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Document Version

Final published version

Citation (APA)

Panigrahi, A., Rukanova, B. D., de Reuver, M., & Tan, Y. (2026). Mapping Tensions In Digital Product Passport Ecosystems: Insights From The Green Steel Transition. In *European Conference on Information Systems 2026 proceedings: Twin Transition Track* (pp. 1). Article ECIS2026-1472 Association of the Information Systems (AIS). <https://aisel.aisnet.org/ecis2026/twin/twin/1/>

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European Conference on Information Systems
(ECIS)

June 2026

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Recommended Citation

Panigrahi, Anshuman; Rukanova, Boriana; de Reuver, Mark; and Tan, Yao-hua, "Mapping Tensions In Digital Product Passport Ecosystems: Insights From The Green Steel Transition" (2026). *ECIS 2026 Proceedings*. 1.

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MAPPING TENSIONS IN DIGITAL PRODUCT PASSPORT ECOSYSTEMS: INSIGHTS FROM THE GREEN STEEL TRANSITION

Short Paper

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Abstract

The Eco-design for Sustainable Products Regulation (ESPR) mandates Digital Product Passports (DPPs) to enhance product traceability and enable circular value chains. While DPPs are expected to improve material transparency and compliance, their implementation also impacts value exchanges across industrial ecosystems. This research-in-progress paper examines how DPPs reconfigure information flows and value exchanges within the green steel transition, reshaping business ecosystems and generating tensions. Using value modelling of the Groeien met Groen Staal (GGS) ecosystem, the study identifies inter-actor tensions and develops a preliminary taxonomy across three dimensions: transparency versus control, coordination versus autonomy, and value creation versus value capture. The taxonomy provides a structured lens for analysing how digital infrastructures redistribute information, governance, and value in circular ecosystems. Future empirical iterations will validate and refine the taxonomy through stakeholder engagement within the GGS consortium.

Keywords: Digital Product Passport, Circular Business Ecosystem, Green Steel, Taxonomy of Tensions.

1 Introduction

Following the European Union's (EU) focus on circularity and digital technologies, industrial systems are currently undergoing a twin transition, which involves the synergetic interaction between both digital and sustainability transformation to achieve competitive advantage (European Commission, 2019; Tabares et al., 2025). Through the Eco-design for Sustainable Products Regulation (ESPR), the EU is mandating Digital Product Passports (DPPs) to enhance product transparency and enable circular practices across value chains (European Union, 2024). At the same time, complementary policies such as the Carbon Border Adjustment Mechanism (CBAM) emphasise Europe's strategic autonomy by reducing dependency on external markets (European Union, 2023). Within this policy landscape, steel emerges as a key material of strategic, economic, and environmental importance.

Steel is the backbone of modern life. With an annual production of nearly 1.9 billion tonnes, it is essential for buildings, transport, and infrastructure. However, its production accounts for about 7% of the global CO₂ emissions from energy systems (IEA, 2020). While steel is technically recyclable, maintaining its quality across multiple life cycles remains a challenge due to contamination with alloys such as copper and a general lack of traceability regarding its material composition (Daehn et al., 2017). As a result, steel often undergoes *downcycling*, which means being used in lower-grade applications rather than

retained in high-value uses such as automotive production (Helbig et al., 2022). Addressing these challenges requires systemic solutions that not only reduce environmental impacts but also support the EU's strategic goals of resource security and industrial competitiveness.

In this context, Digital Product Passports (DPPs), defined as *“a structured collection of mandatory, machine-readable (where appropriate), product-related data with pre-defined scope and agreed data management- and access rights extracted from a standardized product dataspace thanks to a unique product identifier and that is accessible via electronic means through a data carrier”* (Archer et al., 2024), offer a potential breakthrough. By embedding product-level data on material composition, origin, and lifecycle events, DPPs can provide end-of-life actors such as dismantlers and recyclers with the information needed to improve separation, ensure quality, and retain the value of steel in high-grade applications (Lopes & Barata, 2024). Beyond technical benefits, DPPs also serve regulatory functions by enabling compliance with due diligence, carbon reporting, and circularity requirements (Wicaksono et al., 2025). However, while DPP is a promising digital tool, its implementation alone does not create business value. Unlocking its potential requires new circular business models and ecosystem configurations that incentivise firms to share sensitive data and coordinate circular practices across the value chain (Petrik et al., 2025).

Most academic work to date remains firm-centric, emphasising individual adoption and technological standards (Berger et al., 2023; Domskienė & Gaidule, 2024). In contrast, the **ecosystem perspective**, which recognises that circularity emerges through the interaction of heterogeneous actors like producers, recyclers, and regulators remains underexplored, especially in the context of steel. Such a perspective is critical, given that the transition to circular steel and implementing DPPs cannot be achieved by optimising individual firms in isolation but requires ecosystem reconfigurations (Kanda et al., 2021).

Meanwhile, a growing body of research has begun to explore DPPs from an ecosystem perspective. For example, King et al. (2023) conceptualize a Digital Product Passport Ecosystem (DPPE) and identify discrete capabilities, stakeholder requirements, and mechanisms necessary to align actors across value chains. Gieß & Möller (2025) examine how DPPs create and redistribute value across interconnected actors, framing DPPs as boundary objects within multi-actor ecosystems. Similarly, Jensen et al. (2024) use an ecosystem orchestration perspective and propose an adaptation framework that guides practitioners in contextualizing and operationalizing DPPs.

Despite these advances, little is known about how DPPs reconfigure inter-organisational relationships and how such reconfigurations generate new tensions among actors in the context of circular steel ecosystems. As DPPs alters information flows, they also shift value exchanges and strategic dependencies within existing ecosystems (Zhang & Seuring, 2024). Understanding these dynamics is essential for designing circular business models that align incentives while maintaining competitiveness.

This research gap leads to the central research question of this paper: *“What tensions emerge among actors in DPP-enabled circular steel ecosystems?”* To address this question, this study aims to develop a taxonomy of tensions that captures the tensions arising from DPP-enabled reconfigurations of business ecosystems in the green steel transition. Accordingly, this research-in-progress paper presents the first iteration of the taxonomy focusing on conceptual development and analytical framing, leaving empirical iterations and validation for future work.

The remainder of this paper is structured as follows: Section 2 reviews literature on circular business models and DPPs. Section 3 outlines the research design and approach to taxonomy development. Section 4 presents preliminary results from value modelling and the first iteration of the taxonomy. Section 5 concludes with implications and outlines next steps for future iterations and validation.

2 Literature Review

2.1 Sustainable and Circular Business Models

The Circular Economy (CE) has emerged as a guiding paradigm for addressing sustainability challenges by closing resource loops through reuse, recycling, and remanufacturing (Geissdoerfer et al., 2017). Within this paradigm, sustainable and circular business models (CBMs) provide the organisational and

strategic means to operationalise CE principles, focusing on how firms create, deliver, and capture value, aligning not only their economic but also their environmental and social values to create sustainable impact (Panigrahi et al., 2025). While early CBM research has largely focused on firm-level innovations such as product-service systems, resource recovery, or sharing models (Bocken et al., 2016), a more recent stream has started to recognise the importance of coordination across ecosystems of actors, giving rise to an ecosystemic perspective on CBMs (Kanda et al., 2021).

The ecosystem lens emphasises interdependencies among different actors such as producers, users, recyclers, and regulators. Circularity is often constrained not by individual firm capabilities but by misaligned incentives, insufficient traceability, lack of trust, and fragmented information across the value chain (Radavičius et al., 2025). This shift from single-firm models to ecosystem-level reconfiguration further stresses the need for business model research to integrate ecosystem orchestration and governance perspectives (Jensen et al., 2024).

2.2 Digital Product Passports

Studies of DPPs have so far concentrated on technical aspects, including metadata design, standardisation, and traceability pilots in sectors such as batteries, textiles, and electronics (Berger et al., 2023; Domskienė & Gaidule, 2024; Zhang & Seuring, 2024). These pilot projects show that DPPs not only act as repositories of material and sustainability information but also enable new forms of collaboration. Despite such progress, implementations remain fragmented, as most sectors operate within their own data standards and governance frameworks.

From an Information Systems (IS) perspective, DPPs can be understood as part of Information Infrastructures (IIs) that span organisational boundaries and facilitate data sharing across heterogeneous actors (Hanseth & Lyytinen, 2010). They play a dual role of enabling data interoperability while reconfiguring relationships, product lifecycles, and value exchanges among firms (Gieß & Möller, 2025). For instance, the introduction of DPPs in a steel value chain could give rise to new intermediaries such as DPP data analysts, verifiers or auditors and redefine how value is distributed between steelmakers, manufacturers, recyclers, and dismantlers. This could lead to the tensions of collaboration, access rights, and incentive structures, which remain underexplored in the current literature. Understanding these configurations and mapping tensions within them is essential to design viable business models for DPP-enabled circular ecosystems.

3 Methodology

3.1 Research Design

This study follows the taxonomy development methodology of Nickerson et al. (2013) to construct a taxonomy of tensions that emerge during the reconfiguration of DPP-enabled business ecosystems. A taxonomy offers a systematic way to identify, organize, and conceptualize complex phenomena, which in this case, are tensions that arise when firms attempt to balance data transparency, governance roles, and value creation in circular ecosystems (Ferlito & Faraci, 2024; Luoma et al., 2023).

The empirical context is the Groeien met Groen Staal (GGS) consortium (*Groeien Met Groen Staal*, 2025), where actors within the steel ecosystem aim to develop DPP-enabled practices for steel traceability and recycling. This multi-actor environment provides a rich setting for analysing the tensions that occur when DPPs intersect with established industrial and organizational structures.

3.2 Taxonomy Development Process

Based on Nickerson et al. (2013)'s methodology, the study will alternate between conceptual and empirical iterations. The four main steps in the taxonomy development process are as follows:

Defining Meta-characteristic: Based on the previous sections, the meta-characteristic guiding the taxonomy is: “*Characteristics of tensions among actors in DPP-enabled circular steel ecosystems.*”

Determine Ending Conditions: Both objective and subjective ending conditions are exactly as per Nickerson et al. (2013). Objective conditions include parameters like the stability of dimensions, the absence of new characteristics in subsequent iterations, and comprehensive coverage of observed tensions. Subjective conditions include clarity, parsimony, and usefulness for analysing and designing DPP-enabled ecosystems. The taxonomy will be finalised once all ending conditions are satisfied.

Empirical & Conceptual Iterations: The first conceptual iteration applied e³-value modelling (Gordijn & Akkermans, 2003) to represent the business ecosystem of the GGS automotive steel ecosystem. Two value models were constructed: the current configuration representing the current ecosystem (based on GGS document analysis, actor inputs and Muslemeni et al. (2021)'s schematic of steel industry supply chain), and a DPP-enabled configuration illustrating a potential conceptual reconfiguration of the current model based on the generic DPP value ecosystem of Gieß & Möller (2025). These were validated through two preliminary interviews with stakeholders from actors from *Steel Makers & Recyclers* and *Producer Responsibility Organisation roles*, along with a poster presentation at a GGS internal meeting where the maps were discussed with actors across the ecosystem within the GGS consortium. These value models depict how actors exchange values and resulted in the development of actor-tension matrices. These matrices served as analytical foundations for detecting tensions and translating them into a preliminary taxonomy of tensions, which is presented later in this short paper. Future empirical iterations will be based on qualitative data from multiple embedded case studies of actors within the GGS ecosystem. Data shall be collected through semi-structured interviews, workshops, and document analysis involving stakeholders across the steel ecosystem. The trajectory of future conceptual and empirical iterations is further elaborated in section 5.

Evaluation and Refinement: The final taxonomy will be validated through expert review and interactive workshops with GGS industrial and academic partners. Practitioners would assess the taxonomy's clarity and its capacity to reflect real-world coordination challenges, while researchers examine theoretical alignment and conceptual rigour. Feedback from both groups will inform the final refinement of the taxonomy.

4 Preliminary Results

4.1 Mapping the Automotive Steel Ecosystem

In the current automotive steel configuration (Figure 1 (a)), the value exchanges are largely transactional and unidirectional. Information gaps exist between stakeholders, particularly between upstream and downstream actors. For instance, dismantlers and shredders have limited visibility into alloy composition or embedded contaminants in scrap steel, resulting in downcycling and low-value material recovery. The relationships between actors are characterised by fragmented incentives, while manufacturers pursue cost efficiency and compliance, shredders and dismantlers are optimised for throughput and labour cost, often at the expense of material quality. This configuration reveals an ecosystem optimised for linear efficiency rather than circular value retention.

The DPP-enabled configuration (Figure 1 (b)) introduces DPP Service Providers (DPPSPs) that enable product-specific data, such as material composition, origin, and lifecycle history, to circulate across previously disconnected actors. Their introduction represents a structural change in the ecosystem, as they act as intermediaries responsible for managing data infrastructures, verifying information integrity, and facilitating interoperability across organisational boundaries. The integration of DPPs transforms both information flows and business relationships, reconfiguring the ecosystem towards a more interdependent circular configuration. In this configuration, recyclers gain traceability for feedstock and can verify recycled input quality, while dismantlers and shredders receive actionable data for selective disassembly and sorting. Also, manufacturers and the Product Responsibility Organisation (PRO) can facilitate Extended Producer Responsibility (EPR) compliance and validate end-of-life recovery targets better. This also enables new business models, such as certification services from manufacturers certifying dismantled parts through the information from DPPs, which creates a new market for certified second-hand parts and adds an additional revenue stream for dismantlers, enabling customers to reuse

these parts while retaining warranty. However, this digital interdependence also introduces new strategic tensions, discussed in the next section.

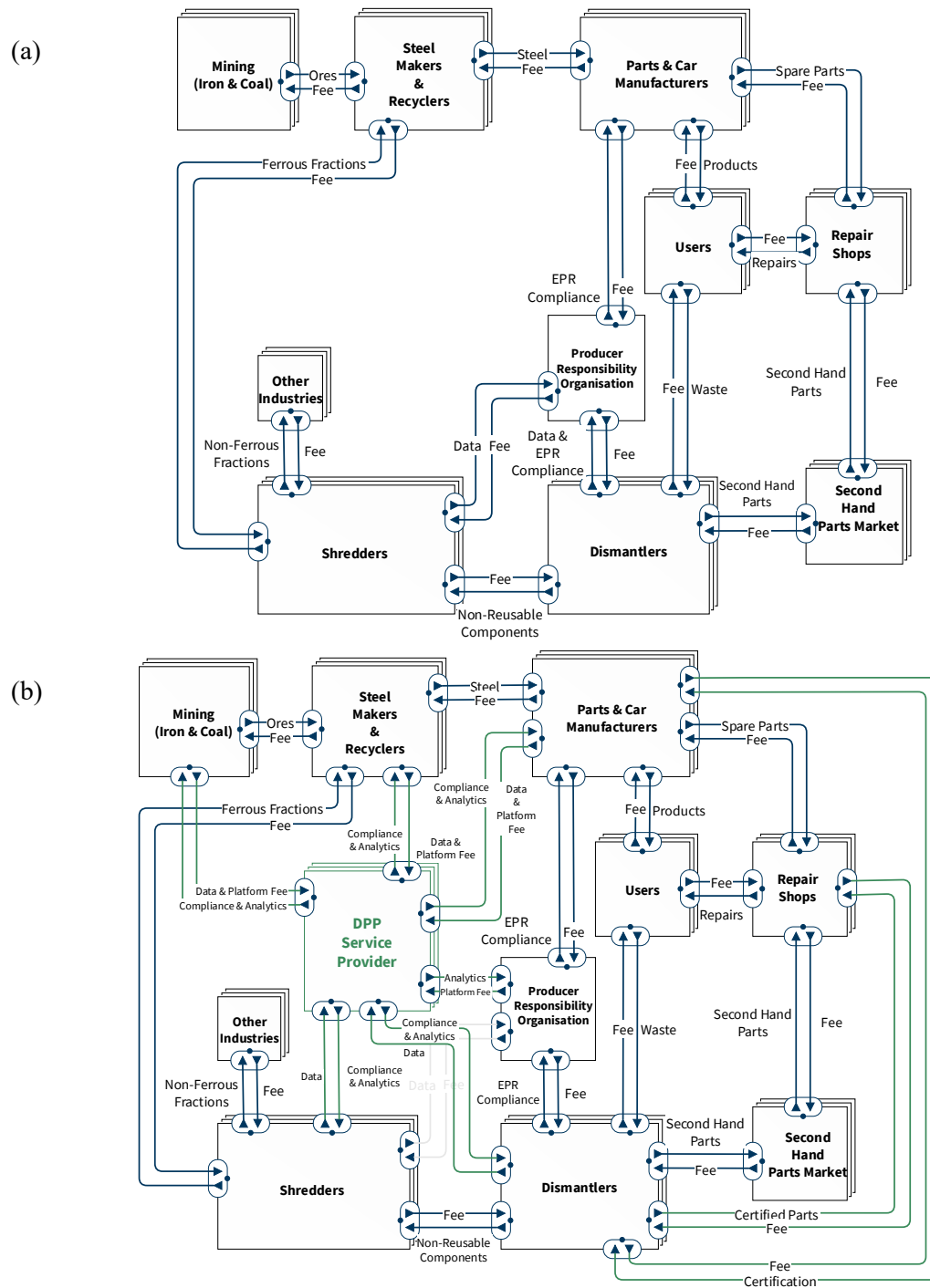


Figure 1. (a) Current and (b) DPP-Enabled Automotive Steel Business Configuration.

4.2 Towards a Taxonomy of tensions

To systematically capture these dynamics, tension matrices were analytically developed for each configuration. Each cell represented a potential tension between two actor groups, derived based on the first author's understanding of the actor's interdependencies and value exchanges in the e³-value models. This led to a total of 128 potential tensions, 55 for the current and 73 for the DPP-enabled tension matrix. These were based on the value exchanges where actors faced new obligations without proportional

benefits, had to provide access to strategically sensitive information, or had competing priorities. Some of these tensions are explained in detail in the next paragraph. A snippet of the tension matrices is tabulated in table 1 for reference. The left diagonal of the matrix shows the tension within the actor, while the other boxes show the tensions between the actors.

Faced by \ Due to	Steel Makers & Recyclers	Dismantlers	DPPSPs
Steel Makers & Recyclers	Data Sovereignty vs Collaboration	Scrap Purity vs Cost of Dismantling	Data Protection vs Collaboration
Dismantlers	Material Info vs Capability	Digitalisation vs Profitability	Data Sharing vs Benefit
DPPSPs	Standardisation vs Flexibility	Data Collection	Neutrality vs Profit Motive

Table 1. *A snippet from the Tension Matrix of DPP-enabled Automotive Steel Ecosystem.*

The tension matrix of the current configuration highlights tensions linked to limited traceability and misaligned incentives. Actors operate in silos, and most tensions stemmed from information gaps, quality uncertainty, and short-term cost priorities. For example, dismantlers and shredders face challenges in accessing reliable data about material composition, leading to scrap mismanagement and eventual downcycling. This configuration also creates an information gap for upstream actors like mines, steelmakers and manufacturers, where they cannot collect reliable end of life (EOL) data from downstream actors, which is essential to ensure reporting and compliance. The DPP-enabled matrix showed how new digital connections introduce both opportunities and tensions. Information now flows more freely, but this also raises new tensions about data ownership, verification mechanisms, and value distribution. For instance, dismantlers gain access to valuable product information but must also bear the cost of data collection. Meanwhile, upstream actors like steelmakers and manufacturers can improve reporting from better EOL data collection but might be resistant to sharing sensitive information like material composition and assembly drawings that might be of value to the EOL actors. Better data availability also leads to new business opportunities, like that of certified second-hand parts discussed in the previous sub-section. While this might be lucrative for manufacturers and dismantlers, and opens a better alternative for users, it could marginalise the unorganised second-hand market by shifting demand towards certified and digitally verifiable spare parts. Also, while DPPSPs enable new forms of traceability and coordination, they may also introduce additional tensions related to data protection, dependency, and value capture. For example, firms may become reliant on third-party providers to manage sensitive product data, raising concerns about control over proprietary information and the distribution of costs associated with maintaining the DPP infrastructure. These matrices provide an initial conjecture on such actor tensions, which shall be validated with GGS actors as the research progresses.

The tensions from these matrices were thematically coded and clustered into three higher-order dimensions, each representing informational, governance and economic tensions in circular ecosystems grounded in theory (Ferlito & Faraci, 2024; Jensen et al., 2024; Luoma et al., 2023). Within each dimension, tensions were further clustered into characteristics abductively to capture recurring patterns in these tensions. This resulted in the first iteration of a taxonomy of tension, tabulated in table 2.

Dimension	Characteristic	Description
Transparency vs Control	Data Sensitivity	Firms treat material composition, sourcing, and process data as strategic assets, creating reluctance to disclose information that might erode competitive advantage.
	Access Rights Asymmetry	Uneven privileges in data visibility and modification arise between upstream and downstream actors, depending on contractual arrangements and technological interfaces.
	Verification Mechanisms	Technical and institutional mechanisms are employed to assure data integrity and build inter-firm trust.

Dimension	Characteristic	Description
Coordination vs Autonomy	Standardisation vs Customisation	Pressure to conform to shared DPP schemas clashes with firm's desire to maintain internal data models and operational standards, generating friction in ecosystem alignment.
	Governance Structure	Disagreements occur over who orchestrates the DPP, leading to different governance structures.
	Operational Flexibility	Firms attempt to optimise local processes and supply-chain decisions while adhering to ecosystem-level constraints, creating tensions between efficiency and independence.
Value Creation vs Value Capture	Redistribution of Roles	New intermediaries such as data service providers, auditors, and certification agencies alter the traditional roles and profit within the ecosystem.
	Incentive Asymmetry	Actors experience disproportionate costs and benefits from adopting DPP infrastructures, leading to conflicts about who should finance and maintain the digital system.
	Business Model Transformation	The transition from linear to circular business logic necessitates new revenue mechanisms such as data-driven services and product as a service models, that challenge existing practices.

Table 2. Taxonomy of Tensions – Iteration 1

The first dimension, **Transparency versus Control**, addresses the tension between the need for openness and traceability to achieve circularity and that of confidentiality to maintain a competitive advantage. As DPPs expand the availability of product-level information across ecosystems, actors face dilemmas about how much data to disclose and under what conditions (Luoma et al., 2023). Steelmakers and manufacturers, for instance, may recognise the systemic benefits of sharing material composition data with dismantlers and recyclers, yet remain cautious due to the risk of revealing proprietary process knowledge, supplier relationships or other Intellectual Properties (IPs). The balance between transparency and control, therefore, becomes a negotiation over trust, access rights, and data governance.

The second dimension, **Coordination versus Autonomy**, captures the organisational tension between collective alignment and individual flexibility. The adoption of DPPs necessitates coordination among actors around common data standards, protocols and information sharing practices. However, while standardisation enhances interoperability and ecosystem efficiency, it can also restrict the autonomy of individual firms to design internal processes or maintain independent data infrastructures (Jensen et al., 2024). DPP-enabled ecosystems thus face the challenge of establishing shared governance frameworks that promote coordination without imposing excessive conformity that hinder innovation.

The third dimension, **Value Creation versus Value Capture**, relates to the redistribution of economic benefits and responsibilities that accompany this reconfiguration. As new intermediaries (such as DPPSPs) emerge, the value flow across the ecosystem shifts, creating potential misalignments in incentives (Ferlito & Faraci, 2024). Some actors, such as steelmakers that benefit from improved feedstock quality, may benefit more directly than dismantlers, who incur additional operational costs for selective disassembly and data collection. The resulting tensions in perceived value capture may lead to resistance to share data, even when it benefits the collective ecosystem.

The three dimensions discussed are interdependent rather than discrete, meaning that decisions that enhance transparency may affect autonomy, and new business models may demand renegotiation of data sharing rights. The next set of empirical iterations are expected to uncover additional DPP-enabled configurations and tensions that might expand the taxonomy. New dimensions and characteristics may be derived from these, further improving this preliminary taxonomy of tensions.

5 Conclusion and Future Steps

This research-in-progress examined how DPPs mediate informational and organisational boundaries in green steel ecosystems. Through e³-value modelling and preliminary tension matrices, the study

illustrated how DPP-enabled reconfigurations introduce tensions across three dimensions: transparency vs control, coordination vs autonomy, and value creation vs value capture. The first iteration of the taxonomy of tensions highlights that the integration of DPPs is not only a technical implementation but also an ecosystem level transformation that might redistribute information, power, and value among interdependent actors. The proposed taxonomy is currently grounded in the context of the European automotive steel industry and the regulatory environment surrounding DPP implementation. As DPP adoption in this sector is largely policy-driven, tensions may manifest differently in sectors where digital traceability systems emerge voluntarily or where ecosystem structures differ significantly, which are avenues for future research.

As an ongoing study, several steps remain to advance the taxonomy towards conceptual and empirical maturity. The next phase will involve qualitative data collection within the GGS consortium through semi-structured interviews, workshops, and document analyses. The empirical iterations will involve a multiple case study of different actors within this ecosystem. Purposeful sampling will be used to approach key stakeholders within GGS, followed by snowball sampling to identify additional actors (also non GGS) and refine the value models. Further conceptual iterations will explore DPPs from platform, II and boundary object perspective to identify its attributes to design additional DPP-enabled configurations that may emerge within the automotive steel ecosystem. These data will inform subsequent empirical and conceptual iterations of the taxonomy, ensuring that the identified dimensions and characteristics reflect real-world tensions and sector-specific nuances. These iterations will continue until both objective and subjective ending conditions are satisfied. Finally, expert validation through focused workshops with consortium partners will assess the accuracy and practical relevance of the taxonomy. The final taxonomy is expected to advance IS research and support a deeper understanding of how DPPs shape transformations in heavy industries such as steel.

Acknowledgements

This research is part of the ‘Groeien met Groen Staal’ Growth Fund program (project number NGFS23005) and was co-funded by the National Growth Fund of the Dutch Government.

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