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Adopting Digital Product Passports in Supply Chains: Insights from the ABCDE Model and Sectoral Comparisons

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Abstract. This paper examines the adoption of Digital Product Passports (DPPs) as enablers of transparency, traceability, and circularity across supply chains. It aims to clarify what Antecedents, Barriers, Challenges, Drivers, and Effects shape DPP deployment in light of emerging EU regulations such as the Green Deal and the Ecodesign for Sustainable Products Regulation (ESPR). A systematic literature review was conducted to synthesize insights from journal papers published between 2020 and 2025. The review integrates the Technology–Organization–Environment (TOE) lens with the ABCDE Model to examine DPP evolution and implementation across industries. Findings show that antecedents include regulatory mandates, circular economy ambitions, and technological advancements. Barriers and Challenges relate to data fragmentation, interoperability gaps, organizational resistance, and inconsistent legislation. Drivers emerge from sustainability priorities, compliance requirements, and digital innovation. The resulting Effects include enhanced traceability, transparency, and resilience, yet issues persist around governance complexity and SME readiness. Sectoral comparisons reveal divergent regulatory timelines and data priorities spanning from technical standardization, consumer transparency, to repairability and recyclability. This paper contributes a systematic synthesis of the fragmented DPP literature, proposing the ABCDE Model as a comprehensive model for assessing socio-technical and regulatory readiness. Hence, offering the first integrated application of the ABCDE and TOE frameworks to DPP research. It highlights research gaps in interoperability, data governance, and human-centric integration, guiding future policy and practice toward Industry 5.0 objectives of sustainability, inclusivity, and resilience.

Keywords: Digital Product Passport, Circular Economy, Supply Chain Transparency, ABCDE Model, ESPR.

1. Introduction

In recent years, the pursuit of sustainability has reshaped how industries design, produce, and manage products across their lifecycles. Among emerging paradigms, the Circular Economy (CE) has become a cornerstone of sustainable industrial transformation, promoting a shift from the traditional linear “make-use-dispose” model to one that emphasizes resource efficiency, reuse, and product longevity [1–3] . This transition aims to decouple economic growth from resource consumption by ensuring materials remain in circulation for as long as possible.

However, realizing the CE vision requires more than design and policy innovation; it demands systematic management of product information across the entire value chain [1]. In practice, organizations continue to face Challenges such as fragmented, inaccessible, or inconsistent product data, which hinders their ability to achieve circular outcomes [4–6]. Parallel to these sustainability efforts, digital transformation has begun reshaping industrial value chains through technologies such as the Internet of Things (IoT), blockchain, and digital twins. These technologies enable continuous tracking, verification, and simulation of data throughout the product lifecycle [7–9]. Digitalization enables innovative tools that operationalize transparency and traceability, such as the Digital Product Passport (DPP). When oriented to circular-economy objectives, these tools prioritize data on durability, repairability, and recyclability [10,11].

DPPs are structured digital records that consolidate lifecycle information on products, including their origin, composition, performance, maintenance, and end-of-life options [5,12–14]. Earlier tracking mechanisms such as barcodes, RFID tags, and proprietary databases, provided limited interoperability and lacked cross-sectoral visibility [4,15]. Building on these systems, DPPs address the limitations by creating a common system for collecting, storing, and sharing data, improving transparency and traceability in global supply chains [6,16]. Data silos at the firm, industry, or national levels often prevent effective monitoring of environmental performance, ethical sourcing, and regulatory compliance [6,17]. The urgency of DPP adoption has been further heightened by emerging regulations; most notably, the European Union’s Ecodesign for Sustainable Products Regulation (ESPR) [12], which mandates digital product-level transparency to support CE implementation [18].

Within this regulatory and technological context, DPPs serve as strategic enablers of sustainability, transparency, and traceability. They integrate life-cycle assessment (LCA) data to support carbon reduction and resource efficiency [12,13,19]; ensure accessible and verifiable information for regulators, businesses, and consumers [4,5]; and enable product-level traceability across multiple lifecycles, aiding recyclers and improving resilience to disruptions [6,15,16].

Given the new introduction of the DPP by the European Union in 2020 [10], and despite the growing interest, the research landscape on DPPs remains fragmented and exploratory, with limited integration across technological, regulatory, and sectoral dimensions. Consequently, there is a need for systematic synthesis to identify the Antecedents, Barriers, Challenges, Drivers, and the overall Effects of the DPP adoption. This is important to clarify how DPPs can effectively advance circularity within supply chains and what dimensions shape their adoption. In this context, this paper conducts a Systematic Literature Review on DPP implementation across industries. It synthesizes existing insights on DPPs, material passports, battery passports, and related systems, and organizes findings using the ABCDE Model, analyzing Antecedents, Barriers, Challenges, Drivers, and Effects. Furthermore, it compares sectoral pathways across different industries to reveal differences in regulatory timelines, data requirements, and implementation Challenges. Finally, the study proposes a research agenda for scholars and actionable implications for policy and practice, offering guidance for advancing DPP integration in support of circular and transparent supply chains.

Accordingly, this paper aims to consolidate fragmented DPP research using the ABCDE framework to identify factors influencing DPP adoption. The study, therefore, examines the following research questions:

- RQ1: How have DPPs emerged, and what regulatory milestones and earlier technologies underpin their development?

- RQ2: What are the technological, organizational, and environmental Antecedents, Barriers, Challenges, Drivers, and Effects of DPP implementation reported across sectors?

The following sections of this paper are organized as follows. Section 2 describes the research methodology and review process. Section 3 outlines the theoretical frame of reference, while Section 4 presents the main findings covering DPP evolution, regulatory, technological, and organizational dimensions. Section 5 discusses the implications for policy and practice, and Section 6 concludes with key insights and future research directions.

2. Methodology

This study employed a Systematic Literature Review, adapted from the evidence-informed framework of [20]. This method was selected as it provides a structured, transparent, and replicable process for synthesizing heterogeneous bodies of research, while minimizing bias and enhancing rigor [20]. The review was conducted in three stages: planning, conducting, and synthesizing [20]. By combining systematic selection, quality appraisal, and thematic integration, this method established a comprehensive and reliable evidence base to advance both academic understanding and practical insights into the implementation and future path of DPPs. Starting with planning, a review protocol was defined to examine the emerging concept of DPPs, and synthesize their regulatory milestones, earlier technological developments, and the main implementation factors across sectors.

The inclusion criteria comprised (i) peer-reviewed journal articles; (ii) explicit coverage of DPPs, or related approaches such as material passports or battery passports, where insights were transferable; and (iii) studies published between 2020 and 2025, a period aligned with the regulatory rise of DPPs in the European Union. However, to capture the evolution dimension (RQ1), backward snowballing was used to locate pre-2020 foundational works, which were reviewed as a supplementary set. Additionally, the policy briefs from the European Commission were reviewed to contextualize the regulatory landscape and expectations linked to forthcoming legislation. On the other hand, the exclusion criteria eliminated non-academic sources (reports, news articles), publications with only passing mention of passports, and purely technical papers lacking relevance to product lifecycle or sustainability contexts.

A total of 210 studies were initially identified through Scopus, as illustrated in Figure 1. After applying the inclusion and exclusion criteria, this number was narrowed down to 124 studies, which were further screened for quality and relevance. Following full-text assessment, 60 studies were finally selected for in-depth analysis. The timeline for the reviewed articles is presented in Appendix 1: Timeline of the reviewed articles. The papers spanned diverse sectors, reflecting the cross-sectoral nature of DPP applications. Each study was subjected to a quality appraisal assessing methodological robustness before being coded through structured data extraction (authors, year, title, method, context, and findings/contributions). The extracted data were thematically coded, yielding key clusters enabling the discussion about DPPs' evolution, application across supply chain stages, relevance to the regulatory landscape, connection with technological advancement, and data requirements. This thematic synthesis enabled mapping the evolution of DPP adoption, from early conceptual discussions (2020–2021) exemplified by [14,21], through pilot implementations (2022–2023) in papers such as [4,16], toward sectoral deployment and regulatory embedding (2024–2025) as in [5,6]. To interpret adoption dynamics, the TOE (Technology–Organization–Environment) framework was applied [22], as it provides a widely used theoretical lens for explaining technology adoption, helping to identify Antecedents, Barriers, Challenges, Drivers, and Effects shaping DPP uptake across contexts.

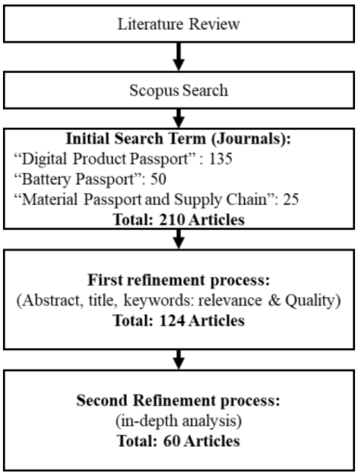

Figure 1. Used Methodology

3. Methodology

3.1 The ABCDE Model

The ABCDE Model, as followed by [23], offers a comprehensive framework for analyzing supply chain visibility by integrating fragmented insights into a balanced structure. It encompasses five components: Antecedents, which trigger organizational engagement; Barriers, factors currently too difficult to overcome and that may block implementation; Challenges, difficult yet tractable issues that can be mitigated with appropriate resources or design; Drivers, denoting motivating incentives; and Effects, capturing performance and relational outcomes.

The model's strength lies in its holistic view, combining enabling factors, obstacles, and results within a single analytical lens [23]. Subsequent studies have adopted the ABCDE Model to examine transparency and sustainability issues, such as [24], who applied it in the agri-food sector to categorize factors influencing sustainability-oriented visibility. This growing application highlights its versatility as a generalizable framework for examining complex visibility dynamics across regulatory, technological, and organizational dimensions [23,24]. Given the similar nature of DPP related to data sharing and visibility, the ABCDE Model provides a valuable foundation for understanding the multifaceted factors shaping DPP adoption, where similar dynamics of transparency, data integration, and regulatory compliance are at play.

3.2 Technology–Organization–Environment (TOE) framework

The Technology–Organization–Environment (TOE) framework, developed by [22], explains how the adoption of technological innovations within organizations is influenced by three key contexts: the technological, organizational, and environmental contexts. The technological context relates to the characteristics of the technology and the existing technological infrastructure; the organizational context includes factors such as firm size, managerial structure, and available resources; while the environmental context encompasses external pressures such as market competition, regulatory environment, and support from technology providers [25]. The framework is widely recognized for its flexibility and applicability across different industries, as it allows researchers to adapt contextual variables to specific technologies and sectors [26].

Despite its broad utility, the TOE framework has been criticized for its generality and for lacking explicit mechanisms describing how the contexts interact [26]. Nevertheless, as [27] notes, TOE remains a valuable lens for examining organizational adoption of emerging technologies, such as DPPs, because it captures the interplay among technological capabilities, organizational readiness, and regulatory drivers that shape firms' implementation decisions.

4. Results

This section presents the findings of the systematic literature review, structured around the ABCDE framework supported by the TOE perspective. The results synthesize insights that highlight how regulatory, technological, and organizational factors collectively shape the adoption of DPPs. The analysis begins by tracing the evolution of DPPs and their policy underpinnings, then examines the regulatory, technological, and organizational landscapes that influence their deployment. Subsequently, the section explores key stakeholder roles, sectoral differences, and the overall implications of DPP implementation across industries.

4.1 DPP evolution

Within the ESPR, the DPP is positioned as a key digital tool to enable product information accessibility among stakeholders across the value chain and to strengthen end-to-end product traceability [18]. In practice, it is intended to support better consumer decisions through access to relevant product information, enable supply-chain actors to contribute and update lifecycle data, and allow competent authorities to fulfil oversight duties while safeguarding confidential business information [18].

Several researchers adopted this policy-aligned view of the DPP as a transparency and traceability enabler embedded in EU regulation and value-chain governance [5,13,14]. Others argue for a more holistic conception: the DPP as a system-of-systems or ecosystem that spans multiple actors, organizations, processes, and technical systems that must interoperate to deliver the overarching capability; in this perspective, DPPs are seen as networks of organizations and technologies and ultimately as socio-technical systems where technical, managerial, and cultural arrangements jointly condition improved traceability and transparency [8,28–30].

[29] has also highlighted that before the formal establishment of DPPs, a wide range of precursor systems and initiatives were developed to enhance product traceability, sustainability, and lifecycle management. While these tools are designed on the same premises as DPPs, the scope and application differ as each type was designed to solve different and specific problems. These included sector-specific solutions such as Circularity.ID in fashion [31], which standardized data to support recycling and resale, and the Global Battery Alliance Passport, which tracked environmental and social metrics of EV batteries [32]. Other frameworks, like the Product Circularity Data Sheet [21], Cradle-to-Cradle Scorecards [33], and the EU's European Product Registry for Energy Labelling (EPREL) registry, focused on measuring product circularity, material health, and energy performance [34]. Similarly, building-related systems such as EU Level(s) [35] and Buildings as Material Banks (BAMB) material passports captured sustainability data across the construction sector [36]. In manufacturing and supply chains, tools like the International Material Data System (IMDS) for automotive materials [37] and the International Dismantling Information System (IDIS) for vehicle dismantling provides traceability, compliance, and lifecycle information [38]. Many of these initiatives relied on advanced technologies to share verified information on provenance, safety, and environmental performance. A summary of the previous initiatives is available in Appendix 2: Pre-DPP Traceability Initiatives.

These initiatives laid the groundwork for DPPs by demonstrating the technical feasibility and practical benefits of digitally encoding product-level sustainability and lifecycle information; hence can be considered part of the technological foundation that is required for the full DPP maturity [27,29]. Despite strong momentum, practical implementation remains at an early stage. Currently, there is no universally standardized format for DPP, and sector-specific initiatives are advancing in parallel across industries [12,39]. The final structure and operating model of DPPs are still under development, while access to reliable and consistent data remains limited.

4.2 Regulatory Landscape

Regulation plays a widespread role across the ABCDE Model of DPP deployment. As an Antecedent, regulatory compliance forms a key foundation for DPP development, with evolving European Union frameworks setting the trajectory for implementation and sectoral prioritization [12,14,29,40,41]. However, regulation can simultaneously act as a Barrier, as unclear or inconsistent legal definitions and fragmented policy execution generate uncertainty and uneven implementation across sectors and Member States [42,43]. At the Challenge level, the absence of EU-wide cross-border regulatory alignment complicates interoperability and data exchange within globalized supply chains, particularly for multinational manufacturers operating across jurisdictions [8,44]. Conversely, policy mandates act as strong Drivers, providing both direction and legitimacy for DPP integration by embedding traceability, sustainability, and circularity obligations into law, while incentivizing firms to invest in digital infrastructures aligned with these emerging standards [6,14].

The evolution of sustainability-oriented legislation led by the European Union is shaping the regulatory landscape for DPP. As the European Union regulations mandate transparency within supply chains, the current data management systems fail to meet the requirements, as it is heavily reliant on siloed approaches limited to proprietary databases [5–7]. The fragmented information flow leads to partial visibility and limited interoperability across businesses and even national borders [7,12,14,17]. This poses issues for ensuring product safety, verifying reported sustainability efforts, and conducting effective product end-of-life management that enables the circular economy [4]. These persistent problems are highly problematic in sectors with multi-tiered supply chains, where numerous stakeholders, including manufacturers, importers, distributors, dealers, repairers, recyclers, and customs authorities, require differentiated yet reliable access to product information [15,29].

In response, the European Union has established the ESPR as the primary legislative framework for the deployment of DPPs [10]. The ESPR mandates Ecodesign requirements aimed at improving durability, repairability, energy efficiency, and recyclability across diverse product categories [10]. Together with the Energy Labelling Framework Regulation (ELFR), it addresses consumer choice and supports the investment in sustainable product innovation [45]. Regulatory pressures extend beyond product-level performance to include supply chain accountability. The Corporate Sustainability Reporting Directive (CSRD) obliges large and listed companies to disclose sustainability and environmental, social, and governance (ESG) data [46], while the Corporate Sustainability Due Diligence Directive (CSDDD) extends responsibility to managing environmental and human rights impacts within global value chains [47]. Complementary directives, such as the EU Green Claims Directive, directly target the problem of greenwashing by mandating transparent and verifiable product-level claims [48]. For all, the DPP plays a crucial role by embedding traceable, standardized data that can be accessed by regulators, consumers, and civil society organizations [10]. Sectoral legislation further reinforces this momentum. The Textiles Strategy, the Construction Products Regulation (CPR) [49], and the new EU Battery Regulation [50] all incorporate the DPP, in different formats. This sets different versions of DPP as the primary compliance mechanism, ensuring durability, recyclability, and consumer-facing transparency in each respective domain.

Positioning circularity and decarbonization as essentials for EU competitiveness, the broader policy context is provided by the Clean Industrial Deal [51]. It promotes the usage of affordable energy, financing clean transitions, boosting demand for sustainable products, and strengthening access to materials [51]. It also establishes conditions for DPP implementation, where traceability can facilitate the integration of circular practices and secure supply resilience, linking industrial competitiveness with climate objectives [51]. This is particularly crucial in energy-intensive sectors such as steel, aluminum, and chemicals [51]. These regulations position the deployment of DPP as a compliance instrument and a strategic enabler of transparency, competitiveness, and

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systemic transformation in European industry. The full timeline for the DPP-related legislation is available in Appendix 3: Timeline of DPP-Related Regulations.

4.3 Technological Landscape

Technology forms the backbone of DPP deployment, influencing every stage of the ABCDE dimensions. As an Antecedent, DPPs build on existing technological foundations such as digital identifiers, material databases, and early traceability systems that demonstrated the feasibility of capturing and exchanging product-level data [14,41,52–55]. Yet, persistent technical limitations, including reliance on synthetic or incomplete data, infrastructure gaps, legacy IT systems, poor data availability, and data integrity risks, continue to act as major Barriers [12,53,56–58]. At the Challenge level, issues of interoperability, data integration, and standardization remain unresolved, while questions of data granularity and scalability hinder cross-sector implementation [44,52,55,59]. Nonetheless, rapid technological advancements, notably in automation, digitalization, and Industry 4.0, and the development of data ecosystems, along with emerging validation tools that improve reliability, are key Drivers enabling progress [56,60,61]. Ultimately, these developments lead to Effects such as enhanced data ecosystems and interoperability gains, fostering a single source of reliable product data that supports transparency, efficiency, and collaboration across supply chains [9,28,54,61].

The effective implementation of DPPs depends on both the quality of data captured and the maturity of the underlying technologies that enable and drive their deployment [53,54,56,61]. Accordingly, the following sections discuss the data required for DPP deployment and the underlying technologies that function as both Antecedents and Drivers of DPP development.

4.3.1 Digital Product Passport Technological Enablers

The technological foundations of DPPs lie in early identification and traceability systems such as radio frequency identification (RFID), QR codes, barcodes, serial numbers, and smart labels, which demonstrated the feasibility of linking physical products to digital records [15,16,29,62,63]. Combined with sensor networks and embedded data carriers, these technologies enabled item-level data capture across manufacturing, logistics, and recycling, laying the groundwork for digital traceability and lifecycle visibility [27,64]. Data management systems like enterprise resource planning have evolved from isolated repositories into interconnected infrastructures that support the storage, exchange, and retrieval of traceability information across organizations [8,27] . These systems underpin DPP interoperability but continue to face Challenges in data integration, schema consistency, and cross-platform standardization [57,65].

On the same note, DPP deployment is driven by advanced digital technologies that enable secure, scalable, and intelligent data ecosystems. These technologies can be used together as part of the ecosystem or individually as an overarching solution. Blockchain and smart contracts ensure immutable, verifiable data exchange and automate compliance verification among distributed actors [7,9,53,57,58,66]. Artificial Intelligence (AI) and Big Data analytics enhance data interpretability and circularity by predicting maintenance, optimizing resource flows, and identifying reuse opportunities [62–64,67,68]. Digital twins provide real-time virtual representations of physical products, integrating sensor and lifecycle data to improve traceability and performance management [30,60,69]. Federated Learning (FL) enhances collaboration and data privacy by enabling decentralized analytics without direct data sharing, supporting secure multi-stakeholder cooperation [9,65]. Meanwhile, the Internet of Things (IoT) enables continuous data exchange and real-time updates, ensuring that product information remains current and verifiable across value chains [67,70,70,71]. These technologies transform DPPs from static documentation tools into intelligent, interoperable systems that evolve through continuous feedback, supporting transparency, circularity, and regulatory compliance across industries [28,40].

4.3.2 Digital Product Passport Required Data

The ESPR refrains from prescribing fixed or universal data attributes, acknowledging that data requirements must be tailored to each product group and will be further developed through delegated and implementing acts [10,72]. This approach allows for flexibility in the definition of product-specific data while maintaining a coherent framework for interoperability across European data spaces [10,72]. The Battery Passport illustrates this principle as the first operational implementation of a delegated specification [72]. The corresponding DIN DKE SPEC 99100 translates legislative requirements into seven thematic clusters; identifiers and product data, symbols and conformity documentation, carbon footprint, due diligence, materials and composition, circularity, and performance and durability, thus demonstrating how sectoral adaptation can operationalize the DPP concept within a regulated context [72].

Research complements this regulatory architecture by proposing broader frameworks for structuring DPP data. [59] present one of the most detailed and comprehensive classifications, dividing product-related data into four principal domains: product information, utilization information, value-chain information, and sustainability information. These are further differentiated into twenty-one subcategories and sixty-two attributes, fifty-one of which can already be derived from existing organizational information systems such as ERP. The classification captures both static and dynamic data, encompassing geometric and material descriptions, operational and service data, supplier and compliance records, as well as ecological and social performance indicators [59]. It is intended to guide developers in conceptualizing DPP content architectures and to serve as a common language for circular product information management. When compared to the more operational structure of the DIN DKE SPEC 99100 battery framework, clear parallels emerge. The regulatory clusters on identifiers, composition, and durability correspond to Stratmann's product and utilization domains, while the due diligence and carbon footprint clusters map onto his sustainability category. This alignment demonstrates how scientific taxonomies provide the conceptual foundation upon which delegated acts translate data requirements into sector-specific formats [59,72].

The assurance of data reliability, accuracy, and verifiability remains a crucial condition for the DPP's credibility and functionality. [21] highlight that fragmented data markets, inconsistent definitions, and unverifiable sustainability reporting currently undermine trust in circularity data. [73] similarly, argue that robust data-governance frameworks are necessary to define how product data is generated, stored, and accessed, while [42] underscores the legal Challenge of balancing data openness with the protection of commercially sensitive information. [74] and [13] add that modular and adaptable DPP data models are required to secure compliance with the ESPR across diverse industrial sectors. Technical studies reinforce these findings; [57] and [75] show that blockchain-based and hybrid distributed-ledger systems can ensure immutability, traceability, and authenticity within common data environments. [30] extend this discussion by highlighting the importance of sovereign and interoperable data ecosystems, while [76] stress that the "reasonability" of data must be evaluated based on stakeholder needs and lifecycle relevance. These perspectives demonstrate that reliable, accurate, and verifiable data are indispensable for the DPP's success, and that achieving them will depend on the integration of sound governance mechanisms, trusted infrastructures, and sector-specific regulatory guidance.

4.4 Organizational Landscape

Across industries, the organizational conditions shape DPP deployment. In such cases, begin with Antecedents anchored in firm-level sustainability strategies and ESG roadmaps that position DPPs as instruments for credible disclosure, eco-design feedback, and compliance-by-design [8,16,42,43,77]. Yet these intentions confront Barriers, including high deployment and integration costs, operational constraints from legacy system stacks, and resistance to change where transparency is seen as exposing performance gaps [19,42,78,79]. Additionally, Challenges compound in multi-tier, global supply networks and legacy product portfolios, where stakeholder coordination, chain-of-custody, and selective disclosure must be governed across heterogeneous actors and jurisdictions [8,21,44,66].

Despite these constraints, a clear set of Drivers sustains adoption: demonstrated business value in efficiency, resilience, and competitiveness, alongside network collaboration benefits, consumer empowerment through credible product information, and business-model innovation in repair, reuse, remanufacturing, and secondary markets [5,8,77,79,79]. Expected Effects include reduced compliance costs, improved supply-chain collaboration, stronger decision-making from standardized lifecycle data, and broader ecosystem transformation toward resource and operational efficiency as governance, schemas, and assurance mature [16,19,43,44,78]. As DPPs are multi-actor socio-technical systems, the next section identifies the stakeholders that shape data generation, exchange, and governance.

4.4.1 Digital Product Passport Stakeholders

DPPs operate as a socio-technical ecosystem spanning product-side and regulation-side stakeholders [8,12,28–30]. The stakeholders were exemplified in the ESRP [10]; however, researchers such as [29,30,63] had further categorization and inclusion within their system of system discussions. At the governance end, EU institutions/policymakers and competent national authorities, including market surveillance and customs, need assured, role-based access for oversight and enforcement; civil-society organizations, trade unions, and researchers use public fields to examine claims and inform debate; and consumers rely on credible disclosures for informed choice [29]. Along the value chain, raw-material suppliers and first/second-tier suppliers contribute composition/provenance and certification data; manufacturers/brand owners curate lifecycle information and orchestrate updates; while importers, distributors, wholesalers, logistics/warehousing, and retailers add chain-of-custody and cross-border events that sustain product history [63]. After-sales actors such as repairers, refurbishers, and remanufacturers write back service events that extend useful life; recyclers and waste operators use composition and hazard flags to improve recovery and should feed back end-of-life outcomes [29,63]. Supporting this, remanufacturing research also highlights structured feedback models that channel remanufacturing insights back into design to support circularity [80].

Technology, data, and assurance functions cut across all groups. IT/data-infrastructure providers enable secure capture, validation, and inter-company sharing of passport data [30]; this directly addresses legacy silos, trust/legal concerns, and the need for common schemas and governance [8,12,30] . In parallel, business analysts/planners, standards bodies, and life-cycle-assessment/assurance practitioners define methods, indicators, and verification so that DPP disclosures are comparable and auditable across sectors, supporting both regulatory compliance and market trust [29].

4.5 Sectoral Comparison

The rollout of DPPs varies across sectors due to differing regulatory timelines, data requirements, and implementation Challenges [10,11]. Under the ESPR, the European Commission prioritizes product groups based on circularity potential, environmental impact, market relevance, and the need for adaptive regulatory updates [11]. This structured approach reflects the EU's intent to balance environmental ambition with industrial feasibility [11].

As per [10,11] motivations differ by sector; this is evident as the strategic autonomy and competitiveness drive early adoption in batteries, steel, and aluminum, while consumer transparency and behavioral change underpin initiatives in textiles and electronics. Circularity and waste reduction are central to tyres, mattresses, and furniture [10,11]. Accordingly, data requirements range from highly technical, standardized datasets in batteries to consumer-facing sustainability information in textiles and hybrid repairability–recyclability models in electronics [10,11].

Phased implementation mirrors these priorities: early deployment in high-impact industrial sectors such as batteries and steel, mid-phase in consumer goods like textiles and tyres, and later adoption in lower-impact categories, including furniture and mattresses [10,11]. Cross-sectoral baselines on repairability and recyclability ensure minimum harmonization [10,11].

The battery sector leads the way, with mandatory "Battery Passports" for industrial and EV batteries by 2026/2027 under the EU Battery Regulation [50]. The DIN DKE SPEC 99100 standard defines key data attributes, carbon footprint, sourcing, and recyclability, reflecting the sector's strategic role in decarbonization and resilience [72]. Key Challenges remain around the secure exchange of sensitive, technical data across global supply chains [72]. In textiles, the EU Strategy for Sustainable and Circular Textiles [49] integrates DPPs to extend lifetimes, enhance repairability, and provide verifiable sustainability data [10]. Implementation is planned for 2027, aligned with the revised Textile Labelling Regulation [49]. Compared with batteries, textile DPPs emphasize consumer transparency over technical standardization, with fragmented global supply chains posing major Barriers [11].

Electronics and ICT products fall under horizontal ESPR measures; repairability scores by 2027 and recycled-content obligations by 2029 [10]. Here, DPPs must merge consumer repair information with detailed data on recyclability and critical raw material traceability to address rapid innovation cycles and escalating e-waste [11]. Other sectors follow with staggered timelines: steel (2026) and aluminum (2027) for strategic autonomy and emissions reduction; tyres (2027) for recyclability and end-of-life management; furniture (2028) for resource efficiency; and mattresses (2029) for waste reduction [10,11].

This differentiated rollout reflects the EU's effort to align circularity with industrial realities [5,14]. Yet, divergent timelines and sector-specific standards risk creating interoperability gaps and additional compliance burdens, particularly for cross-sectoral firms [6,7,30]. Fragmented DPP implementations, stemming from incompatible data frameworks and sector-driven ontologies, threaten seamless data exchange and undermine cross-industry interoperability. Moreover, firms face increased compliance costs and regulatory uncertainty as evolving DPP requirements demand complex lifecycle data management and continuous system adaptation [78,81]. Without greater harmonization of standards and robust data-sharing mechanisms, DPPs may remain primarily compliance instruments rather than Drivers of systemic sustainability transitions [8,21].

5. Discussion

5.1 The ABCDE Model

Interpreting the findings through the ABCDE Model provides a comprehensive view of how DPP adoption unfolds as a multi-dimensional socio-technical transformation, as presented in Figure 2. The analysis reveals that the five dimensions are interdependent, collectively shaping the trajectory of DPP implementation across industries. The Antecedents are predominantly regulatory and technological. The increasing rise of European sustainability policies, such as ESPR, constitutes the institutional foundation that compels firms to adopt DPPs [10,12]. Technological readiness, including the maturity of enabling technologies such as blockchain, IoT, and digital twins, further underpins DPP feasibility [8,9,16].

The Barriers and Challenges identified in this review reinforce the view that the DPP is not merely a technological innovation but an organizational and institutional one. Data fragmentation, a lack of interoperability standards, and uncertainties around data ownership and confidentiality continue to hinder widespread adoption [42,57,76]. These obstacles align with findings from [27] and [81], who emphasize the role of governance and data standardization as persistent bottlenecks in DPP implementation. Conversely, the Drivers reveal growing strategic motivations that extend beyond compliance. Regulatory mandates act as enforcing pressures, but DPPs are increasingly viewed as instruments for operational efficiency, resilience, and competitive differentiation [12,43].

Finally, the Effects anticipated, including enhanced traceability, transparency, and circularity, validate the original intent of the DPP initiative [10]. However, the findings also caution against "visibility overload," where excessive or poorly governed transparency may expose proprietary information and undermine trust among supply chain partners. This highlights the need for calibrated transparency, a balance between openness and protection of competitive knowledge.

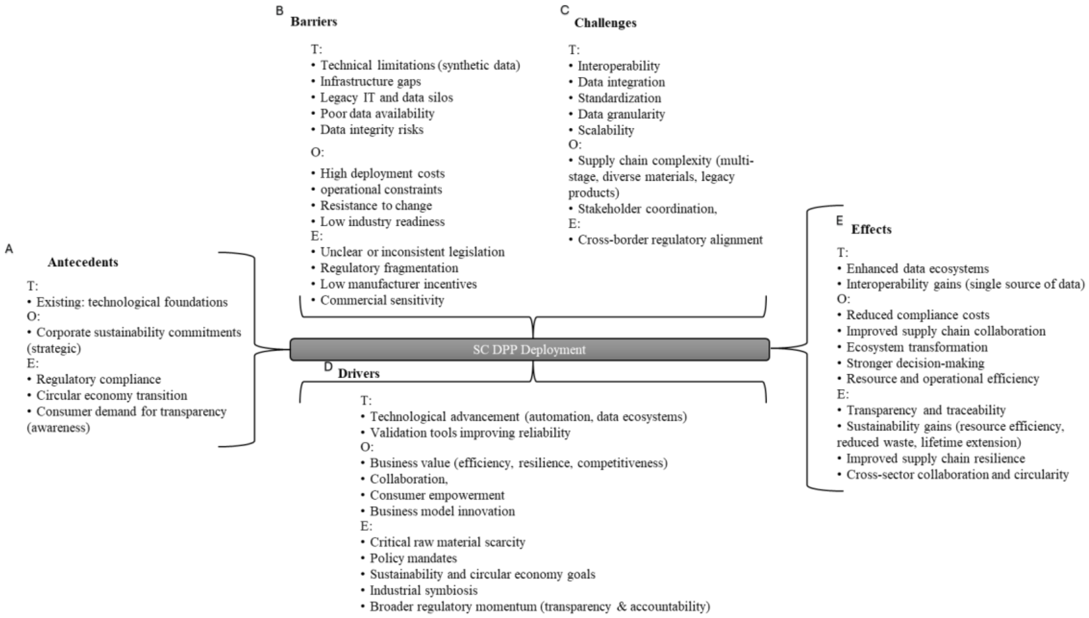

Figure 2. The ABCDE Model for DPP Deployment

5.2 Comparison with Prior Literature Review Studies

Compared with earlier reviews, this study provides a broader and more integrated understanding of DPP adoption. For example, [27] offered an early systematic review that only identified Drivers and Barriers, mainly through the TOE framework. While thorough, their analysis treated these factors as fixed and disconnected from real regulatory and sectoral contexts. This paper builds on their work by applying the ABCDE framework, which also captures how Antecedents and Effects are connected to concrete policy and industry conditions. On the other hand, [81] focused on the technical architecture of DPP systems and Industry 4.0 technologies but paid limited attention to governance and cross-sector comparison. This review extends their insights by examining how governance structures, such as data standardization and required verification mechanisms, link technology with policy implementation.

Similarly, [82] proposed a blockchain-based model for real-time DPP updates but concentrated mainly on use-phase data management. The current study broadens that scope by situating these technical approaches within a wider regulatory and organizational setting. Finally, [83] explored DPP deployment in the textile industry, offering useful insights into circular design and consumer transparency. In contrast, this review provides a cross-sectoral synthesis, comparing industries with different regulatory timelines, data structures, and levels of readiness. Given that, this paper advances the DPP discussion by being the first to combine the ABCDE and TOE frameworks, include sectoral comparison, and integrate the evolving regulatory landscape into a unified analytical model.

5.3 The Role of Regulation in Shaping the Deployment Landscape

Regulation emerges as the defining environmental variable in the DPP ecosystem. The ESPR anchors the digitalization of product information in the EU industrial strategy, complemented by horizontal instruments such as the CSRD, CSDDD, and the Green Claims Directive [10,48]. Together, these regulations establish a layered governance system that makes transparency a legal requirement rather than a voluntary practice [14,40]. However, this research reveals that regulation is a double-edged Driver. On one hand, it legitimizes and accelerates adoption by establishing common data and verification standards [72]. On the other hand, inconsistent national interpretations and misaligned sectoral timelines generate compliance asymmetries and interoperability risks, particularly for multinational firms operating across EU borders [6,8].

Sectoral differentiation further reinforces these tensions. The battery sector benefits from early regulatory clarity and detailed data clusters under the EU Battery Regulation, facilitating rapid progress toward full DPP deployment [72]. By contrast, the textile industry faces fragmented global supply chains and limited digitalization, delaying its readiness [49,83]. The electronics sector occupies a middle ground, where advanced technology meets short product lifecycles, creating challenges in maintaining data continuity and ensuring recyclability [11].

Across EU borders, the challenge intensifies as non-EU suppliers, who are integral to many product value chains, face difficulties in complying with EU-level DPP requirements due to divergent data infrastructures and limited regulatory convergence. Without harmonized international standards, DPP adoption risks becoming an EU-centric exercise, creating visibility gaps beyond European markets [7,30]. Addressing these cross-border complexities requires the establishment of interoperable data protocols and trust frameworks that extend beyond the EU's jurisdiction.

5.4 Theoretical and Managerial Implications

From a theoretical standpoint, this review extends the ABCDE framework by integrating it with the TOE model, linking organizational factors with regulatory pressures. This integration moves beyond static lists of Drivers and Barriers to a causal, configurational perspective in which adoption emerges from interacting factors rather than isolated variables. Furthermore, the study indicates that effective DPP governance requires tailoring who sees what to their role. This role-aligned visibility balances transparency with the need to safeguard sensitive capabilities.

For practitioners, the findings emphasize that DPP adoption must be approached as a strategic transformation initiative, not a compliance exercise. Organizations should prioritize interoperable IT infrastructures, establish clear data governance protocols, and promote cross-functional coordination between sustainability, compliance, and operations teams. Industry groups and alliances can play a crucial role in reducing implementation costs and supporting SMEs through shared data infrastructures and standardized templates.

From a policy perspective, harmonizing data taxonomies across product categories, supporting SMEs, and aligning third-country requirements with EU standards are critical to ensuring inclusive and effective DPP deployment.

6. Conclusion

This paper aimed to consolidate fragmented DPP research by applying the ABCDE framework to identify the factors influencing DPP adoption. It deepens the understanding of DPPs as tools for transparency, traceability, and circularity in supply chains. By integrating the ABCDE Model with the TOE framework, it offers a unified lens for understanding the technological, organizational, and regulatory factors shaping DPP adoption. Rather than viewing DPPs as mere compliance tools, the study positions them as transformative systems for managing product information in circular economies.

Findings show that while digital and sustainability goals drive DPP development, progress is slowed down by structural, technological, and governance challenges. Cross-sectoral analysis reveals how technology maturity, regulatory design, and organizational readiness influence adoption. The study contributes an integrated analytical model that organizes fragmented literature and highlights key interdependencies.

Limitations include reliance on secondary data and the evolving nature of EU legislation, which may shift before 2030. The synthesis reflects knowledge up to 2025, and future empirical studies are needed to validate and refine these insights.

Future research could focus on:

- Longitudinal studies tracking DPP evolution and its impact on governance and collaboration.
- Interoperability through shared standards, ontologies, and technologies like federated learning and blockchain.
- Empirical validation of the ABCDE model to test its explanatory power across industries.

These directions will strengthen the foundations for DPP implementation and support the Industry 5.0 vision of sustainability, resilience, and inclusivity.

References

[1] De Giovanni P 2022 Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives *Int. J. Oper. Prod. Manag.* 42 959–94
[2] Geissdoerfer M, Savaget P, Bocken N M P and Hultink E J 2017 The Circular Economy – A new sustainability paradigm? *J. Clean. Prod.* 143 757–68
[3] Ghisellini P, Cialani C and Ulgiati S 2016 A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems *J. Clean. Prod.* 114 11–32
[4] Ospital P, Masson D, Beler C and Legardeur J 2023 Toward product transparency: communicating traceability information to consumers *Int. J. Fash. Des. Technol. Educ.* 16 186–97
[5] Popowicz M, Pohlmann A, Schöggl J and Baumgartner R J 2025 Digital Product Passports as Information Providers for Consumers—The Case of Digital Battery Passports *Bus. Strategy Environ.* bse.4346
[6] Wagner E 2025 Information Barriers to Circularity for Electronic Products and the Potential of Digital Product Passports *Sustainability* 17 5554
[7] Hulea M, Miron R and Muresan V 2024 Digital Product Passport Implementation Based on Multi-Blockchain Approach with Decentralized Identifier Provider *Appl. Sci.* 14 4874
[8] Jensen S F, Kristensen J H, Christensen A and Wæhrens B V 2024 An ecosystem orchestration framework for the design of digital product passports in a circular economy *Bus. Strategy Environ.* 33 7100–17
[9] Kim M J, Han C H, Park K J, Moon J S and Um J 2025 A Blockchain-Based Digital Product Passport System Providing a Federated Learning Environment for Collaboration Between Recycling Centers and Manufacturers to Enable Recycling Automation *Sustainability* 17 2679
[10] European Commission 2025 Ecodesign for Sustainable Products Regulation - European Commission
[11] European Commission 2024 *Ecodesign for sustainable products regulation: study on new product priorities.* (LU: Publications Office)
[12] Chaudhuri A, Wæhrens B V, Treiblmaier H and Jensen S F 2025 Impact pathways: digital product passport for embedding circularity in electronics supply chains *Int. J. Oper. Prod. Manag.* 45 1213–26
[13] Psarommatis F and May G 2024 Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing *Sustainability* 16 396
[14] Adisorn T, Tholen L and Götz T 2021 Towards a Digital Product Passport Fit for Contributing to a Circular Economy *Energies* 14 2289
[15] Alves L, Sá M, Cruz E F, Alves T, Alves M, Oliveira J, Santos M and Rosado Da Cruz A M 2023 A Traceability Platform for Monitoring Environmental and Social Sustainability in the Textile and Clothing Value Chain: Towards a Digital Passport for Textiles and Clothing *Sustainability* 16 82
[16] Koppelaar R H E M, Pamidi S, Hajósi E, Herreras L, Leroy P, Jung H-Y, Concheso A, Daniel R, Francisco F B, Parrado C, Dell'Ambrogio S, Guggiari F, Leone D and Fontana A 2023 A Digital Product Passport for Critical Raw Materials Reuse and Recycling *Sustainability* 15 1405

[17] Berger K, Schöggl J-P and Baumgartner R J 2022 Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases *J. Clean. Prod.* 353 131492
[18] European Union 2024 Regulation - EU - 2024/1781 - EN - EUR-Lex
[19] Jansen M, Meisen T, Plociennik C, Berg H, Pomp A and Windholz W 2023 Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems *Systems* 11 123
[20] Tranfield D, Denyer D and Smart P 2003 Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review *Br. J. Manag.* 14 207–22
[21] Mulhall D, Ayed A-C, Schroeder J, Hansen K and Wautelet T 2022 The Product Circularity Data Sheet—A Standardized Digital Fingerprint for Circular Economy Data about Products *Energies* 15 3397
[22] Tornatzky L and Fleischer M 1990 *The process of technology innovation, Lexington, MA.*
[23] Kalaiarasan R, Olhager J, Agrawal T K and Wiktorsson M 2022 The ABCDE of supply chain visibility: A systematic literature review and framework *Int. J. Prod. Econ.* 248 108464
[24] Wang G, Wang Y, Li S, Yi Y, Li C and Shin C 2024 Sustainability in Global Agri-Food Supply Chains: Insights from a Comprehensive Literature Review and the ABCDE Framework *Foods* 13 2914
[25] Oliveira T and Martins M F 2011 Literature Review of Information Technology Adoption Models at Firm Level
[26] Awa H O, Ojiabo O U and Orokor L E 2017 Integrated technology-organization-environment (T-O-E) taxonomies for technology adoption *J. Enterp. Inf. Manag.* 30 893–921
[27] Abedi F, Saari U A and Hakola L 2024 Implementation and Adoption of Digital Product Passports: A Systematic Literature Review *2024 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC)* 2024 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC) (Funchal, Portugal: IEEE) pp 1–9
[28] Gieß A and Möller F 2025 Exploring the value ecosystem of digital product passports *J. Ind. Ecol.* 29 561–73
[29] King M R N, Timms P D and Mountney S 2023 A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns *J. Clean. Prod.* 384 135538
[30] Pohlmeyer F, Möbitz C and Gries T 2024 A Sovereign and Interoperable Data Ecosystem for an Eco-Efficient Nonwovens Industry *Sustainability* 16 10735
[31] Haeggblom J 2021 CIRCULARITY.ID White Paper 2021
[32] Stanislaus M, Eckart J, Kemene E and Zaragoza A 2019 Battery Passport
[33] C2C 2021 CRADLE TO CRADLE CERTIFIED PRODUCT STANDARD
[34] European Commission 2022 EPREL for Suppliers - Energy Efficient Products - European Commission *Eur. Comm. – EPREL Guidel.*
[35] European Commission 2025 Level(s) - Green Forum - European Commission
[36] Heinrich M and Lang W 2019 Materials Passports Best Practice *BAMB*
[37] DXC 2021 IMDS Information Pages - Home - IMDS Public Pages
[38] IDIS 2025 IDIS | The International Dismantling Information System
[39] Plociennik C, Kunz L and Ruskowski M 2025 Digital Product Passport enabled Quality Assessment in Dynamic Circular Supply Chain Networks *Procedia CIRP* 135 606–11
[40] Schuberth J, Ebert T, Schlegel M-C, Rödig L, Jepsen D, Memelink R and Hauschke F 2024 The Front-Runner Approach—Facilitating Progressive Product Policy by Using Information from EU Product Databases *Energies* 17 504
[41] Walden J, Steinbrecher A and Marinkovic M 2021 Digital Product Passports as Enabler of the Circular Economy *Chem.-Ing.-Tech.* 93 1717–27
[42] Ducuing C and Reich R H 2023 Data governance: Digital product passports as a case study *Compet. Regul. Netw. Ind.* 24 3–23
[43] Haase L M, Lythje L S, Skouboe E B and Petersen M L 2025 More Than Legislation: The Strategic Benefits and Incentives for Companies to Implement the Digital Product Passport *J. Circ. Econ.* 2
[44] Uusitalo T, Karhu M, Majaniemi S, Kivikytö-Reponen P, Hanski J and Vatanen S 2023 Digital Product Passports in Circular Economy: Case Battery Passport *EcoDesign for Sustainable Products, Services and Social Systems I* ed S Fukushige, H Kobayashi, E Yamasue and K Hara (Singapore: Springer Nature Singapore) pp 175–86
[45] European Union 2017 Regulation - 2017/1369 - EN - EUR-Lex- setting a framework for energy labelling and repealing Directive 2010/30/EU
[46] European Union 2022 Directive - 2022/2464 - EN - CSRD Directive - EUR-Lex
[47] European Union 2024 Directive - EU - 2024/1760 - EN - EUR-Lex- on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859
[48] European Parliament 2024 “Green claims” directive: Protecting consumers from greenwashing | Think Tank | European Parliament

[49] European Commission 2022 Textiles strategy - Environment - European Commission- EU Strategy for Sustainable and Circular Textiles
[50] European Union 2023 Regulation - 2023/1542 - EN - EUR-Lex- concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC
[51] European Commission 2025 Clean Industrial Deal - European Commission
[52] Gleich K, Behrendt S, Hörger M, Benfer M and Lanza G 2024 An Asset Administration Shell-Based Digital Product Passport as a Gaia-X Service *Procedia CIRP* 127 224–9
[53] Greiner M, Seidenfad K, Langewisch C, Hofmann A and Lechner U 2024 The Digital Product Passport: Enabling Interoperable Information Flows Through Blockchain Consortia for Sustainability *Innovations for Community Services* Communications in Computer and Information Science vol 2109, ed F Phillipson, G Eichler, C Erfurth and G Fahrnberger (Cham: Springer Nature Switzerland) pp 377–96
[54] Kebede R, Moscati A, Tan H and Johansson P 2024 A modular ontology modeling approach to developing digital product passports to promote circular economy in the built environment *Sustain. Prod. Consum.* 48 248–68
[55] Mollahassani D, Göbel J C and Juresa Y 2025 Towards Model-based Definition of Digital Product Passports Supporting Sustainable Smart Product Lifecycles *Teh. Glas.* 19 43–8
[56] De Diego S and Gutiérrez I 2025 Decentralized Digital Product Passport Building Blocks for Enhancing Supply Chain Sovereignty and Circular Economy Practices
[57] Jaskula K, Kifokeris D G, Papadonikolaki D E and Rovas D V 2025 Blockchain-Based Decentralized Common Data Environment: User Requirements and Conceptual Framework *J. Constr. Eng. Manag.* 151
[58] Miron R, Hulea M and Muresan V 2025 Transforming Lifecycle Management: A Systematic Review of Blockchain-Driven Digital Product Passports in Circular Economy Frameworks *Innovations in Mechatronics Engineering IV* Lecture Notes in Mechanical Engineering ed J Machado, J Trojanowska, F Soares, P Rea, S Butdee and B Gramescu (Cham: Springer Nature Switzerland) pp 301–15
[59] Stratmann L, Hoeborn G, Pahl C and Schuh G 2023 Classification of product data for a Digital Product Passport in the manufacturing industry ed D Herberger, M Hübner and V Stich
[60] Fuhrländer-Völker D, Lindner M, Von Elling M, Frieß T, Karnapp S and Weigold M 2025 Method for the development and application of digital twins in manufacturing *Prod. Eng.*
[61] Kemmner F-A, Legenvre H and Hameri A-P 2025 Sharing data to implement the circular economy: the case of digital product passports *Ind. Manag. Data Syst.* 1–20
[62] Petrik D, Dzierzawa F and Warthmann K 2025 A Maturity Model for Digital Product Passports: A Design Science Study *IEEE Access* 13 114575–94
[63] Telfort T E and Valilai O F 2025 A Framework for Sustainable Textile Waste Management using Digital Product Passports and Artificial Intelligence *Procedia CIRP* 134 909–14
[64] Kinnunen P, Karhu M, Yli-Rantala E, Kivikytö-Reponen P and Mäkinen J 2022 A review of circular economy strategies for mine tailings *Clean. Eng. Technol.* 8 100499
[65] Tzionis G, Kougka G, Gialampoukidis I, Vrochidis S, Kompatsiaris I, Vlachopoulou M, Afolaranmi S O and Martinez Lastra J L 2025 A Review on Digital Product Passports as Drivers of Digital Transformation in Industry *2025 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC)* 2025 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC) (Valencia, Spain: IEEE) pp 1–10
[66] Abreu H, Pereira V N S S and Barata J 2025 Blockchain-based digital product passport: design principles and demonstration *Int. J. Prod. Res.* 63 5863–82
[67] Al-Khatib A W 2023 Internet of things, big data analytics and operational performance: the mediating effect of supply chain visibility *J. Manuf. Technol. Manag.* 34 1–24
[68] Dubey R, Luo Z, Gunasekaran A, Akter S, Hazen B T and Douglas M A 2018 Big data and predictive analytics in humanitarian supply chains: Enabling visibility and coordination in the presence of swift trust *Int. J. Logist. Manag.* 29 485–512
[69] Kannappan R, Hatin J, Bertin E and Crespi N 2025 Enhancing Digital Product Passport Through Decentralized Digital Twins *2025 12th IFIP International Conference on New Technologies, Mobility and Security (NTMS)* 2025 12th IFIP International Conference on New Technologies, Mobility and Security (NTMS) (Paris, France: IEEE) pp 300–8
[70] Frendi M, Nachet B and Adla A 2024 Physical Internet Based Ontology for Supporting Traceabilityin Logistic IoT *Int. J. Comput. Digit. Syst.* 15 427–40
[71] Radhika K, Mohammed S, Tadepalli S K and Puvvula K 2024 Food Supply Chain Management by Leveraging AI, IoT, and Blockchain Technologies *The Future of Agriculture: IoT, AI and Blockchain Technology for Sustainable Farming* ed K Pandey, S Jain, D Pandey and O Kaiwartya (BENTHAM SCIENCE PUBLISHERS) pp 119–41

[72] Freund T and Sciulli M-F 2025 DIN DKE SPEC 99100:2025-02, Anforderungen an Datenattribute des Batteriepasses; Text Englisch
[73] Piétron D, Staab P and Hofmann F 2023 Digital circular ecosystems: A data governance approach *GAIA - Ecol. Perspect. Sci. Soc.* 32 40–6
[74] Gianvincenzi M, Marconi M, Mosconi E M, Pennino D and Tola F 2025 Digital Product Passports: A Framework for Developing Adaptable and Compliant Data Models *Design Tools and Methods in Industrial Engineering IV* Lecture Notes in Mechanical Engineering ed P Di Stefano, F Gherardini, V Nigrelli, C Rizzi, G Sequenzia and D Tumino (Cham: Springer Nature Switzerland) pp 182–9
[75] Tortola D, Felicioli C, Canciani A and Severino F 2025 Authenticated data visualization for hybrid blockchain-based digital product passports *Comput. Commun.* 236 108110
[76] Mêda P, Hjelseth E, Calvetti D and Sousa H J C 2024 Exploring the significance and priority of digital product passports implementation in building renovation projects targeting circular economy *Smart Sustain. Built Environ.*
[77] Kuhn M, Baumann M, Volz F and Stojanović L 2025 Digital Product Passport Design Supporting the Circular Economy Based on the Asset Administration Shell *Sustain. Switz.* 17
[78] Büchel J and Neligan A 2025 Digital Product Passport: Finding the Right Balance Between Transparency for Circularity and Added Red Tape *Intereconomics* 60 160–4
[79] Zhang A and Seuring S 2024 Digital product passport for sustainable and circular supply chain management: a structured review of use cases *Int. J. Logist. Res. Appl.* 27 2513–40
[80] Lindkvist Haziri L and Sundin E 2020 Supporting design for remanufacturing - A framework for implementing information feedback from remanufacturing to product design *J. Remanufacturing* 10 57–76
[81] Wicaksono H, Mengistu A, Bashyal A and Fekete T 2025 Digital Product Passport (DPP) technological advancement and adoption framework: A systematic literature review *Procedia Comput. Sci.* 253 2980–9
[82] Wan P K and Jiang S 2025 Enabling a dynamic information flow in digital product passports during product use phase: A literature review and proposed framework *Sustain. Prod. Consum.* 54 362–74
[83] Carvalho C, Silva C J and Abreu M J 2025 Circular Economy: Literature Review on the Implementation of the Digital Product Passport (DPP) in the Textile Industry *Sustainability* 17 1802
[84] Chalmers Industriteknik KEEP innovation project

Appendix 1: Timeline of the reviewed articles

The number of reviewed articles was fixed and concluded on the 13th of October 2025. Below figures present the timeline of these articles and their corresponding numbers.

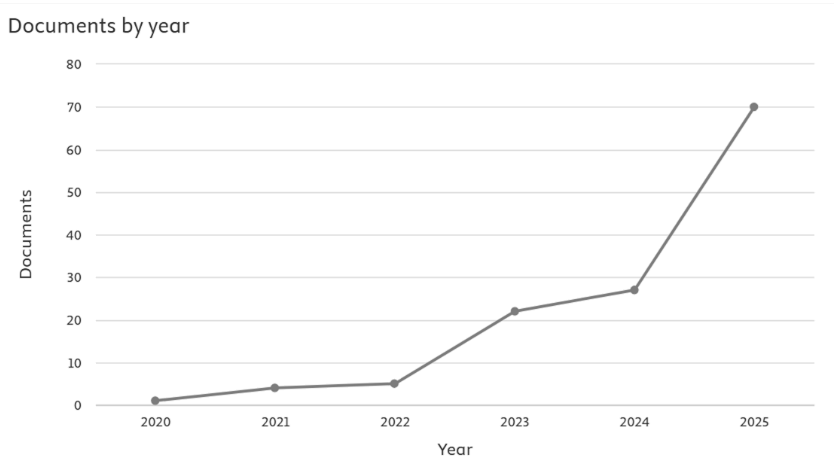

Figure 3. “Digital Product Passport” Journals- Scopus Search (October 2025)

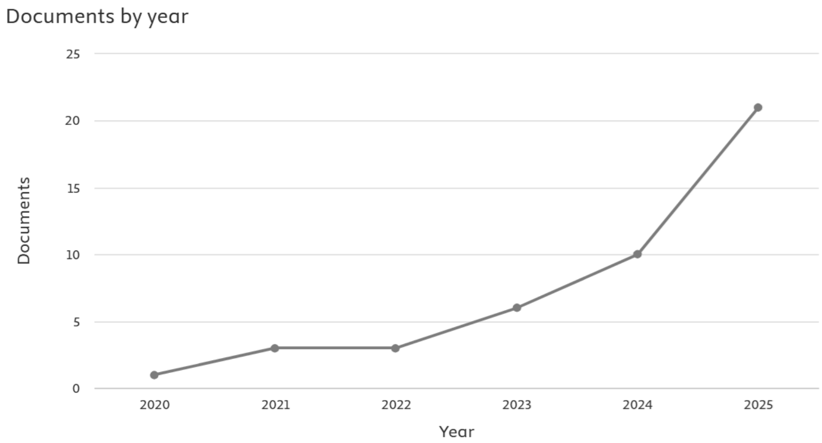

Figure 4. "Battery Passport" Journals- Scopus Search (October 2025)

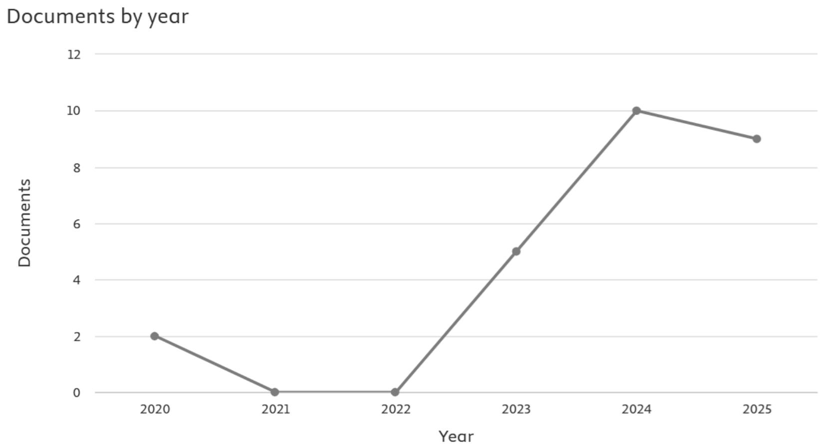

Figure 5. "Material Passport & Supply Chain" Journals- Scopus Search (October 2025)

Appendix 2: Pre-DPP Traceability Initiatives

A summary of pre-DPP traceability initiatives is available in this section. These initiatives laid the groundwork for DPPs by demonstrating the technical feasibility and practical benefits of digitally encoding product-level sustainability and lifecycle information; hence can be considered part of the technological foundation that is required for the full DPP maturity [27,29].

Table 1. Pre-DPP Traceability Initiatives

Name	Sector	Launch Year	Summary
Global Battery Alliance (GBA) Battery Passport	Batteries & e-mobility	2023 (proof-of-concept)	Defines a global reporting framework for ESG and lifecycle data at the cell/pack level; arguably the most mature DPP archetype, proving digital passports at scale [32].
EU Level(s)	Construction & real estate	2020	Common EU framework for reporting building sustainability across life-cycle metrics; provides structured performance data that DPP-like building passports can leverage [35].

Circularity.ID (Open Data Standard)	Fashion & textiles	2019	Provides a machine-readable product data model + digital IDs for garments, enabling sorting, resale, and recycling to access accurate product information; an early DPP-like blueprint for fashion [31].
European Product Registry for Energy Labelling (EPREL)	Energy-labelled products (appliances, B2C & B2B)	2019	Central EU database that requires suppliers to register product models and publish key energy data; establishing regulated, searchable product records akin to a DPP backbone [45].
Product Circularity Data Sheet (PCDS / ISO 59040)	Cross-industry manufactured products	2018	Creates a uniform, auditable circularity dataset per product ("digital circularity fingerprint"), directly anticipating DPP data schemas and exchange [21].
KEEP Traceability System for Electrical & Electronic Products	Electrical & electronic equipment (EEE)	2018	Prototyped an "electronic passport" for EEE with unique IDs and full lifecycle data (origin, composition, repair, EoL), demonstrating the feasibility of DPP-style traceability in electronics [84].
Buildings as Material Banks- (BAMB) Material Passports	Construction	2015	Introduced material/component passports to track building parts over time, enabling reuse and high-value recovery; precursor to building-sector DPPs [38].
International Dismantling Information System (IDIS)	Automotive (end-of-life vehicles)	2008	Manufacturer-compiled dismantling & safety data repository for ELVs; gives downstream actors standardized product information, a key DPP-style use case.
Cradle-to-Cradle Certified® Product Scorecards	Cross-industry products & materials	2005	Standardized scorecards and disclosures on material health, circularity, and social fairness laid early foundations for structured product attribute reporting that DPPs can reference [33].
International Material Data System (IMDS)	Automotive	2000	Industry-wide material database tracing every component to basic substances to meet ELV/REACH, etc.; long-running supply-chain data infrastructure that DPPs can build upon [37].

Appendix 3: Timeline of DPP-Related Regulations

This section represents the timeline of the DPP-related regulations shown in Figure 5. As the ESPR declares [10], the DPP efforts are a continuation of previously developed legislation, integrated with horizontal requirements within the Green Deal.

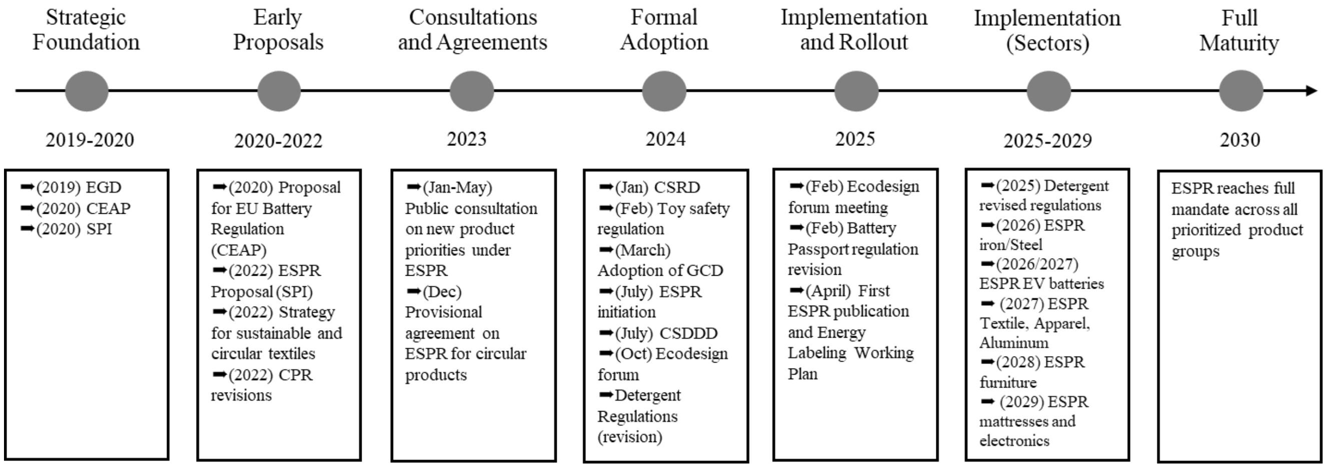

Figure 6: DPP-Related Regulations 2019 ongoing

- EGD: European Green Deal
- CEAP: Circular Economy Action Plan
- SPI: Sustainable Products Initiative
- ESPR: Ecodesign for Sustainable Products Regulation
- CPR: Construction Products Regulation
- CSRD: Corporate Sustainability Reporting Directive
- GCD: Green Claims Directive
- CSDDD: Corporate Sustainability Due Diligence Directive