interoperability and identify weak spots in the machine-readable representation of this data at the ontological and terminological level.
- Investigate the appropriate level of disclosure and machine-readable representation of compositional information of building and construction materials, offering solutions for the nuanced role-based accessibility of this information across the product life cycle.
- Investigate techniques to persistently attach appropriate identifiers to building and construction materials or – where not possible – to document this information over long time periods (up to decades) so that this information is preserved for future generations.

Recommendations for organizational challenges:

- Develop measures to mitigate an imminent skill shortage for domain experts familiar with the digital documentation of product information on building and construction materials.
- Develop measures to increase the level of digitization and datafication in the building and construction sector to mitigate an imminent skill shortage for IT professionals in this area.

- Pay attention to cost burdens stemming from implementation and maintenance efforts of a DPP under special consideration of SMEs.

Recommendations for legal challenges:

- Investigate compliance issues for manufacturers and construction companies with respect to warranty obligations and privacy preservation arising from the long-term availability of building and construction information.

Battery Life Cycle Management

Recommendations for technological challenges:

- Evaluate and ensure maximum reusability of existing product information contained in product sheets and other documentations provided by battery manufacturers and service providers specialized in state-of-health solutions.
- Screen existing product registries and repositories for syntactic and semantic interoperability and identify weak spots in the machine-readable representation of this data at the ontological and terminological level.
- Investigate the appropriate level of disclosure and machine-readable representation of compositional information of batteries, offering solutions for the nuanced role-based accessibility of this information across the product life cycle.
- Investigate techniques to persistently attach appropriate identifiers to batteries or – where not possible – to document this information along the product lifecycle under special consideration of change of ownership.

Recommendations for organizational challenges:

- Investigate how to better document and streamline the flow of materials, components and products across a battery's life cycle to ensure maximum extension of lifetime through repairability, reuse and recycling.

Recommendations for legal challenges:

- Investigate interactions between IPR protection, usage rights, and disclosure of technical specifications along an extended battery lifecycle.
- Investigate warranty issues and responsibilities for second-life applications of used batteries under special consideration of product-safety.

End-of-Life / Waste Management

Recommendations for technological challenges:

- Investigate the necessary granularity and machine-readable description of information on materials and substances for the purpose of workflow efficiency in sorting, recycling, and disposal.
- Investigate techniques to efficiently extract and collect product information from dumped products at the item or batch level.

Recommendations for organizational challenges:

- Develop measures to mitigate an imminent skill shortage for domain experts familiar with the digital documentation of product information for the end-of-life phase and purpose of disposal.
- Develop measures to increase the level of digitization and datafication in the waste management sector to mitigate an imminent skill shortage for IT professionals in this area.
- Pay attention to cost burdens stemming from implementation and maintenance efforts of a DPP in the waste management sector under special consideration of SMEs.

Recommendations for legal challenges:

- Investigate the legal liabilities of the waste management sector as an enabler for the reuse and second life of waste and warranty issues deriving from this.

Consumers

Recommendations for technological challenges:

- Investigate appropriate levels of information richness and complexity-reducing visualizations provided to consumers in a cascaded manner so that different degrees of knowledge about and interest in product information can be served.
- Develop techniques and solutions that preserve the privacy of users, especially when they are willing to share product usage data or interact with DPPs in general.
- Envision and design user-friendly services for consumers with varying degrees of intellectual, cognitive, or physical capabilities to draw additional benefits from DPPs beyond the mere provision of factual information.

Recommendations for organizational challenges:

- Consider attitudinal and lifestyle related factors in the user-friendly provision and compilation of product information.

Recommendations for legal challenges:

- Investigate usage policies and licenses that allow consumers to actively participate in a DPP ecosystem.

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Table of Tables

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Annex 1: List of interview partners

The following experts participated in the interviews:

Company/ Organisation	First Name	Last Name	Function	Sector	Stakeholder Role
Allora Immobilien	Peter	Ulm	CEO	Building & Construction	Construction
Baumit	Jürgen	Lorenz	Research & Development	Building & Construction	Manufacturer
	Matthias	Hanke	Head of Product Management		
bauXund	Thomas	Belazzi	CEO	Building & Construction	Construction
BMW	Thomas	Becker	Head of Sustainability & Mobility	Battery Mgmt / Automotive	Manufacturer
	Kai	Zöbelein	Spokesperson Business and Finance Communications		
DigiCycle	Felix	Badura	CEO	End-of-Life-/Waste Management	Service Provider

Gebauer & Griller	Florian	Thallinger	Manager Compound Development	Battery Mgmt / Automotive	Manufacturer
Holcim	Berthold	Kren	CEO	Building & Construction	Manufacturer
MA48	Ulrike	Volk	Public Relations	End-of-Life-/Waste Management	Waste Collection
	Regina	Marschalek	Expert for problematic substances	End-of-Life- / Battery Mgmt	
Madaster	Werner	Weingraber	CEO	Building & Construction	Service Provider
Müller Gutenbrunn	Armin	Blutsch	Head of group IT	End-of-Life-/Waste Management	Recycling
ÖBB Rail Cargo	Gerhard	Leitgeb	Group Environmental Officer	End-of-Life-/Waste Management	Recycling
Pulswerk	Markus	Meissner	Expert waste management	Building & Construction	Service Provider
Rhomberg	Theresia	Tschol-Alsantali	Sustainability Officer	Building & Construction	Construction
Rubner Holzbau	Marcus	Warnecke	Research & Development Officer	Building & Construction	Manufacturer

Schneider Electric	Jürgen	Grebe	Chief Data Officer	Battery Management / Electronics	Manufacturer
	Gerold	Göldner	Head of Marketing Sustainability		
	Oskar	Koschaintsch	Health & Safety Manager Austria		
Texaid	Anna	Perhsson	Textile Engineer & Recycling Specialist	End-of-Life-/Waste Management	Recycling
Twingz	Werner	Weihs-Sedivy	CEO	Battery Management / E-Mobility	Service Provider
Platform Industry 4.0 Austria	Verena	Halmschlager	Project Manager	Battery Management / Misc.	Industry Association
	Roland	Sommer	CEO	Battery Management / Misc.	

Table 23: List of interview participants

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