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Digital Product Passport Ecosystem and Its Formation Drivers

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ABSTRACT

Digital Product Passports (DPPs) are becoming a central digital infrastructure for the circular economy because they enable cross-organizational data exchange and improve life-cycle management of products. Building on a systematic review of academic literature, regulatory documents, and publicly available evidence from ongoing DPP deployments, this thesis develops a generalized conceptual model of the DPP value ecosystem. The model specifies the roles of suppliers, manufacturers, consumers, end-of-life actors (repair, refurbishment, recycling, and waste management), and regulators, and clarifies the core information and value flows among them. The study highlights that interoperability (standardized data formats and protocols), reliable global identifiers and data carriers (e.g., QR codes linked to unique digital identifiers), and confidentiality-preserving data exchange (access control and modern cryptographic approaches) are decisive factors for scaling DPPs across supply chains. Practical cases (e.g., consumer-facing transparency and anti-counterfeiting applications) demonstrate that DPPs can strengthen supply-chain transparency, compliance assurance, resource efficiency, and consumer trust. Overall, DPPs should be treated not only as a technical tool but as a socio-technical ecosystem that aligns stakeholder incentives, data governance, and circular-economy objectives.

Keywords: Digital Product Passport (DPP), Circular Economy, Industrial Ecology, Value Ecosystem, Interoperability, Data Governance.

Introduction

Digital Product Passports consolidate product life-cycle data into a structured information asset that can be accessed by multiple stakeholders. In circular-economy settings, the DPP serves as a shared reference point to reduce information gaps about product origin, composition, environmental impacts, use, maintenance, and end-of-life options. As regulatory and market requirements for sustainability information expand, DPPs increasingly become a prerequisite for placing certain products on the market (e.g., battery-related initiatives in the EU). Therefore, understanding how value is created and distributed through a DPP ecosystem is essential for organizations planning adoption and for policymakers designing enabling frameworks.

Recent studies conceptualize the DPP as a socio-technical ecosystem rather than a standalone IT artifact. King et al. (2023) propose a universal definition of a DPP ecosystem,

emphasizing stakeholder capabilities, requirements, and concerns. Langley et al. (2023) provide guiding principles for orchestrating DPPs to support a smart circular economy, highlighting governance and interoperability. Berger et al. (2023) focus on confidentiality-preserving data exchange as a prerequisite for sustainable product management via DPPs. In the built environment, Cetin et al. (2023) map data requirements and availability constraints for material passports. Finally, critical perspectives on circular economy (Corvellec et al., 2022) underline the need for realistic implementation pathways and well-designed incentives.

A mixed conceptual methodology was applied, combining: (i) systematic literature review of peer-reviewed research on DPPs, material passports, and circular-economy information infrastructures; (ii) analysis of relevant regulatory sources, including EU frameworks; and (iii) synthesis of public evidence from practical cases and pilot implementations. The analysis is used to derive a generalized stakeholder map and to model aggregate information/value flows in the DPP ecosystem.

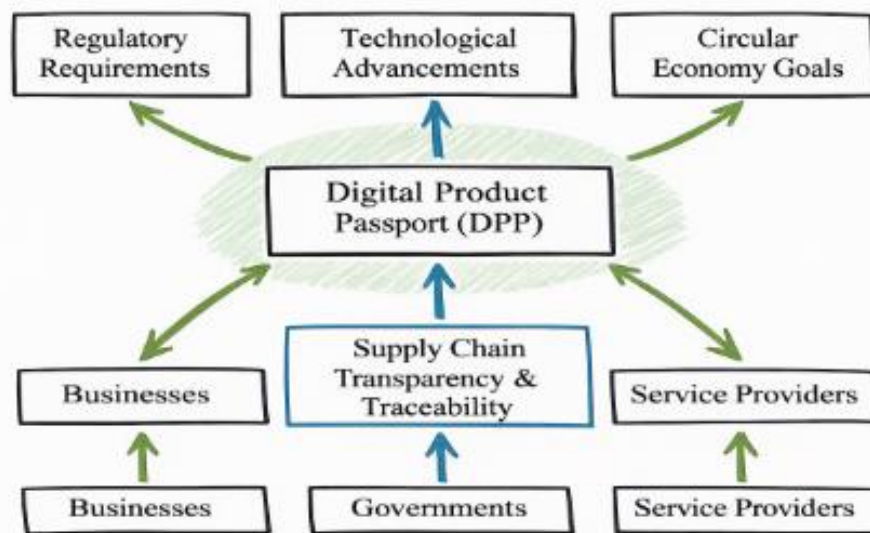


Figure 1. Key drivers and structure of the digital product passport ecosystem.

The proposed model positions the DPP as a boundary object shared across heterogeneous actors. The primary data providers are suppliers and manufacturers, who populate the DPP with product identifiers, bill of materials, origin and compliance information, and sustainability indicators (e.g., resource use and emissions). Downstream users include consumers (accessing simplified views for informed choices), market surveillance and regulators (compliance verification), repair and refurbishment services (maintenance histories and repairability guidance), and waste-management/recycling operators (material composition and disassembly instructions). Interoperability requires standardized data structures and protocols that allow systems to exchange DPP data without manual reconciliation. At the same time, a key barrier is the confidentiality of commercially sensitive information; therefore, role-based access, encryption, and confidentiality-preserving data exchange mechanisms are crucial for ecosystem participation(fig 2).

Public cases illustrate how DPP-like infrastructures create measurable value. For example, consumer-facing transparency solutions enable brands to communicate verified origin and producer narratives through QR-based access. Anti-counterfeiting use cases show that unique identifiers can help detect gray-market channels and improve customer relationship management by capturing scan analytics. In addition, end-of-life requirements such as automated disassembly and e-waste processing strengthen the demand for machine-readable product state data, reinforcing the DPP's role as a life-cycle information backbone. These observations suggest that early adoption should prioritize high-impact segments where

regulatory pressure, counterfeiting risks, or end-of-life complexity are highest, while progressively expanding DPP scope and data depth.

Conclusion

The study demonstrates that DPPs function as a strategic infrastructure for circular economy and industrial ecology by enabling transparent life-cycle information exchange and supporting resource optimization and waste minimization. Successful scaling depends on three interdependent conditions: interoperability through standard data formats and exchange protocols, reliable global identifiers and data carriers for product-level access and data governance that balances transparency with confidentiality, using access control and cryptographic protection. Future research should operationalize the conceptual model into measurable KPIs for ecosystem performance and explore scalable architectures for cross-sector DPP interoperability in emerging economies.

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