

Digital Product Passport: A Digital Catalyst for a Circular Transformation

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Abstract

This review explores the importance of the digital product passport as a catalyst for circular transformation. In response to the European Union's recent regulatory efforts to enhance product transparency and circularity, the digital product passport is set to become mandatory across an increasing range of product categories. By enabling access to product-related data throughout the value chain, the digital product passport offers significant potential to support the implementation of circular strategies. Although recent studies have advanced our understanding of digital product passports, this study aims to update the current status of research in the context of the manufacturing industry with particular attention to circular ecosystems. The findings show that prior research gives little attention to pre-use circular strategies and continues to emphasize the digital product passport's regulatory scope, leaving its role in supporting circular value creation underexplored. The developed framework supports companies in adopting circular solutions enabled by the digital product passport and offers a conceptual foundation for further academic research on smart circular ecosystems.

Keywords Digital Product Passport · Circular Economy · Ecosystem · Actor · Digital Technologies · Data

1. Introduction

The digital product passport (DPP) is gaining increasing importance as a pivotal instrument in the transition toward a circular economy (King et al., 2023; Lopes & Barata, 2024; van Capelleveen et al., 2023). Overall, the circular economy aims to enhance resource efficiency and close material loops by driving a systemic reconfiguration of economic processes (Geissdoerfer et al., 2017). As in other industries, the manufacturing sector is increasingly pressured to reduce waste, optimize resource use, and implement circular practices (Bocken et al., 2025, Bühler et al., 2025a). Circular economy tools such as the 9R-framework by Potting et al. (2017) provide actionable strategies that help companies translate circular ambitions into concrete operational measures.

However, the implementation of the circular economy depends on comprehensive lifecycle and product information to enable business cases that enhance, for example, component repair or reuse by providing repair instructions or data on usage intensity. Such information is often unavailable or restricted to specific actors, as there is no holistic product lifecycle data management that grants access across the entire value chain (Alcayaga & Hansen, 2025, Bühler et al., 2025b). Recently, the DPP has emerged as a key instrument to address this gap by enabling the transparent exchange and integration of critical product information among a diverse set of ecosystem actors (Berger et al., 2023; Plociennik et al., 2022; van Capelleveen et al., 2023).

At the policy level, the European Union has positioned the DPP as a central tool for distributing information across the value chain through legislation such as the Ecodesign for Sustainable Product Regulation (ESPR) and the Battery Regulation (King et al., 2023; Wan & Jiang, 2025). By standardizing critical lifecycle data,

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including materials used or maintenance guidelines, the DPP enables manufacturers, consumers, recyclers and other actors in the broader ecosystem to make data-driven decisions (Fendt et al., 2026). This structured exchange of information enhances transparency and builds trust among ecosystem actors, facilitating collaborative efforts toward circular practices (Berger et al., 2023; Zhang & Seuring, 2024). Nonetheless, implementing the DPP across industries remains challenging, as many ecosystem actors face difficulties in developing the necessary infrastructures, aligning information systems, and ensuring compliance with emerging regulations. Overcoming these barriers will be essential for unlocking the full potential of circular strategies globally (Lopes & Barata, 2024; Psarommatis & May, 2024, Papert et al., 2024).

Despite the increasing interest in DPPs, a considerable gap remains in regarding the implementation of DPPs to enable circular strategies (Wicaksono et al., 2025). While some studies describe how the DPP can support specific use cases or particular R-strategies through digital technologies, data points and processes (Pohlmann et al 2024, Pulikottil et al 2025, Plociennik et al 2024), to the best of our knowledge, no study has systematically connected R-strategies, digital technologies, actors, roles and data points to describe a DPP-centered circular ecosystem. A clear conceptualization of the ecosystem enables actors to understand the DPP in its system-wide context and provides companies and industries with a structured foundation to operationalize R-strategies within the ecosystem (Gieß & Möller, 2025).

When comparing existing review articles to the focus of our research, it is evident that many articles address specific elements of the DPP ecosystem. For example, some reviews concentrate on the digital technologies required for the DPP (Lopes & Barata, 2024; Voulgaridis et al., 2024; Wan & Jiang, 2025; Wicaksono et al., 2025), the necessary data points (Berger et al., 2022; Kostia et al., 2025; Lopes & Barata, 2024; Psarommatis & May, 2024; van Capelleveen et al., 2023; Wan & Jiang, 2025; Zhang & Seuring, 2024) or the actors involved in the DPP ecosystem (Berger et al., 2022; Carvalho et al., 2025; Gieß & Möller, 2025; Psarommatis & May, 2024; van Capelleveen et al., 2023; Zhang & Seuring, 2024). While these contributions provide valuable insights into individual components, the integration of these elements into a comprehensive ecosystem has so far only been attempted by Gieß and Möller (2025) through an e3-value model. The model offers limited detail on how the ecosystem is created and how interactions take place. By focusing primarily on product, monetary, and informational flows without concrete application examples, it provides only a partial view of the complexity and interdependencies inherent in a DPP-centered ecosystem.

This article builds on existing reviews (Gieß & Möller, 2025; Wan & Jiang, 2025), extends the analysis of the literature, and adds a new layer by systemizing and clarifying the connections among aspects such as R-strategies, digital technologies, actors, roles and data points. To address this research gap, the study is guided by the following overarching research question:

“How can digital product passports enable and shape holistic circular ecosystems, integrating R-strategies, digital technologies, actors, roles and data points?”

The study therefore aims to provide a comprehensive understanding of DPP-centered circular ecosystems within the manufacturing sector. First, it maps how these ecosystems emerge in relation to R-strategies. Second, it categorizes and analyzes digital technologies and associated data points that support DPP implementation, examining how they enable information flows and facilitate lifecycle management within the ecosystem. Third, it identifies actors (e.g. DPP-ecosystem-participants) involved in DPP-centered circular ecosystems along with their DPP-related-roles, and explores how these actors interact and contribute to operationalizing circular strategies.

2. Method

This study employs a systematic literature review (SLR) approach following the guidelines of Tranfield et al. (2003). To ensure transparency and replicability, we structured the review in accordance with the recommendations of the PRISMA framework (Page et al., 2021) as illustrated in Figure 1, consisting of the identification of relevant studies, screening for relevance and quality, and systematic extraction and analysis of data.

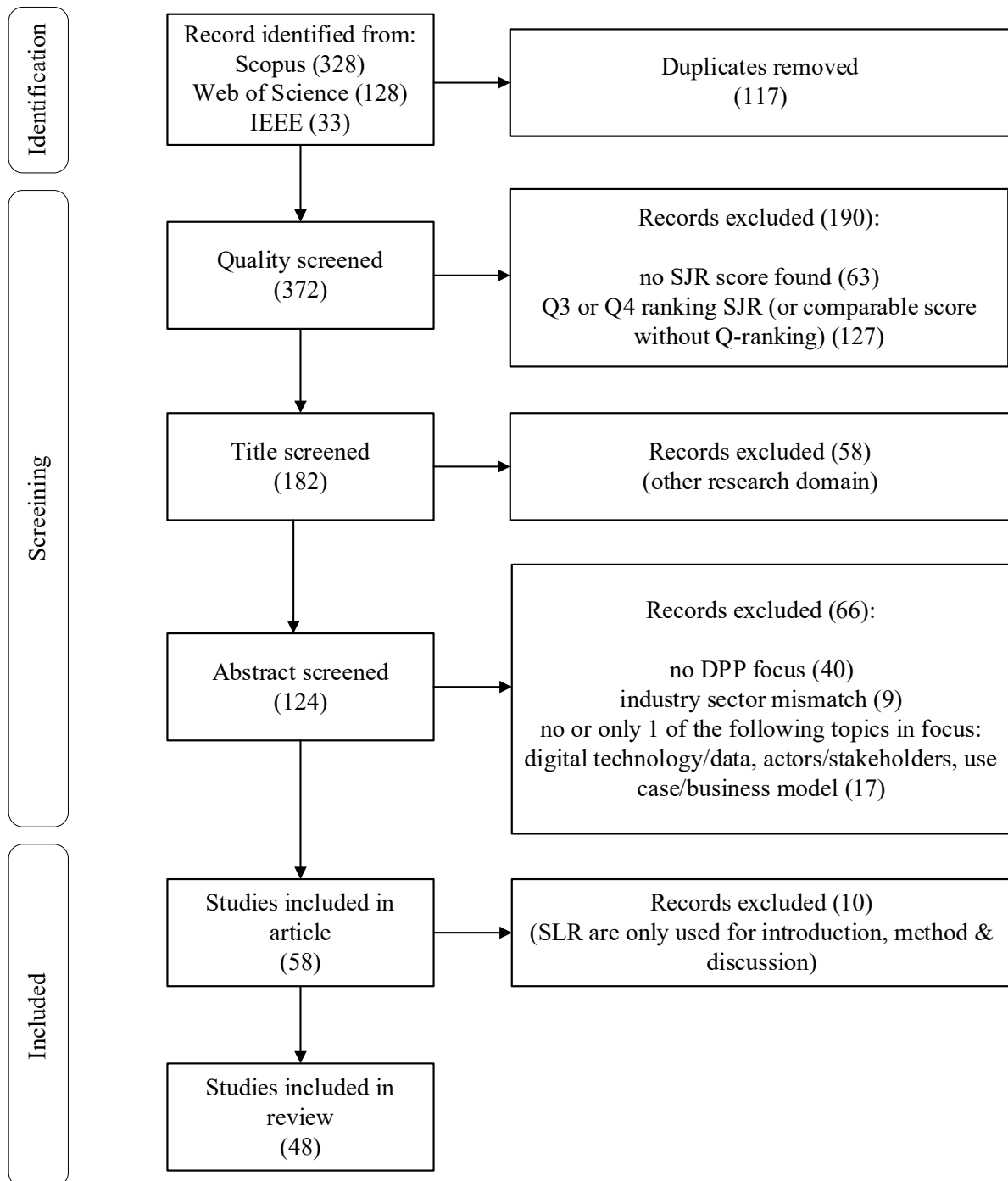


Figure 1. Selection of Articles for Review (Adapted from Page et al., 2021)

2.1. Identification of relevant studies

A systematic search was performed in Scopus, Web of Science and IEEE Xplore in July 2025 using the search string “product passport*” applied to titles, abstracts, and keywords. These three databases were selected because they provide complementary disciplinary coverage across management, engineering, information systems, and sustainability research. The search string aims to include all studies that are either overarching or related to industries that manufacture physical products. Only peer-reviewed journal and conference articles written in English and published from 2019 onward were included, reflecting the emergence of the DPP concept following the European Green Deal (European Commission, 2019). The database search yielded 328

articles from Scopus, 128 from Web of Science, and 33 from IEEE Xplore. After removing 117 duplicates, the initial pool consisted of 372 unique articles.

2.2. Screening and Selection

To ensure relevance and consistency, the authors developed predefined inclusion and exclusion criteria prior to screening. The selection process involved three sequential stages. In the first stage, quality screening, 190 publications from the initial pool of 372 articles were excluded. Studies were evaluated for methodological quality using the Scimago Journal & Country Ranking (SJR). Journals without an SJR score, and studies published in Q3 or Q4 journals (or equivalent) were excluded. In the second stage, title screening, 58 articles were excluded because they did not address at least two of the following three topics: management, digitization, and sustainability. In the third stage, abstract screening, articles were excluded based on three criteria. Forty articles were removed because they lacked a clear focus on DPPs, nine were excluded because their industry context did not match the manufacturing focus, and 17 were excluded because they addressed none or only one of the following dimensions: digital technology, data, actors or stakeholders, and business model or use case. This ensured that the review concentrated on physical products within manufacturing, excluding sectors such as energy, construction, food, mining, and waste management. Following the abstract screening, 66 articles were excluded, leaving 58 for full-text assessment. In addition, to ensure that the synthesis was based on primary empirical evidence, ten systematic literature reviews on DPPs were excluded to avoid duplication of findings. These systematic literature reviews served solely to support the relevance, methodology, and discussion sections of this article. This resulted in a final corpus of 48 articles for inclusion in the systematic review listed in appendix 1.

2.3. Data Extraction and Coding

To analyze DPP-centered circular ecosystems within the selected articles, the study adopted a deductive coding and classification approach based on Adner's (2017) ecosystem-as-structure framework. Adner (2017) defines ecosystems through the alignment of activities around a value proposition, structured by activities, actors, positions, and links. This perspective is particularly suited to the DPP, as it enables a structured analysis of how previously unconnected actors become interdependent through DPP-enabled information flows, jointly contributing to data exchange, compliance processes, and the development of new value propositions around the DPP (Adner, 2017). Alternative ecosystem conceptualizations, such as Moore's (1996) network-centric view, are less applicable in this context because they emphasize only the network of actors rather than the alignment of activities needed to implement the DPP. In contrast, Adner's framework explicitly captures how the DPP reshapes existing value chains by introducing new roles, dependencies, and digitally-mediated interconnections across the ecosystem.

To translate this theoretical perspective into an empirical analysis, the study systematically examined the literature to identify how DPPs manifest within ecosystem structures. In particular, we focused on how ecosystem elements, including activities, actors, positions, and links, align around a central value proposition and how these configurations relate to circular strategies. This required translating Adner's (2017) framework into an operational form to guide the coding process, which is described in the following section to ensure methodological transparency.

The **value proposition** captures the benefits that emerge from ecosystem interactions (Adner, 2017) and was examined through business models and use cases linked to R-strategies. Deductive coding was applied according to the 9R-framework by Potting et al. (2017) to cluster the described business models or use cases. As not all articles explicitly applied the 9R-framework by Potting et al. (2017), the reported applications of the DPP were interpreted within this broader conceptual context and were linked to the ten R-Strategies, thereby demonstrating the system-level value propositions that DPPs offered for the implementation of different circular strategies. For this purpose, the definitions of the R-strategies and the examples provided by Potting et al (2017) were used. The interpretation and subsequent assignment to R-strategies in articles where the 9R-framework was not applied were conducted separately by the authors, and in cases of disagreement, consensus was reached through discussion. Most articles addressed more than one R-strategy, either in different subsections or within a single subsection which, for example, analyzed refurbish and remanufacture together. Fifteen articles did not address a specific R-strategy.

Activities were defined as discrete actions associated with DPP implementation and, in particular, the digital technologies and data-related processes required to support it, while activities limited to physical product handling or service delivery were not considered. The inductively coded activities were subsequently mapped to the DPP solution component framework proposed by Wan and Jiang (2025), which groups DPP-digital-technologies into four subcategories: data carrier, data source, data security, and user access/verification. Our mapping process initially applied these four subcategories as an a-priori structure. During the analysis, however, we identified activities and technologies that could not be meaningfully assigned to any of the predefined subcategories. We therefore expanded the mapping frame inductively by adding two additional subcategories, data discovery and data application, to capture these instances.

Actors were deductively coded based on the classification of DPP-ecosystem-participants by Gieß and Möller (2025), which includes authorities, manufacturers, suppliers, end-of-life-actors, consumers, and DPP. The understanding of the 'DPP as an actor' was expanded to encompass the various technology and service entities operating within the DPP-system (DPP-system-operator). Some actors identified in the literature could not be aligned with those defined by Gieß and Möller (2025), leading to the introduction of the subcategory "others" with 5 coded segments³.

The actor's **positions** within the ecosystem were operationalized as DPP-related-roles, coded inductively and clustered into three subcategories: data providers, data users, and DPP-infrastructure provider, reflecting the different ways actors interact with the DPP-system.

Links were understood as connections between actors through the exchange of data. DPP-data-points were deductively mapped to lifecycle stages (design, take, make, distribute, use, end-of-life (eol), overarching, or not applicable) following Araujo et al. (2025) and were further classified as static (remains unchanged after entry into DPP) or dynamic (changed throughout use or post-use). In case of ambiguity, DPP-data-points were classified as both static and dynamic or several lifecycle stages.

Coding and analysis were conducted using MAXQDA 24 for qualitative analysis and Excel for synthesis, facilitating the identification of patterns, interrelations, and research gaps in the existing body of literature. For a consistent analysis, we identified and separated ecosystem-segments in each article that describe the implementation of the DPP. This approach enabled the systematic examination of how activities, actors, positions, and links align around a value proposition within DPP-centered ecosystems. A coding manual was created at the beginning of the coding process, offering detailed definitions of each element together with illustrative examples. This supported a consistent understanding of each deductive code among the authors.

3. Results

The temporal distribution of publications demonstrates a continuous increase in research activity related to DPPs, as presented in Figure 2. Between 2019 and 2021, only two publications on DPPs were identified. The number of publications increased from two in 2022 to ten in 2023, indicating a substantial rise in research attention. Research output continued to grow, with eleven publications in 2024 and twenty-three in the first seven months of 2025. Notably, these 23 publications represent more than half of the total sample of 48 studies. These developments demonstrate that DPPs have rapidly emerged as a dynamically expanding research field within the broader context of sustainable product development and the circular economy.

³ When referring to segments, parts of an article containing one or more words related to a specific code are considered. For example, in the case of actors, the segment "battery manufacturer" was assigned the subcode manufacturers. For better understanding of the relevance of the number of segments, the number of articles is also detailed within the figures in the results in chapter 3.

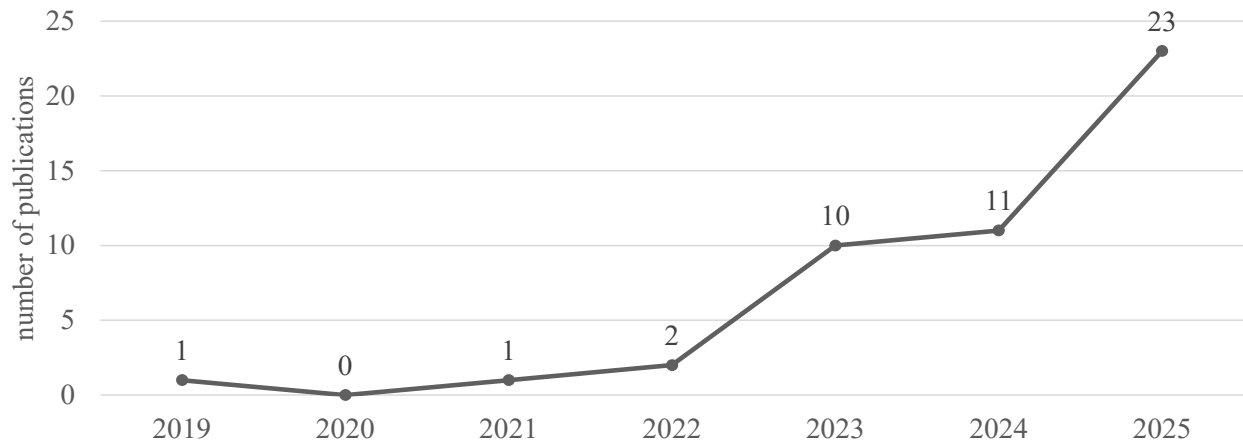


Figure 2. Publications per Year

Examining the industry focus of the selected articles provides insight into the sectors within manufacturing where DPPs are being studied and applied, as illustrated in Figure 3. Nineteen of the 48 articles adopt a cross-industry perspective, without focusing on a specific sector. Among the sector-specific studies, nine examine the fashion and textile industry, seven focus on the automotive sector with an emphasis on electric vehicles, and four articles each address the general manufacturing and electronics industries.

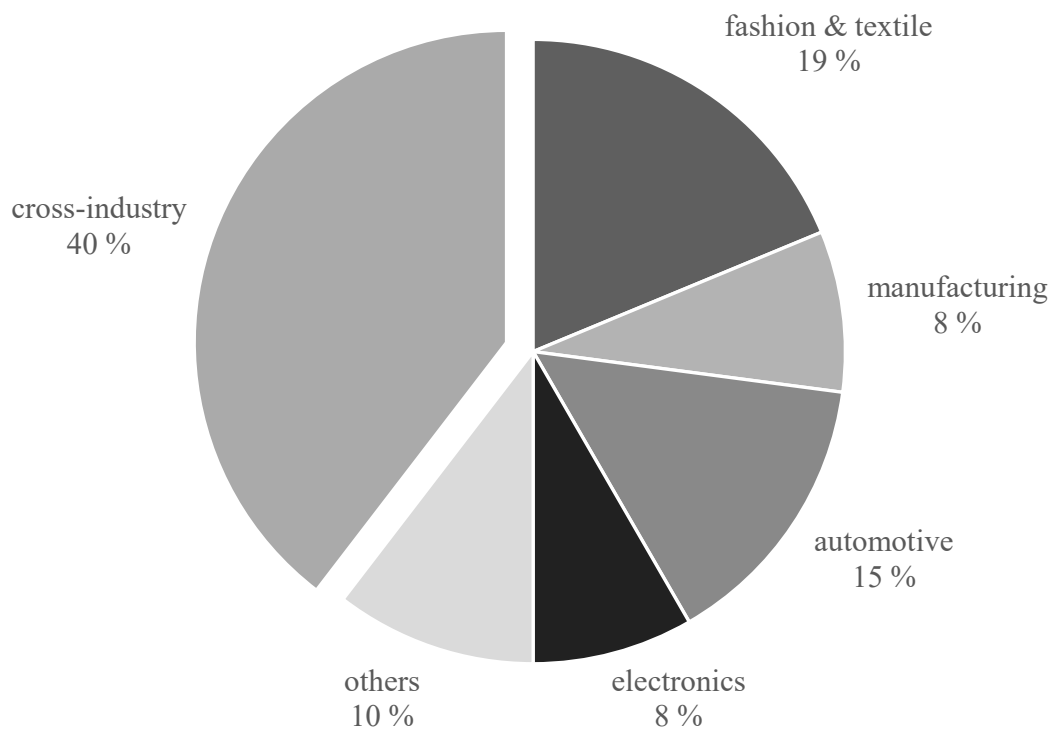


Figure 3. Distribution of (Manufacturing) Industries Covered in the Selected Articles

In the following subsections, all elements relevant to Adner's ecosystem-as-structure theoretical framework are analyzed, forming the focus of this study.

3.1. DPP-value-proposition (Value Proposition)

The DPP-value-proposition lies in their ability to actively support circular strategies across the entire product lifecycle, as evidenced by the coding of specific R-strategies. The *refuse* strategy (n=7) describes a shift toward more eco-friendly materials during product development (Reich et al., 2023). Rethink (n=21) illustrates how

DPPs enable improvements in product design based on insights from the use phase while fostering transparency and promoting sustainable design and usage practices (Ospital et al., 2023). The *reduce* strategy, represented in 37 segments, demonstrates the potential of DPPs to support design optimization, sustainable procurement, predictive maintenance, and the efficient management of post-use processes (Berger et al., 2023; Hakola et al., 2025; Werner et al., 2025).

Prolonging the product lifetime through a second use is a central feature of the *reuse* strategy (n=35). DPPs support this by enhancing transparency and traceability, which enables more informed decisions at the end of a product's first lifecycle (Berger et al., 2023; Jensen et al., 2023; Ospital et al., 2023). Similarly, the *repair* strategy (n=40) is facilitated through DPPs by providing actionable information for disassembly, assessing product condition, and ensuring the availability of spare parts, all of which increase the likelihood and efficiency of repair processes (Krüger et al.; Kühn et al., 2025; Werner et al., 2025). For *remanufacture* (n=48), *refurbish* (n=49) and *repurpose* (n=22), the literature highlights use cases that emphasize disassembly, transparency, traceability, and usage history, reflecting how DPPs can support extended product lifecycles (Berger et al., 2023; Jensen et al., 2023; Ospital et al., 2023).

In the case of *recycle*, disassembly, sorting, post-use decision support, and traceability emerge as dominant themes, all contributing to more efficient and effective recycling processes (Chaudhuri et al., 2025; D'Adamo et al., 2025; Kühn et al., 2025). Notably, recycle is the most frequently observed R-strategy, with 62 segments. The *recover* strategy (n=20) often appears alongside recycle, and is associated with similar themes, including traceability, optimization of end-of-life decisions, and sorting, suggesting that these strategies are closely interlinked in practice (Berger et al., 2023; Kühn et al., 2025; Pulikottil et al., 2025).

Figure 4 shows that DPP research focuses on use and post-use phases, supporting refurbish, remanufacture, and recycle. By contrast, repurpose and pre-use strategies like refuse and rethink are rarely addressed, revealing a gap in early-stage circular interventions.

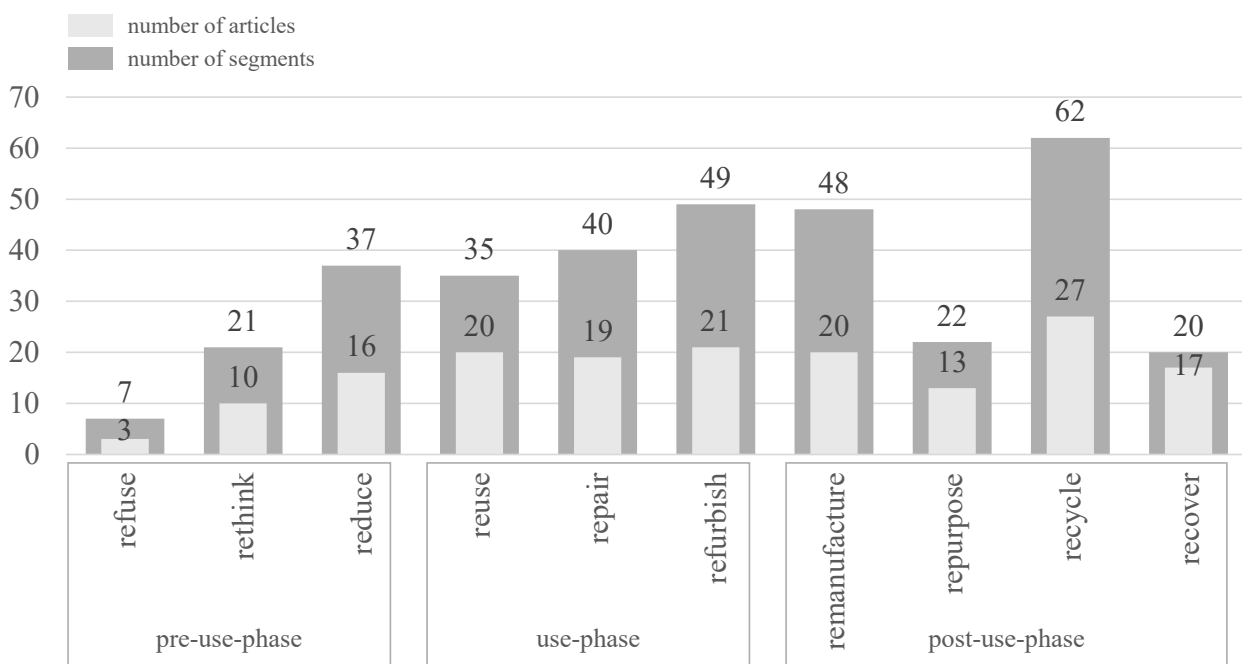


Figure 4. Number of Segments and Articles per R-strategy

3.2. DPP-Digital-Technologies (Activities)

The digital technologies were clustered as solution components of a DPP (Wan and Jiang 2025) with two subcategories added by the authors that emerged during the coding process. Activities describe how actors interact on a digital level to implement R-strategies with the support of a DPP.

Data discovery refers to a set of technologies (e.g. sensors) that is used to collect data from products or processes across the lifecycle and is only found in four segments. It includes data that is created during

production of raw materials as well as information collected during manufacturing or recycling of a product. (Gligoric et al., 2019).

Technologies included in *data source* (n=49) on the other hand are combining different concepts and technologies on how to store and share data. Digital twins emerge as one of the most frequently discussed concepts (n=15) (Pronk et al., 2025), others are the Asset Administration Shell (AAS) (Adisorn et al., 2021), blockchain technology (Domskienė & Gaidule, 2024) and data spaces (Ducuing & Reich, 2023).

The literature highlights *data carriers* (n=41) as a critical link between the physical product and the digital component (DPP) (e.g., QR codes or RFID-tags) (Colasante et al., 2025; Petrik et al., 2025). All technologies referenced are serving to enable the transfer of product information into the digital environment and typically integrated directly into the physical product.

The *user access* subcategory (n=21) comprises technologies and concepts that regulate which ecosystem actor can view or interact with specific product information. Within this subcategory data spaces (n=6) (Kim et al., 2025; Koppelaar et al., 2023) and blockchain solutions (n=8) (Hulea et al., 2024; Kim et al., 2025) are most frequently referenced technologies, primarily for enabling differentiated access rights across actor groups.

The *data security* subcategory (n=21) involves largely the same technologies and concepts as described in the user access subcategory, but here they are discussed in relation to safeguarding product data from unauthorized use (Hulea et al., 2024; Jansen et al., 2023).

To translate DPP information into business value, the literature points to *data application* technologies (n=18). These include e.g. data analytics methods and physical implementations (Kühn et al., 2025; Neri et al., 2025; Werner et al., 2025), all of which support the operationalization of DPP data within products and processes.

Overall, our SLR indicates that the strongest emphasis in the reviewed studies lies on data carriers and data sources as foundational components of DPPs. In contrast, a substantially lower number of contributions address data security, user access, data application technologies, and data discovery technologies (see Figure 5).

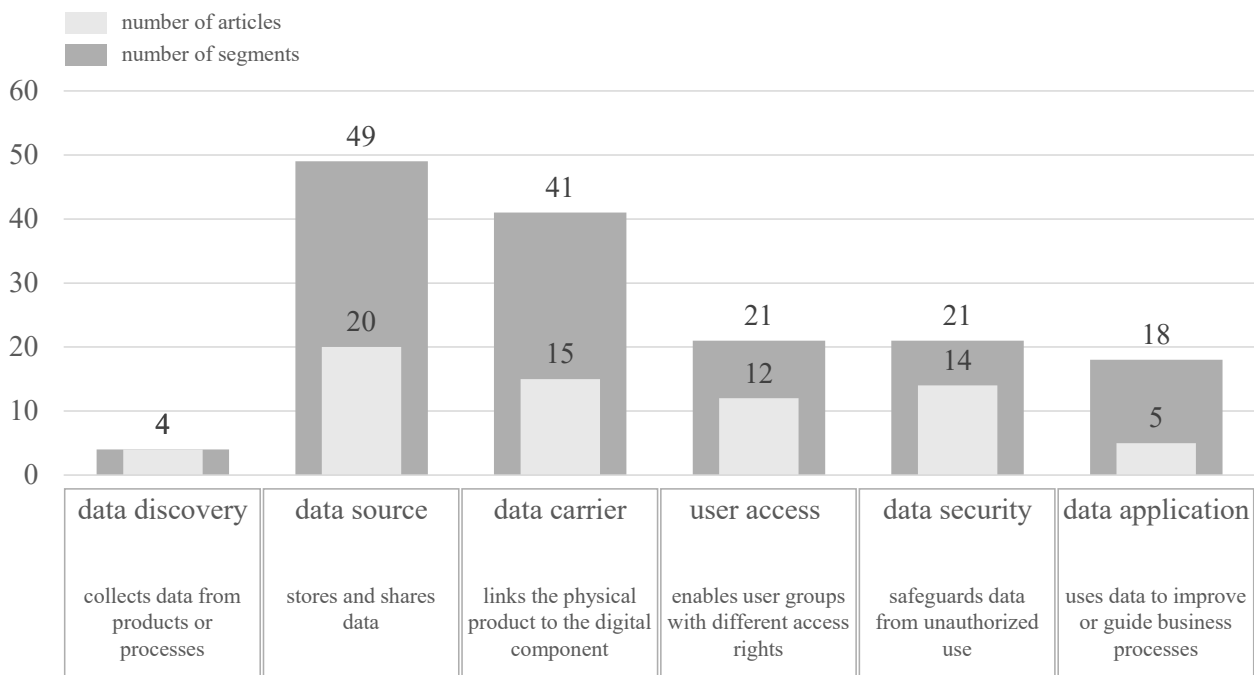


Figure 5. Number of Segments and Articles of DPP-Digital-Technologies

3.3. DPP-Ecosystem-Participants (Actors)

The literature emphasizes a core set of DPP-ecosystem-participants that are consistently positioned as central to the functioning of DPP-centered circular ecosystems. *Manufacturers* are the most frequently referenced group, appearing in 58 segments (Abreu et al., 2025; Kim et al., 2025; Neri et al., 2025). Suppliers,

consumers, and end-of-life-actors also appear prominently. The *supplier* (n=42) subcategory includes a spectrum of actors, spanning from raw material suppliers to component manufacturers (Hakola et al., 2025; Telfort & Valilai, 2025). The *consumer*, predominantly involved in the use phase, appeared in 35 segments (Jensen et al., 2024; Krüger et al.; Telfort & Valilai, 2025). *End-of-life-actors* (n=43) encompass waste managers, brokers, sorting companies, dismantlers, remanufacturers, recyclers, and collector actors (Gleich et al., 2024; Jensen et al., 2024; Koppelaar et al., 2023; Mulhall et al., 2022; Plociennik et al., 2024). *Authorities* (n=8), including legislators, governments, public authorities, and standards organizations (Ducuing & Reich, 2023; Pulikottil et al., 2025), are mentioned more frequently than *DPP-system-operator* (n=5) (Hulea et al., 2024; Kim et al., 2025; Pohlmeier et al., 2024). Further actors, grouped in the subcategory *others* (n=5), include trade federations, auditors, and certifying entities (Abreu et al., 2025; Ducuing & Reich, 2023).

As shown in Figure 6 manufacturers, suppliers, consumers, end-of-life-actors, authorities, DPP-system-operator, and other actors vary in how often they are referenced in the literature. When analyzing links to R-strategies, manufacturers, consumers, and end-of-life-actors emerge as the most significant groups for enabling circular practices. Although suppliers are frequently referenced overall, they are less commonly associated with specific R-strategies. Across all strategies, the highest concentration of links involves recycling, where segments referring to manufacturers, consumers, and end-of-life-actors dominate.

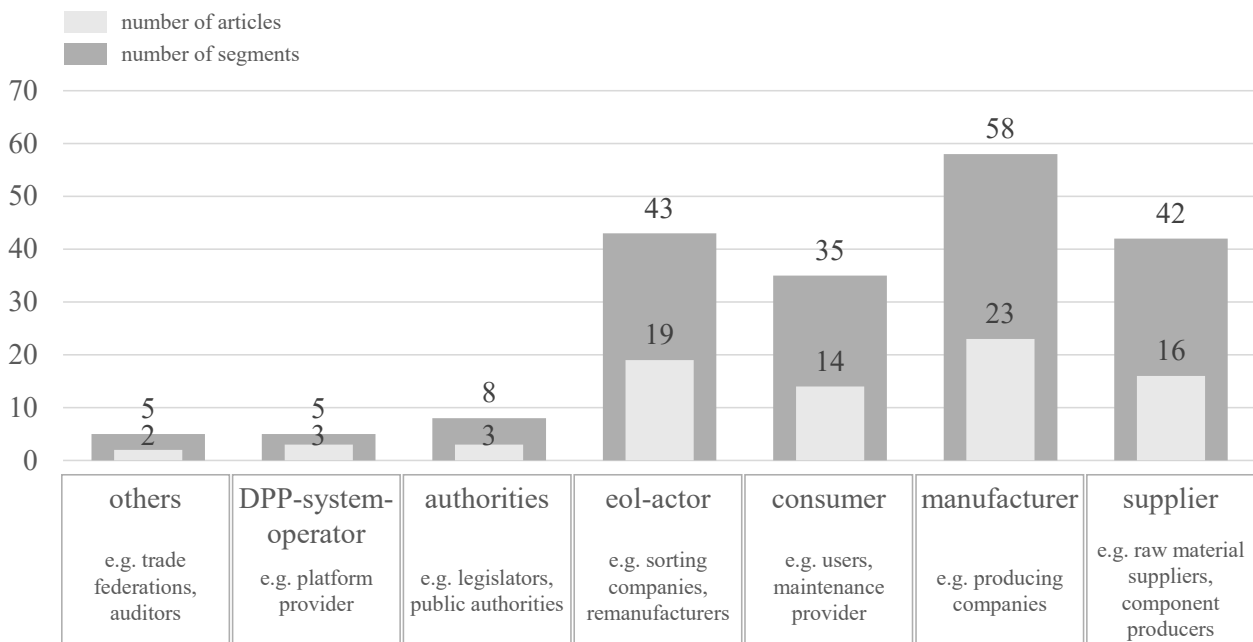


Figure 6. Number of Segments and Articles of DPP-Ecosystem-Participants

3.4. DPP-related-roles (Position)

The analysis of DPP-related-roles reveals distinct patterns in how actors interact with the DPP across the ecosystem. The *data user* emerges as the most prominent role, comprising 54 coded segments, reflecting the centrality of receiving and leveraging product information. Examples from the literature include receiving or consuming data (Hermann et al., 2025), and utilizing metrics for circular decision-making (Pulikottil et al., 2025). *Data providers*, represented by 32 segments, encompasses actors who supply essential product and process information into the DPP. Illustrative examples include registering new products or events on the blockchain (Abreu et al., 2025), providing product data (Pronk et al., 2025), or transmitting data for lifecycle monitoring (Hermann et al., 2025). The *DPP-infrastructure provider* role, with 10 segments, is less frequently highlighted but crucial for enabling the ecosystem. Actors in this role manage the DPP-system and ensure secure operation, including access control (Abreu et al., 2025), system management, and information exchange (Hulea et al., 2024). This role therefore establishes governance mechanisms that define how data is accessed, validated, and used across the ecosystem, ensuring reliability and accountability in DPP-enabled processes (see Figure 7).

When linking actors to DPP-related-roles and R-strategies, clear patterns emerge. Suppliers predominantly take on the data provider role, supporting strategies that rely on accurate product and process information. Consumers primarily act as data users, engaging with the DPP to implement strategies such as reuse, repair, remanufacture, and recycle. Manufacturers are mentioned whenever the DPP-infrastructure provider role is active, but they also participate as data providers and data users, supporting a wide range of R-strategies across the product lifecycle. End-of-life-actors engage in all three DPP-related-roles, with a focus on data user and provider, reflecting their central role in post-use strategies, particularly recycle, recover, and refurbish.

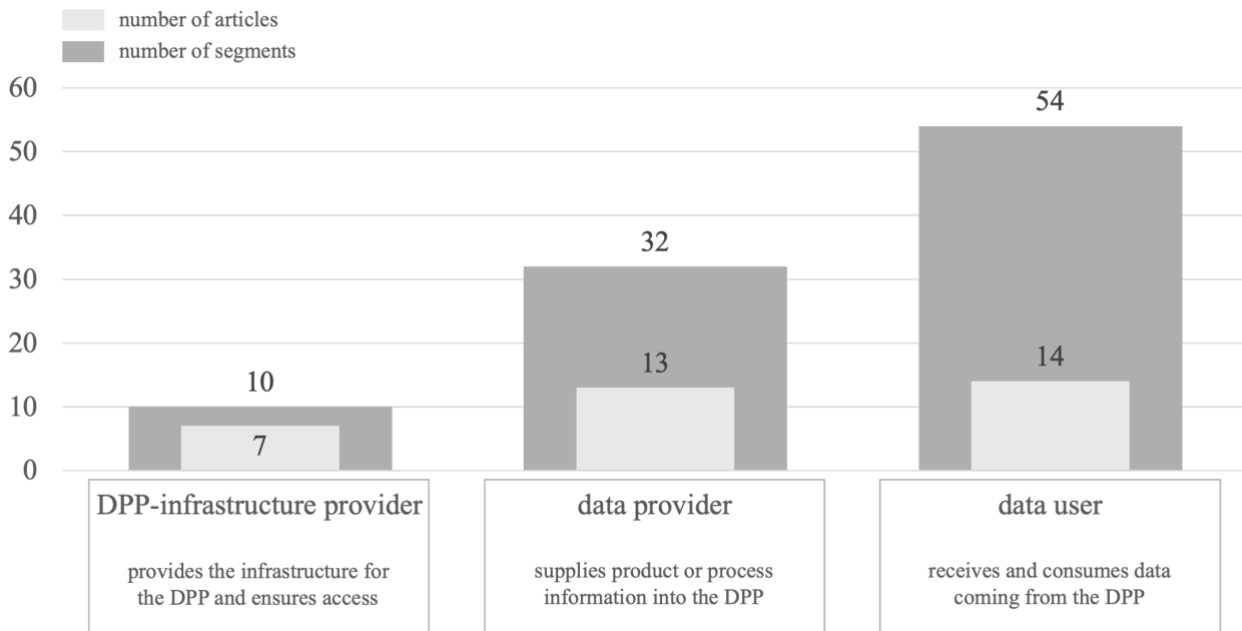


Figure 7. Number of Segments and Articles of DPP-Related-Roles

3.5. DPP-Data-Points (Links)

The analysis reveals 702 DPP-data-points discussed across the literature, with *static information* representing the majority (76%) and *dynamic information* accounting for 28%, alongside a small degree of overlap.

Across lifecycle stages, the *design* phase emerges as the most prominently represented subcategory, comprising 243 segments. The literature highlights design-related information such as product composition (Berger et al., 2023) and spare parts and consumables (Kühn et al., 2025). These data points are predominantly static (79%), reflecting information defined at the beginning of the lifecycle that remains stable. Only 40 data points relate to the *take* stage, mainly addressing compliance-related aspects such as country-of-origin (Jensen et al., 2023). The *make* stage is represented by 91 segments, covering production process information (Colasante et al., 2025; Hermann et al., 2025), packaging (Telfort & Valilai, 2025), and emissions generated during production (Gleich et al., 2024; Kühn et al., 2025). The *distribute* stage shows the lowest representation, with 34 segments, focusing on packaging (Pohlmann et al., 2024), transportation information (Hammadi et al., 2025; Telfort & Valilai, 2025), and carbon footprint (Popowicz et al., 2024). Take, make and distribute data points are mostly static, reflecting the pre-use positioning of this lifecycle phase.

The *use* phase, with 190 segments, contains the second highest number of data points. This subcategory includes use instructions (Gleich et al., 2024), repair and maintenance needs as well as history (Berger et al., 2023; King et al., 2023), state-of-health information (Berger et al., 2023; Krüger et al.) and exposure to external conditions (Jensen et al., 2023). In contrast to previous stages, both static and dynamic data points are present in similar proportions, reflecting that use-phase information changes during operation. The *end-of-life* stage comprises 171 segments, containing information such as disassembly instructions (Jensen et al., 2023), return options (Kühn et al., 2025), end-of-life assessments (Popowicz et al., 2024), and recycling- or material-related data (Hammadi et al., 2025; Koppelaar et al., 2023; Kühn et al., 2025). Although positioned at the end of the lifecycle, this subcategory includes a high share of static information, often originating from the design phase.

The *overarching* subcategory, comprising 116 segments, highlights data that is relevant across the entire product lifecycle rather than tied to a specific stage. This includes general product identifiers such as product name (Hermann et al., 2025), as well as environmental information like carbon footprint (Hammadi et al., 2025) and compliance-related data points (Neri et al., 2025). The presence of these lifecycle-spanning data points demonstrates that DPPs not only capture stage-specific information but also provide overarching insights that support circular strategies throughout the lifecycle. Within the subcategory *overarching*, many segments are also classified as dynamic data, such as updated environmental impact metrics, enabling continuous product monitoring and informed decision-making across different actors and lifecycle phases. Figure 8 provides an overview of the distribution of data points across lifecycle stages.

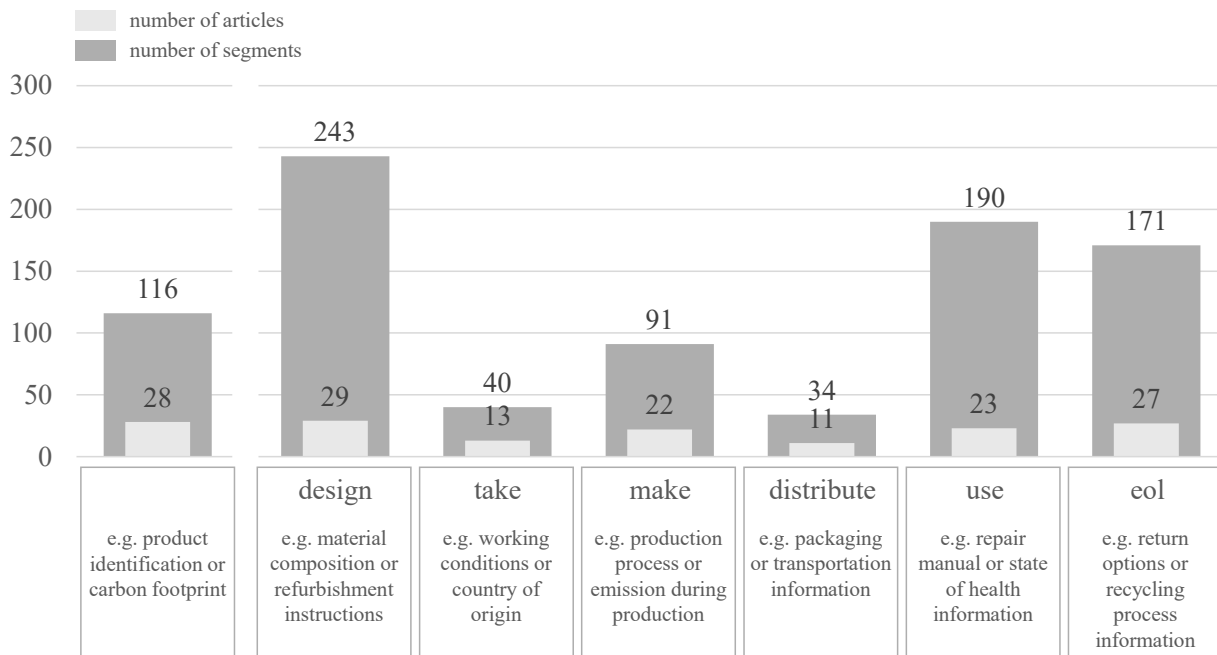


Figure 8. Number of Segments and Articles of DPP-Data-Points across the Product Lifecycle

4. Discussion

The discussion focuses on three main aspects. First, it considers the system-level value propositions, highlighting the predominant focus on post-use strategies and the underexplored potential of pre-use and cross-industry approaches. Second, it addresses data discovery and application and third, it discusses the complexity of actors and their roles. Finally, these insights are integrated into a comprehensive framework for DPP-centered circular ecosystems.

4.1. Broadening Value Propositions

The findings show that current literature links DPP-value-propositions predominantly to post-use strategies, specifically remanufacture, refurbish, and recycle. These R-strategies focus on products after the completion of a lifecycle, reflecting a strong post-use orientation in both research and practice (Kurilova-Palisaitiene et al., 2023). This emphasis likely reflects a narrow perspective in which circularity is primarily associated with managing products at the end of their life to recover materials or extend use through another lifecycle (Kirchherr et al., 2023). Regulatory frameworks, particularly in the automotive sector, may reinforce this orientation (e.g., EU End-of-Life Vehicle Directive (Directive 2000/53, 2000) or the proposed EU regulation on circularity requirements for vehicle design and on management of end-of-life vehicles (European Commission, 2023)). In contrast, pre-use strategies such as refuse and rethink are rarely addressed, indicating that DPPs' potential to influence product design, material selection, and early-stage decision-making is underexplored. This gap likely stems from the product-centric nature of DPPs, which typically become relevant

only after a product concept has been defined (Adisorn et al., 2021; Psarommatis & May, 2024). By that point, the potential for refuse or rethink strategies is limited (Mangers et al., 2021). Expanding the focus toward these strategies is important to fully exploit the potential of DPPs. Use-phase and post-use data captured through DPPs can inform design decisions, reveal which features are actually used, and enable data-driven modification, simplification, or enhancement of products (Popowicz et al., 2024). This supports more customer-centric design and strengthens the foundation for circular business models that prevent waste before it occurs (Skärin et al., 2022). Repurpose is another strategy that remains underrepresented, likely due to limited familiarity or the single-industry focus of much research included in the analysis of this article. Repurpose frequently crosses industry boundaries, such as redeploying electric vehicle batteries for stationary energy storage (Akram & Abdul-Kader, 2024). DPPs play a critical role in enabling repurpose by providing transparent, accessible, and reliable information on product history, state of health, and material composition (Berger et al., 2023). This data allows actors across different industries to assess suitability, plan new applications, and integrate products into new value chains. By facilitating repurpose, DPPs help preserve the highest possible product value within the technical cycle and contribute substantially to resource efficiency (Kurilova-Palisaitiene et al., 2023). Broadening the focus to include repurpose, refuse, and rethink strategies can unlock additional value across the product lifecycle, enhance resource efficiency, and strengthen the contribution of DPPs to truly circular ecosystems.

4.2. Expanding DPP Activities to Discovery and Application

The findings indicate that current research on DPPs predominantly examines core solution components, such as data carriers, sources, and user access (Wan and Jiang 2025). While these components are important, it became apparent that two additional dimensions, data discovery and data application, are critical for understanding how DPPs generate value. Incorporating these dimensions addresses a conceptual blind spot in DPP research, as existing frameworks largely focus on storing, securing, and granting access to data but provide limited insight into how data enters the system and how it is translated into actionable value. In practice, data often exists but remains underutilized or applied only in isolated pilot projects (Azzabi et al., 2024, Bühler et al., 2025). Without systematic integration into decision-making and process optimization, the potential of DPPs to generate value across the product lifecycle remains largely unrealized (Carvalho et al., 2025; King et al., 2023). Literature provides technical examples illustrating how data enters the DPP-system, including sensor-based monitoring of production processes (Hermann et al., 2025) and the collection of disassembly or recycling parameters (Krüger et al., 2025). This data feeds into the DPP-system to support informed operational decisions.

Regulatory and industrial discussions have focused on traceability, interoperability, and standardized exchange formats (Domskienė & Gaidule, 2024; Ducuing & Reich, 2023; Petrik et al., 2025; Piétron et al., 2023; Plociennik et al., 2022; Tortola et al., 2025; Wunderlich et al., 2025), directing research toward data storage and identification. By contrast, data discovery requires alignment with operational processes and often depends on sector-specific infrastructures, limiting generalizability. Data application demands reconfiguration of workflows, decision routines, and cross-organizational collaboration, which presupposes high digital maturity, which is often not achieved throughout the value chain. In fact, companies frequently struggle to collect consistent, high-quality data suitable for downstream analytics (Weber et al., 2017). These findings underline that data discovery and application are not optional but essential for realizing DPP-value-propositions and complying with regulatory requirements. Without reliable capture of necessary data, even the most advanced DPP infrastructures cannot support circular strategies. Similarly, without actionable use, DPPs risk becoming static repositories that offer little improvement to operational efficiency or environmental performance. Finally, the interdependent nature of DPP-centered circular ecosystems becomes evident as also shown in Figure 9. Effective data discovery and application require coordination among manufacturers, service providers, recyclers, and material processors, each contributing at different lifecycle stages (Gleich et al., 2024; Popowicz et al., 2024). Value emerges when actors coordinate their actions and leverage the data effectively across the ecosystem. This highlights that DPPs must be understood not just as technical systems, but as governance-embedded ecosystem tools that coordinate actor behavior and enable actionable insights across the product lifecycle.

4.3. Complexity of Actors and Their Roles

Building on the interdependent nature of DPP-centered circular ecosystems, the findings show that manufacturers, consumers, and end-of-life-actors dominate current literature, reflecting the strong focus on use-phase and post-use applications. The DPP acts as a central enabler by structuring how data is collected, shared, and applied across the product lifecycle. Importantly, this role is not limited to explicit technical functions. The DPP also incorporates implicit data governance mechanisms that influence how actors exchange and work with product-related information. These mechanisms help to ensure that data shared through the DPP infrastructure is reliable, accessible, and usable for analysis. These qualities are essential for supporting data-driven operational and circularity-related decisions across the value network. In this matter, our findings show that suppliers and other upstream actors are less frequently discussed in the literature, usually reduced to the role of data providers. A broader perspective highlights that suppliers could take on more active roles by leveraging use-phase and end-of-life data shared through the DPP infrastructure. With reliable and accessible lifecycle data, they could integrate this information into component design, develop predictive algorithms for durability or maintenance, and support refuse or rethink strategies. Effective coordination, guided by suitable governance rules, is necessary to ensure that this data remains trustworthy and actionable across the ecosystem (Ducuing & Reich, 2023). End-of-life-actors are often treated as a single, undifferentiated subcategory, despite performing a wide range of activities including collection, sorting, dismantling, remanufacturing, and recycling (Fendt et al., 2026). In doing so, they generate valuable data that other ecosystem actors require to implement higher-level R-strategies (e.g., refuse or rethink strategies). The DPP can make this data accessible to the broader ecosystem through governance mechanisms, including standardized protocols for data capture, validation, and sharing. These mechanisms ensure that data remains consistent not only for end-of-life-actors but also for suppliers and other upstream actors, supporting accurate feedback loops of the data and enabling its effective use (e.g., actionable information) throughout the ecosystem (Gleich et al., 2024; Tortola et al., 2025). Our findings also indicate that actors frequently take on multiple, heterogeneous DPP-related-roles (see figure 9). For example, consumers can act as data users, manufacturers as data providers and DPP-infrastructure providers, and end-of-life-actors as both data users and providers.

The heterogeneity and multiplicity of roles make it necessary to determine who can access, modify, or analyze data, representing a key governance challenge that the DPP must address. By establishing clear governance rules, the DPP preserves data integrity and ensures that information generates value through exchanges between data providers and data users. This sharing of data enables coordinated decision-making across the ecosystem, which is particularly important for implementing higher-level R-strategies (e.g., refuse or rethink) (Gleich et al., 2024; Tortola et al., 2025). The multiplicity of roles, however, introduces potential conflicts of interest. For example, if an actor simultaneously serves as a DPP-infrastructure provider and a data user, they could gain an unfair advantage by shaping governance rules to their own benefit. To mitigate this risk, the role of the DPP-infrastructure provider should ideally be assumed by a neutral entity rather than a manufacturer or supplier.

Integrating the complexity of actors and their roles with a governance-oriented perspective highlights the broader potential of the DPP as a lifecycle-spanning tool that translates complex actor interactions and data flows into actionable insights, facilitating more circular, efficient, and responsive product systems (Hakola et al., 2025; Hammadi et al., 2025).

4.4. Integrated framework for a DPP-centered circular ecosystem

When building a DPP-centered circular ecosystem in which R-strategies are implemented, several interdependent components as recommended by Adner (2017) must be considered: system-level value propositions (i.e., coordinated or aligned R-strategies among ecosystem partners), activities (e.g., digital technologies), positions (e.g., DPP-related-roles), and links (e.g., DPP-data-points). Based on the findings of this study, we developed an integrated framework shown in figure 9. The framework operationalizes these components through subcategories and visualizes how they interact. By integrating all components and their interrelations, the framework provides a structured guide for designing, evaluating, and comparing DPP-centered circular ecosystems in both academic and practical contexts.

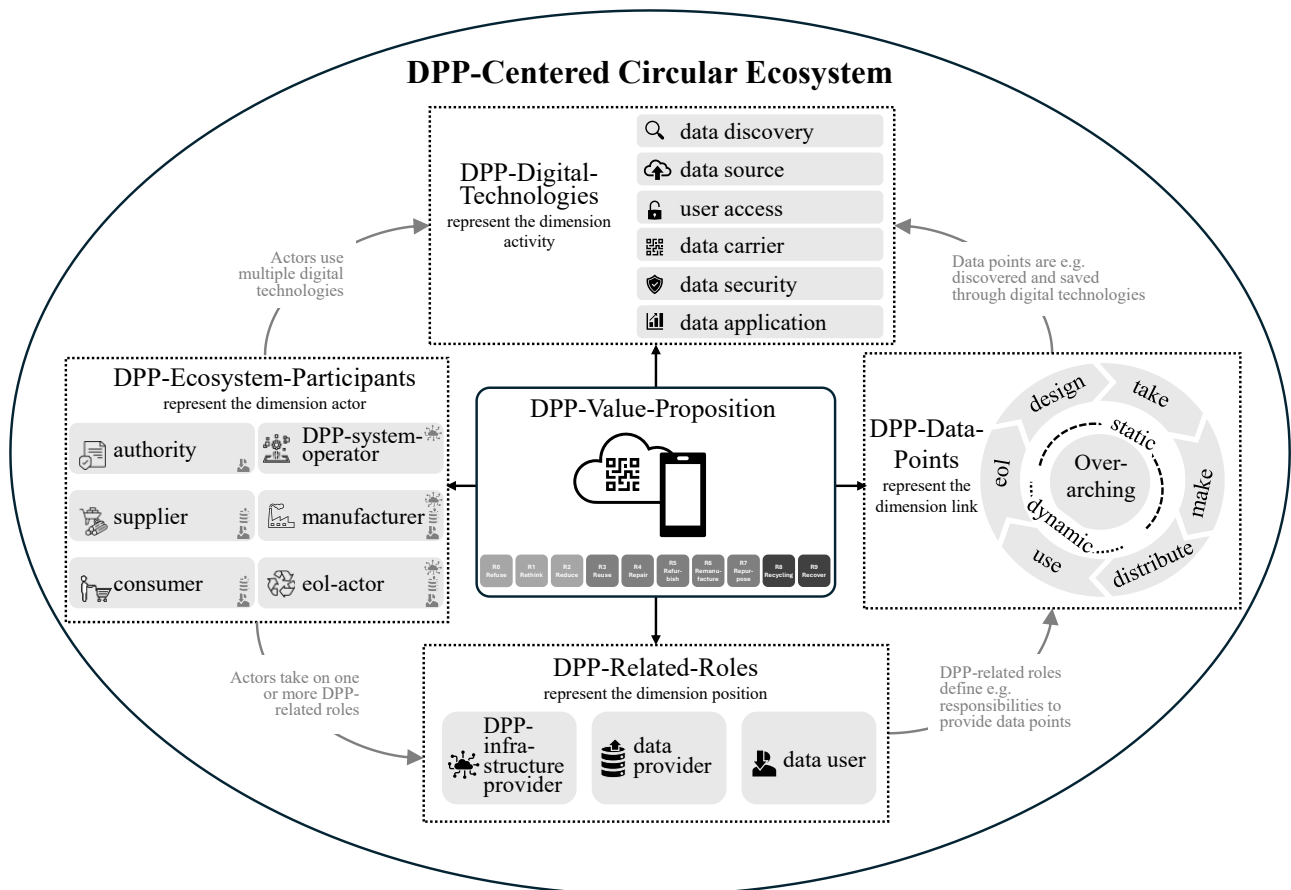


Figure 9. Integrated framework of a DPP-centered circular ecosystem from an ecosystem as structure perspective

5. Conclusion

This systematic literature review examined how DPP-centered circular ecosystems implement R-strategies through the interplay of digital technologies, ecosystem participants, roles and data points, drawing on Adner's ecosystem-as-structure concept (Adner, 2017). By synthesizing existing literature, the study provides an integrated framework for understanding how DPPs can support circular value creation across the product lifecycle.

5.1. Managerial implications

The findings have several important implications for different stakeholders involved in DPP development and implementation. First, they highlight the need to broaden the perspective on DPPs, recognizing their potential to support pre-use R-strategies, such as refuse and rethink, along with including upstream actors, such as suppliers. This offers the greatest opportunities for maximizing circular value. Rather than focusing exclusively on use and post-use applications, product managers and product designers should consider how DPPs can inform early-stage decisions in design, material selection, and product functionality, positioning DPPs as strategic tools that translate distributed lifecycle data into actionable insights, guiding decisions from design to end-of-life and integrating upstream actors and processes to optimize circular outcomes.

For operational and technical roles, such as DPP implementation specialists, IT managers, and data engineers, the results emphasize that designing a DPP system is not solely a matter of technical architecture. They also need to explore practical ways to capture and discover relevant data across the lifecycle, taking into account the complexity of actor roles, and understanding how to apply this data effectively to guide decisions. This includes identifying critical data points, determining who can access and act on them, and establishing processes to translate insights into actionable measures.

Effective management also requires robust data governance. Managers should define clear responsibilities for data provision, access, and usage, establish rules for quality assurance and validation, and ensure compliance with legal and organizational standards.

5.2. Theoretical contributions

The primary theoretical contribution of this study lies in applying Adner (2017)'s ecosystem-as-structure concept to the context of DPP-centered circular ecosystems, offering a coherent analytical lens for understanding how actors, digital technologies, and data collectively enable circular value creation. By conceptualizing the joint ecosystem value proposition as a set of aligned R-strategies, the study reframes circular strategies as the core value logic that structures ecosystem activities, actor roles, and technological requirements.

Furthermore, this study reconceptualizes DPP-related activities as digital technologies across the product lifecycle that enable R-strategies. By extending Wan and Jiang's (2025) framework to include data discovery and data application, we highlight that realizing DPP value requires not only secure storage and controlled access but also systematic data capture and meaningful use. Our findings reveal that existing DPP research often adopts narrow system boundaries, focusing on core components while overlooking lifecycle-spanning activities. By mapping these interactions, we provide a foundation for future research to examine how digital technologies support circularity, operational optimization, and cross-organizational coordination, bridging the gap between infrastructure-focused studies and tangible environmental and business outcomes.

A third theoretical contribution emerges from conceptualizing positions as DPP-related-roles and links as DPP-data-points within the ecosystem structure. This perspective highlights the plurality and variability of actor responsibilities: ecosystem participants may simultaneously function as data providers, data users, and infrastructure provider, depending on the use case, lifecycle phase, and the joint system-level value proposition. Recognizing this complexity advances theoretical understanding by portraying DPP-centered circular ecosystems as dynamic, interdependent socio-technical systems rather than static constellations of predefined actors.

5.3. Limitation

This study is subject to several limitations that stem from both methodological choices and the developmental stage of the research field. First, research on DPPs remains an emerging domain, resulting in a relatively small and fragmented body of publications. Grey literature, including outputs from large-scale EU research projects, were not included. This prioritized conceptual rigor and methodological quality but might have excluded most recent developments. Second, while this study examines manufacturing industries such as batteries, electronics, and textiles, it does not address sectors such as construction, where DPP initiatives are gaining traction. Third, much of the existing literature remains conceptual or exploratory, with limited empirical validation. As a result, this review is primarily informed by proposed architectures, anticipated actor roles, and hypothetical use cases rather than systematically evaluated real-world implementations. A final limitation concerns technical aspects of DPP implementations that were beyond the scope of this review.

5.4. Further research

Future research should build on the conceptual and empirical insights from this study to advance our understanding of DPPs as strategic, socio-technical tools for circular value creation. First, studies should explicitly investigate pre-use R-strategies, including refuse and rethink, as well as underrepresented R-strategies as repurpose, which remain underexplored relative to the other strategies. Second, research should deepen the examination of DPP activities beyond traditional data storage and access. In particular, mechanisms of data discovery and data application require systematic investigation: how data is captured across production, use, and post-use, how it flows across actors and systems, and how it is leveraged to generate actionable insights that shape circular strategies. This research should explicitly incorporate trust dynamics, including how trust between ecosystem actors is established, maintained, and mediated through the DPP. Finally, future studies should explore the integration of DPPs with technical and semantic standards, such as Asset

Administration Shells and data models, to investigate how semantic interoperability and standardized representations of product and lifecycle information can enhance DPP effectiveness.

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Data Availability Data availability is not applicable to this article as no new data were created or analyzed in this study.

Declarations

Competing Interests The authors declare no competing interests.

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Appendices

Appendix 1. List of articles included in SLR

Author	Year	Titel	Journal / Conference
Abreu et al.	2025	Blockchain-based digital product passport: design principles and demonstration	Journal
Adisorn et al.	2021	Towards a Digital Product Passport Fit for Contributing to a Circular Economy	Journal
Berger et al.	2023	Data requirements and availabilities for a digital battery passport – A value chain actor perspective	Journal
Büchel & Neligan	2025	Digital Product Passport: Finding the Right Balance Between Transparency for Circularity and Added Red Tape	Journal
Chaudhuri et al.	2024	Impact pathways: digital product passport for embedding circularity in electronics supply chains	Journal
Colasante et al.	2025	Environmental Concerns in the Fashion Industry: A Twin Transition With the Digital Product Passport	Journal
D'Adamo et al.	2025	An Integrated Business Strategy for the Twin Transition: Leveraging Digital Product Passports and Circular Economy Models	Journal
Domskiene & Gaidule	2024	An overview of technological challenges in implementing the digital product passport in the textile and clothing industry	Journal
Ducuing & Reich	2023	Data governance: Digital product passports as a case study	Journal
Gleich et al.	2024	An Asset Administration Shell-Based Digital Product Passport as a Gaia-X Service	Conference
Glligoric et al.	2019	SmartTags: IoT Product Passport for Circular Economy Based on Printed Sensors and Unique Item-Level Identifiers	Journal
Gösken	2025	Fashioning Authenticity: How Digital Product Passports could shape the future of trade mark law	Journal
Hakola et al.	2025	Smart Tags as Enablers for Digital Product Passports in Circular Electronics Value Chains	Journal
Hammadi et al.	2025	CEF-DPP: A Circular Economy Framework Integrating Digital Product Passport for Improving Circularity of Sustainable Mechatronics Design	Journal
Haupt et al.	2024	Derivation of requirements for life cycle assessment-related information to be integrated in digital battery passports	Conference
Hermann et al.	2025	Digital product passport enabled production control in the context of circular economy	Conference
Hulea et al.	2024	Digital Product Passport Implementation Based on Multi-Blockchain Approach with Decentralized Identifier Provider	Journal
Jansen et al.	2023	Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems	Journal
Jeganathan & Szymkowiak	2025	Bridging Digital Product Passports and in-store experiences: How augmented reality enhances decision comfort and reuse intentions	Journal
Jensen et al.	2023	Digital product passports for a circular economy: Data needs for product life cycle decision-making	Journal
Jensen et al.	2024	An ecosystem orchestration framework for the design of digital product passports in a circular economy	Journal

Appendix 1 (cont.). List of articles included in SLR

Author	Year	Titel	Journal / Conference
Kim et al.	2025	A Blockchain-Based Digital Product Passport System Providing a Federated Learning Environment for Collaboration Between Recycling Centers and Manufacturers to Enable Recycling Automation	Journal
King et al.	2023	A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns	Journal
Koppelaar et al.	2023	A Digital Product Passport for Critical Raw Materials Reuse and Recycling	Journal
Krüger et al.	2025	Ensuring Usefulness: Socio-Technical Design Principles for Digital Product Passports	Conference
Kühn et al.	2025	Digital Product Passport Design Supporting the Circular Economy Based on the Asset Administration Shell	Journal
Langley et al.	2023	Orchestrating a smart circular economy: Guiding principles for digital product passports	Journal
Mulhall et al.	2022	The Product Circularity Data Sheet—A Standardized Digital Fingerprint for Circular Economy Data about Products	Journal
Neri et al.	2025	Fostering lithium-ion battery remanufacturing through Industry 5.0	Journal
Niederhausen et al.	2025	Metrology and the quality infrastructure for the Digital Product Passport	Journal
Ospital et al.	2023	Toward product transparency: communicating traceability information to consumers	Journal
Petrik et al.	2025	A Maturity Model for Digital Product Passports: A Design Science Study	Journal
Pietron et al.	2023	Digital circular ecosystems: A data governance approach	Journal
Plociennik et al.	2022	Towards a Digital Lifecycle Passport for the Circular Economy	Conference
Plociennik et al.	2024	Connecting Producers and Recyclers: A Digital Product Passport Concept and Implementation Suitable for End-of-Life Management	Conference
Pohlmann et al.	2024	Conceptualization of a digital product passport to enable circular and sustainable automotive value chains – the combustion engine use case	Conference
Pohlmann et al.	2025	Digital product passports for electric vehicle batteries: Stakeholder requirements for sustainability and circularity	Journal
Pohlmeyer et al.	2024	A Sovereign and Interoperable Data Ecosystem for an Eco-Efficient Nonwovens Industry	Journal
Popowicz et al.	2024	Circular and sustainable battery design – The case of digital product passports as information providers during the design phase	Conference
Popowicz et al.	2025	Digital Product Passports as Information Providers for Consumers - The Case of Digital Battery Passports	Journal
Pronk et al.	2025	Evolving product passports for effective and efficient (re)commissioning	Conference
Pulikottil et al.	2025	Ease of robotic disassembly metric and information for digital product passports in flexible remanufacturing systems	Journal
Reich et al.	2023	Defining the goals of Product Passports by circular product strategies	Conference
Tabata & Tsai	2025	The Role of Life Cycle Assessments in Digital Product Passport Implementation for Building a Plastic Circular Economy	Journal
Telfort & Valilai	2025	A Framework for Sustainable Textile Waste Management using Digital Product Passports and Artificial Intelligence	Conference

Appendix 1 (cont.). List of articles included in SLR

Author	Year	Titel	Journal / Conference
Tortola et al.	2025	Authenticated data visualization for hybrid blockchain-based digital product passports	Journal
Werner et al.	2025	Modular Digital Twin – an approach for generating and exploiting product sustainability information towards service-oriented business models	Journal
Wünderlich et al.	2025	How to use emerging service technologies to enhance customer centricity in business-to-business contexts: A conceptual framework and research agenda	Journal