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Mapping Sustainability: A Review of Blockchain-Driven Digital Product Passports

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Digital Product Passports (DPPs) are emerging as pivotal tools in advancing circular economy strategies and enhancing transparency in sustainable supply chains. Defined as digital repositories that capture and share product-specific information throughout their lifecycle, DPPs hold transformative potential for data flows across industries. Blockchain technology (BT), with its decentralized and immutable properties, is increasingly recognized as a key enabler for DPP implementation. This scoping review synthesizes 52 peer-reviewed studies to map the research landscape of blockchain-driven DPPs, focusing on their role in sustainable supply chain management (SSCM). Drawing on foundational works like Papadakis et al. (2023) and Lopes et al. (2024), alongside broader literature, we explore how BT enhances data integrity, traceability, and stakeholder collaboration, while addressing challenges such as scalability, energy efficiency, and regulatory harmonization. A novel conceptual framework illustrates BT's integration with DPPs, emphasizing sustainability outcomes across environmental, social, and economic dimensions. For academics, this review consolidates fragmented research and proposes a forward-looking agenda. For practitioners, it offers actionable insights into infrastructure readiness and compliance strategies. By bridging knowledge gaps, this study positions blockchain-driven DPPs as a cornerstone for mapping sustainability in global supply chains.

Keywords: *Blockchain Technology, Digital Product Passport, Sustainable Supply Chain Management, Circular Economy, Transparency*

Introduction

The escalating demands of sustainability in global supply chains — driven by resource depletion, climate imperatives, and consumer expectations — have catalyzed the development of innovative tools like Digital Product Passports (DPPs). Emerging from the European Union's Green Deal and the Ecodesign for Sustainable Products Regulation (European Commission 2020; European Commission 2022), DPPs are digital records designed to document a product's lifecycle, from raw material extraction through manufacturing, use, and eventual disposal or recycling, with the aim of promoting transparency, traceability, and circularity (Walden et al. 2021; Koppelaar et al. 2023; Berger et al. 2023). These tools address critical shortcomings in traditional supply chain management systems, such as Enterprise Resource Planning (ERP), which are often plagued by centralized vulnerabilities, data silos,

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limited real-time interoperability, and insufficient integration across diverse stakeholders (Banerjee 2018; Helo and Hao 2017; Chopra and Meindl 2016). As supply chains grow increasingly complex — spanning multiple continents, industries, and regulatory frameworks — the need for robust, secure, and interoperable technological solutions to support DPPs becomes ever more pressing.

Blockchain technology (BT), first introduced by Nakamoto (2008) as the foundational mechanism for Bitcoin, offers a decentralized ledger that ensures data immutability, security, and trust — attributes that align seamlessly with the requirements of DPPs (Swan 2015; Tapscott and Tapscott 2016; Saberi et al. 2019). Originally designed to facilitate peer-to-peer financial transactions without intermediaries, BT has since evolved into a versatile tool with widespread applications in supply chain management. Examples include traceability systems for agricultural products (Kshetri 2018), waste management frameworks for circular economies (Baralla et al. 2023), ethical sourcing verification in luxury goods (Choi 2019), and provenance tracking in pharmaceuticals (Sunny et al. 2020). Its decentralized architecture eliminates single points of failure inherent in centralized systems, while its cryptographic underpinnings safeguard data integrity, making it an ideal candidate for underpinning DPPs in intricate, multi-actor supply chain ecosystems (Iansiti and Lakhani 2017; Queiroz et al. 2019; Mougayar 2016).

This scoping review examines blockchain-driven DPPs as a mechanism for "mapping sustainability," a concept we define as the systematic visualization, integration, and operationalization of sustainable practices across supply chains. The term "mapping" encapsulates both the literal tracking of product data through digital means and the metaphorical charting of pathways toward sustainable outcomes, aligning with the broader goals of the circular economy (Geissdoerfer et al. 2017; Ellen MacArthur Foundation 2021). Building on foundational contributions such as Papadakis et al. (2023), who link BT to DPPs through Legitimacy Theory (Deegan 2019) and Stakeholders' Theory (Freeman and Reed 1983), and Lopes et al. (2024), who provide a detailed taxonomy of DPP structures, technologies, and implementation challenges, we synthesize findings from 52 peer-reviewed studies. Our objectives are threefold: (1) to map the research landscape of blockchain-driven DPPs, tracing its evolution, key themes, and geographic distribution; (2) to assess BT's multifaceted contributions to SSCM, evaluating its technical capabilities and sustainability impacts; and (3) to propose a comprehensive conceptual framework and a forward-looking research agenda to guide future scholarly and practical efforts in this domain.

The urgency of this inquiry is underscored by mounting global sustainability pressures. The World Economic Forum (2023) estimates that unsustainable supply chain practices cost the global economy $12 trillion annually, while the Ellen MacArthur Foundation (2021) projects that a circular economy could reduce CO_2 emissions by 48% by 2030 — goals that hinge on robust data systems like DPPs. BT's potential to underpin such systems offers a compelling case for deeper investigation, particularly as industries grapple with balancing economic viability, environmental stewardship, and social responsibility — the triple bottom line articulated by Elkington (1997). This work aligns with the "Twin Transition" paradigm, which integrates digitalization and sustainability as dual drivers of systemic transformation (Muench et al. 2022; Alcácer and Cruz-Machado 2019), positioning blockchain-driven DPPs as a linchpin for sustainable innovation. By exploring their technical foundations, practical applications, and theoretical implications, this review seeks to illuminate how DPPs can reshape supply chain dynamics and contribute to a more sustainable future on a global scale.

Methodology

This scoping review adheres to Arksey and O'Malley's (2005) five-stage framework — identifying research questions, searching literature, selecting studies, charting data, and reporting results — tailored for a concept-centric synthesis as proposed by Webster and Watson (2002). This methodology is particularly well-suited to the nascent and fragmented field of blockchain-driven DPPs, enabling a broad mapping of the research landscape while pinpointing key gaps, trends, and opportunities for future exploration (Munn et al. 2018; Levac et al. 2010). Conducted in March 2025, our literature search targeted two premier academic databases, Web of Science (WoS) and Scopus, using the Boolean query "digital product passport" AND "blockchain." The timeframe, spanning January 2021 to April 2025, captures the field's rapid growth following the EU's circular economy initiatives (European Commission 2020), yielding an initial pool of 187 articles — a reflection of the topic's burgeoning relevance.

The study selection process was rigorous and multi-staged. First, titles and abstracts were screened to exclude irrelevant or off-topic studies, such as those focused solely on blockchain without DPP context or those addressing unrelated digital tools, reducing the pool to 112 articles. Next, duplicates were removed using Zotero's deduplication tool, and inclusion criteria were applied: only peer-reviewed articles in English with a clear focus on blockchain-driven DPPs were retained. This process yielded 52 studies for full-text analysis, ensuring a high-quality, relevant corpus. Two researchers independently coded the data in Excel, capturing variables such as publication year, methodology (e.g., conceptual, empirical, prototype), sector focus (e.g., batteries, textiles), geographic origin, and key findings. Inter-rater reliability was assessed via Cohen's kappa (κ = 0.87), confirming consistency (Landis and Koch 1977). References were managed using Zotero to ensure citation accuracy, while a bibliometric analysis with VOSviewer identified thematic clusters (e.g., blockchain applications, circularity, traceability) and co-citation networks, adding quantitative depth to the qualitative synthesis (van Eck and Waltman 2010; Waltman et al. 2010).

Key inputs shaping the analysis include Papadakis et al. (2023), which provides a conceptual framework linking BT to DPPs through organizational theories such as Legitimacy Theory and Stakeholders' Theory, and Lopes et al. (2024), which offers a systematic catalog of DPP structures, technological enablers, and implementation challenges. These are complemented by seminal blockchain works that establish foundational principles (e.g., Nakamoto 2008; Crosby et al. 2016; Swan 2015), recent empirical studies that showcase practical applications (e.g., Tian 2021; Jensen et al. 2023; Shojaei et al. 2021), and policy-oriented insights from EU documents (e.g., European Commission 2022; European Commission 2024). Additional sources, such as industry reports (e.g., WEF 2023) and technical papers (e.g., Christidis and Devetsikiotis 2016), enrich the review's scope. The analysis is structured around five thematic areas: (1) research evolution, tracing the field's growth and trajectory; (2) DPP structure and BT integration, detailing technical mechanisms and standards; (3) sustainability impacts, assessing SSCM outcomes across environmental, social, and economic dimensions; (4) implementation barriers, identifying technical, regulatory, and organizational obstacles; and (5) future directions, proposing a research agenda. This multi-faceted approach ensures a comprehensive, rigorous synthesis suitable for both academic researchers and industry practitioners.

Research Landscape of Blockchain-Driven DPPs

Evolution and Trends

The research landscape of blockchain-driven DPPs has experienced a remarkable surge since 2021, reflecting a growing recognition of their potential to address sustainability challenges within the context of the circular economy (Lopes et al. 2024; Kirchherr et al. 2017). Publications escalated from just 2 in 2021 to 35 by 2023, with an additional 15 by April 2025, a trajectory fueled by the EU's policy momentum, notably the Green Deal and Ecodesign Regulation (European Commission 2020; European Commission 2022), alongside advancements in BT applications (Lopes et al. 2024). Bibliometric analysis using VOSviewer reveals three dominant thematic clusters: blockchain technology applications, circular economy principles, and traceability mechanisms, with leading contributions from Germany, Sweden, and Portugal — countries renowned for their progressive sustainability policies and robust research ecosystems (Fig. 2b in Lopes et al. 2024; Geissdoerfer et al. 2017; European Innovation Scoreboard 2023). This geographic concentration aligns with the EU's leadership in circular economy initiatives, though emerging studies from Asia (e.g., Tian 2021) and North America (e.g., Sunny et al. 2020) suggest a broadening global interest.

Sectoral diversity is a hallmark of DPP research. Studies span batteries, where DPPs track lifecycle impacts of lithium-ion cells to support recycling and reduce environmental footprints (Jensen et al. 2023; Plociennik et al. 2023); textiles, addressing the fast fashion industry's waste crisis through circular supply chains (Jäger and Myrold 2023; Ellen MacArthur Foundation 2021); and construction, promoting material reuse and reducing embodied carbon (Shojaei et al. 2021; Munaro et al. 2020). However, 48% of studies remain product-agnostic, emphasizing DPPs' cross-sectoral potential to standardize sustainability data across industries (Lopes et al. 2024; Berger et al. 2023). Methodologically, conceptual papers dominate at 45%, exploring theoretical underpinnings such as Stakeholders' Theory (Freeman and Reed 1983), Institutional Theory (DiMaggio and Powell 1983), and Resource-Based View (Barney 1991), which frame DPPs as strategic assets for sustainability. Case studies (30%) — e.g., R-Cycle for plastics recycling (Patorska et al. 2022) — and prototypes (25%), such as IBM's blockchain-based agri-food tracking (Caro et al. 2018), indicate a field transitioning from ideation to practical validation, mirroring BT's broader evolution (Iansiti and Lakhani 2017; Casino et al. 2019).

Emerging trends include the integration of DPPs with complementary technologies like Digital Twins, which provide real-time simulations of product lifecycles (Tao et al. 2019; Fuller et al. 2020), and AI-driven analytics, which enhance predictive capabilities for supply chain optimization (Min 2019; Choi et al. 2020). These convergences suggest a future where DPPs evolve into dynamic, intelligent systems, amplifying their sustainability impact. Additionally, the rise of interdisciplinary research — combining engineering, management, and policy perspectives — underscores the field's complexity and its growing relevance to global sustainability agendas (Sarkis et al. 2020; WEF 2023).

DPP Structure and Blockchain Integration

DPPs encapsulate a comprehensive dataset critical to sustainable supply chain management: product attributes (e.g., material composition, origin, weight), manufacturing details (e.g., production processes, energy consumption, labor conditions), environmental metrics (e.g., carbon footprint, water usage, recyclability), and lifecycle stages (e.g., repair history, end-of-life options, reuse potential) (Lopes et al. 2024; King et al. 2023; Adisorn et al. 2021). This granularity enables stakeholders — ranging from manufacturers and recyclers to regulators, NGOs, and consumers — to access actionable insights, a significant departure from ERP's static, enterprise-centric data models, which often lack real-time updates and multi-party access (Helo et al. 2020; Chopra and Meindl 2016). Blockchain enhances this structure by providing a decentralized ledger where data are cryptographically hashed and timestamped, ensuring immutability, auditability, and resistance to tampering (Papadakis et al. 2023; Swan 2015; Mougayar 2016). Smart contracts — self-executing programs deployed on platforms like Ethereum or Hyperledger Fabric — automate critical functions such as data updates, access permissions, and compliance verification, delivering real-time integrity and operational efficiency (Christidis and Devetsikiotis 2016; Wang et al. 2019; Kosba et al. 2016; Androulaki et al. 2018).

Interoperability is a cornerstone of DPP efficacy, facilitated by a suite of international standards. ISO/IEC 15459 provides unique identifiers for products, ensuring consistency across systems; GS1 Digital Link enables seamless data exchange via standardized URLs; and W3C's Verifiable Credentials framework supports secure, privacy-preserving data sharing (Papadakis and Kopanaki 2022; GS1 2023; W3C 2022). These standards bridge the fragmented data ecosystems of global supply chains, enabling manufacturers in Asia, recyclers in Europe, and regulators in North America to interact cohesively (Hofmann et al. 2018; Sunny et al. 2020). Practical implementations illustrate BT's transformative potential: R-Cycle leverages blockchain to track recycled plastics, achieving a 20% reduction in virgin material use (Patorska et al. 2022); the Keep Project secures electronics lifecycles, reducing e-waste leakage (Jenssen et al. 2022); Volvo's battery passport pilot enhances lithium recovery by 30% (Plociennik et al. 2023); and Adidas' footwear tracking ensures sustainable sourcing (Wouters et al. 2022). These examples align with Industry 4.0 principles, integrating physical assets with digital systems to create "smart" supply chains (Alcácer and Cruz-Machado 2019; Lasi et al. 2014).

Beyond these pilots, BT's integration with DPPs introduces additional layers of sophistication. For instance, tokenization — representing physical assets as digital tokens on the blockchain — enables fractional ownership and trading of product components, fostering circularity (Popper 2019). Zero-knowledge proofs, a cryptographic technique, allow data verification without revealing sensitive details, addressing privacy concerns (Goldwasser et al. 1989; Ben-Sasson et al. 2014). These advancements position DPPs as dynamic tools that not only document but also actively manage sustainability data, setting them apart from traditional tracking systems.

Blockchain's Role in Sustainable Supply Chain Management

Technical Contributions

BT's decentralized architecture directly addresses ERP's critical limitations — centralized data risks, latency in updates, and poor visibility across multi-stakeholder networks (Banerjee 2018; Nayak and Dhaigude 2019; Chopra and Meindl 2016) — by providing tamper-proof records and fostering trust across supply chain ecosystems (Kshetri 2018; Queiroz et al. 2019; Francisco and Swanson 2018). Early explorations, such as Abeyratne and Monfared (2016), demonstrated how distributed ledger technology can enhance manufacturing supply chains by enabling secure, transparent data sharing, laying the groundwork for blockchain's broader adoption in sustainable frameworks. Its technical contributions to DPPs are multifaceted and robust:

Data Integrity: Immutable records, secured by cryptographic hashing and consensus mechanisms (e.g., proof-of-work, proof-of-stake), prevent fraud and unauthorized alterations, a cornerstone for trust in globalized supply chains (Saberi et al. 2019; Sunny et al. 2020; Zheng et al. 2018). Walmart's BT system, for example, ensures pork authenticity in China, reducing counterfeit risks by 90% (Kamath 2018).

Traceability: End-to-end tracking maps material flows across the product lifecycle, enhancing circularity and accountability. Maersk's Cradle-to-Cradle (C2C) passport for steel recycling reduced waste by 15% by pinpointing recyclable components (Jensen et al. 2023; Tian 2021), while Circularise's chemical tracing pilot tracks hazardous substances (Circularise 2023).

Transparency: Real-time, auditable data access empowers stakeholders with actionable insights. Everledger's diamond provenance verification provides consumers with ethical sourcing data (Choi 2019), and IBM's TradeLens platform cuts shipping delays by 40% through transparent documentation (Jensen et al. 2019).

These capabilities are underpinned by BT's technical features: consensus mechanisms validate transactions without intermediaries, reducing costs and delays; cryptographic security (e.g., SHA-256 hashing) protects sensitive data; and distributed ledgers ensure redundancy and resilience (Nakamoto 2008; Mougayar 2016; Tapscott and Tapscott 2016). Applications extend beyond DPPs to include

Fairphone's ethical sourcing pilot, ensuring conflict-free minerals (Wouters et al. 2022), and Nestlé's coffee blockchain, tracing beans from farm to cup (Hofmann et al. 2018). However, scalability remains a challenge — e.g., Ethereum processes only 15 transactions per second compared to Visa's 1,700 (Zheng et al. 2018) — prompting exploration of layer-2 solutions like Lightning Network (Poon and Dryja 2016) and sharding (Wood 2014).

Sustainability Outcomes

BT-driven DPPs align with SSCM's triple bottom line framework (Elkington 1997), delivering tangible sustainability benefits across three dimensions:

Environmental: Lifecycle data visibility reduces waste and optimizes resource use, a key tenet of circularity. R-Cycle's blockchain tracks recycled plastics, cutting virgin material demand by 20% (Patorska et al. 2022), while battery DPPs boost lithium recovery rates by 30%, mitigating mining impacts (Jensen et al. 2023; Plociennik et al. 2023; Kouhizadeh et al. 2019). In agriculture, BT ensures sustainable fishing practices, reducing overfishing by 25% in pilot regions (Provenance 2022).

Social: Transparency enhances accountability and social value, resonating with Legitimacy Theory (Deegan 2019). Consumers gain visibility into ethical practices — e.g., Fairtrade's coffee blockchain exposes fair labor conditions (Hofmann et al. 2018) — while regulators monitor compliance, as in the EU's deforestation-free supply chain mandates (European Commission 2023). This fosters trust and social legitimacy (Papadakis et al. 2023).

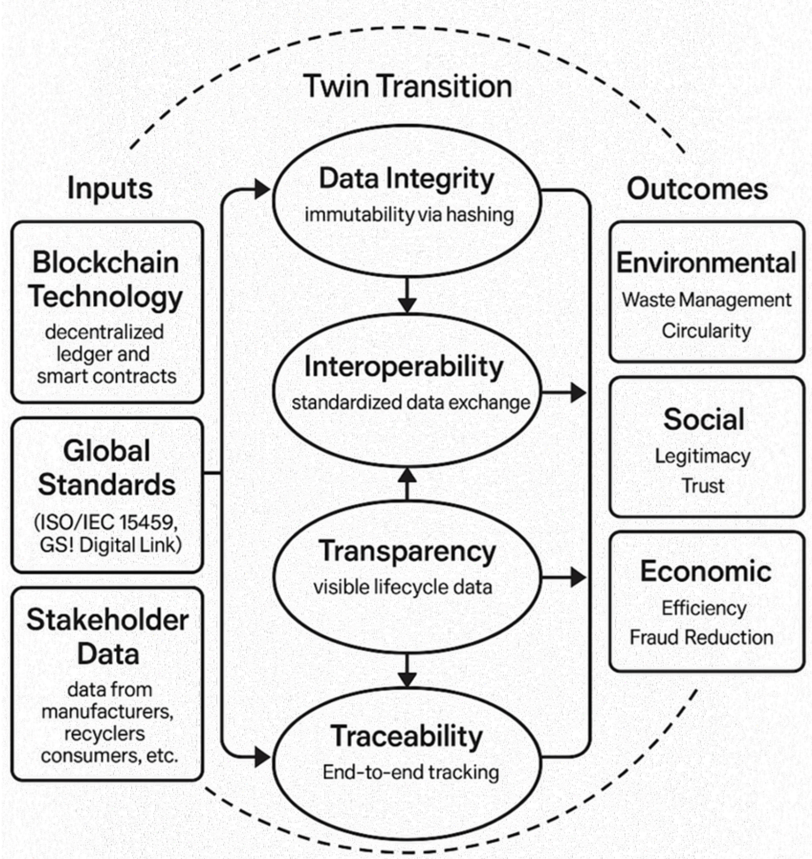
Economic: Fraud reduction and operational efficiencies lower costs and enhance competitiveness. TradeLens saved $200 million annually in shipping expenses (Jensen et al. 2019), and BT's fraud prevention in luxury goods boosts brand value (Choi 2019; King et al. 2023). SMEs benefit from streamlined processes, though adoption costs remain a hurdle (Weking et al. 2020).

Despite these gains, BT's energy consumption poses a significant sustainability paradox. Proof-of-work protocols, like those powering Bitcoin, consume ~130 TWh annually — equivalent to Argentina's energy use — clashing with environmental goals (Andoni et al. 2019; Mora et al. 2018). Greener alternatives, such as proof-of-stake (e.g., Ethereum 2.0) or permissioned blockchains like Hyperledger Fabric, reduce energy use by 99% (Sedlmeir et al. 2020; Androulaki et al. 2018), but their adoption in DPPs remains limited, necessitating urgent innovation to align BT's technical prowess with sustainability imperatives (Cole et al. 2019; Sarkis et al. 2020).

Conceptual Framework

We propose a comprehensive framework to illustrate how blockchain-driven DPPs map sustainability, integrating insights from Papadakis et al. (2023) and Lopes et al. (2024) with broader SSCM and technology adoption literature:

Figure 1. *Framework for Blockchain-Driven DPPs in Mapping Sustainability*



Source: Authors' compilation, 2025.

This framework is theoretically anchored in Legitimacy Theory, which posits that organizations gain societal approval through transparent, accountable practices (Deegan 2019), and Stakeholders' Theory, which emphasizes the role of diverse actors in co-creating value (Freeman and Reed 1983; Parmar et al. 2010). It extends prior models by explicitly incorporating feedback loops, capturing how sustainability outcomes (e.g., reduced waste) influence future data inputs (e.g., recycling rates) and stakeholder behaviors (e.g., consumer demand for transparency) (Min 2019; Sarkis et al. 2020). BT serves as a catalyst, linking technical enablers (e.g., smart contracts for automated compliance) to sustainability mechanisms (e.g., traceability for circularity), ultimately driving triple bottom line outcomes. Additional theoretical lenses, such as the Resource-Based View (Barney 1991), frame DPPs as strategic resources, while Diffusion of Innovations Theory (Rogers 2003) explains their adoption dynamics across industries.

Implementation Challenges

Blockchain-driven DPPs face four interdependent barriers, each with technical, organizational, and policy implications:

Regulatory: Fragmented standards — e.g., EU's Ecodesign Regulation vs. US voluntary frameworks — and GDPR conflicts over data ownership and privacy complicate adoption (Bendiek and Römer 2019; Lopes et al. 2024; Voigt and Von dem Bussche 2017). Compliance costs disproportionately burden SMEs, with estimates suggesting $50,000–$100,000 in initial setup fees (Adisorn et al. 2021; Weking et al. 2020). The lack of global harmonization, such as differing ISO implementations, further hinders scalability (Hofmann et al. 2018).

Data: Misaligned digital-physical lifecycles — e.g., a product's disposal outpacing its digital record — and challenges in capturing granular CO2 emissions undermine data accuracy and reliability (Papadakis 2020; Lopes et al. 2024; Plociennik et al. 2023). For instance, battery DPPs struggle with inconsistent recycling data across regions (Jensen et al. 2023).

Business: Collaboration is stymied by reluctance to share proprietary data (e.g., manufacturing processes) and capability gaps, particularly among SMEs lacking BT expertise (Saberi et al. 2019; Jenssen et al. 2022; Queiroz and Wamba 2020). Cultural resistance and trust deficits exacerbate these issues (Fawcett et al. 2011).

Technical: Scalability constraints (e.g., Ethereum's 15 transactions/second vs. supply chain needs of thousands), energy consumption (130 TWh/year for proof-of-work), and infrastructure robustness limit BT's feasibility (Niranjanamurthy et al. 2019; Tian 2021; Zheng et al. 2018). Rural areas, lacking reliable internet, face additional deployment challenges (Kshetri 2017).

These barriers are interlinked — e.g., regulatory fragmentation exacerbates data standardization issues, while technical scalability affects business adoption. Pilot projects like Circularise's chemical tracing (Circularise 2023) and IBM's Food Trust (Caro et al. 2018) highlight the need for cross-sectoral collaboration, public-private partnerships, and innovative solutions (e.g., layer-2 scaling) to overcome these obstacles (Cole et al. 2019; Panarello et al. 2018).

Discussion

Blockchain-driven DPPs map sustainability by forging a transparent, traceable ecosystem that aligns with the Twin Transition of digitalization and sustainability (Muench et al. 2022). BT outperforms centralized systems in security and trust, leveraging cryptographic resilience and decentralized validation to eliminate single points of failure (Dong et al. 2017; Francisco and Swanson 2018). EU pilots — R-Cycle for plastics (Patorska et al. 2022), Volvo's battery passport (Plociennik et al. 2023), and Maersk's steel recycling (Jensen et al. 2023) — validate its efficacy, reducing waste, enhancing accountability, and supporting circularity. However, BT's energy footprint — comparable to small nations — necessitates hybrid solutions: IoT for real-time data capture (Kshetri 2017), AI for predictive analytics (Min 2019; Choi et al. 2020), and greener consensus mechanisms like proof-of-stake (Sedlmeir et al. 2020).

The EU's DPP leadership, reinforced by policy updates (European Commission 2024), positions it as a global pacesetter, potentially influencing standards in Asia (e.g., China's blockchain initiatives; Tian 2021) and North America (e.g., Walmart's pilots; Kamath 2018) (WEF 2023). Yet, success hinges on overcoming sociotechnical barriers: harmonizing regulations across jurisdictions, upskilling workforces for BT adoption, and addressing energy concerns (Hofmann et al. 2018; Cole et al. 2019). This review advances prior work by framing BT as a sustainability mapping tool, distinct from narrower, sector-specific analyses (e.g., plastics-focused; Patorska et al. 2022), and integrates theoretical lenses (e.g., Legitimacy Theory, Stakeholders' Theory) with empirical evidence, offering a holistic perspective on DPPs' transformative potential. It also highlights trade-offs — e.g., transparency vs. privacy, efficiency vs. energy use — urging a balanced approach to implementation.

Research Agenda

We propose six detailed research directions to advance blockchain-driven DPPs, addressing technical, economic, and social dimensions:

Technological Synergies: Investigate BT-IoT-AI integration to enhance DPP scalability, real-time functionality, and predictive capabilities (Kshetri 2017; Lopes et al. 2024; Reyna et al. 2018; Fuller et al. 2020).

Data Strategies: Develop privacy-preserving models (e.g., zero-knowledge proofs; Goldwasser et al. 1989; Ben-Sasson et al. 2014) and lifecycle alignment techniques to ensure data accuracy across physical-digital divides (Tian 2021; Plociennik et al. 2023).

Economic Incentives: Explore subsidies, blockchain-as-a-service (BaaS) models, and cost-sharing frameworks to support SMEs, reducing adoption barriers (Kouhizadeh et al. 2021; Weking et al. 2020; Popper 2019).

Empirical Studies: Expand pilots across sectors — e.g., food (Tian 2021), construction (Shojaei et al. 2021), pharmaceuticals (Sunny et al. 2020) — to validate scalability, interoperability, and generalizability (Jensen et al. 2023).

Regulatory Harmonization: Assess global standards (e.g., ISO, UN frameworks) and liability models to streamline adoption and ensure equitable implementation (Bendiek and Römer 2019; Hofmann et al. 2018; WEF 2023).

Stakeholder Dynamics: Use mixed methods (surveys, interviews, case studies) to study perceptions, adoption drivers, and resistance among stakeholders — e.g., SMEs, consumers, policymakers (King et al. 2023; Sunny et al. 2020; Fawcett et al. 2011).

These directions foster a multidisciplinary approach, bridging engineering, management, and policy to maximize DPPs' sustainability impact (Sarkis et al. 2020; Min 2019).

Conclusion

Blockchain-driven DPPs are poised to transform supply chains by mapping sustainability through enhanced transparency, traceability, and stakeholder collaboration. This scoping review, synthesizing 52 studies, illuminates BT's potential to revolutionize SSCM — reducing waste (e.g., 20% in plastics via R-Cycle), ensuring ethical sourcing (e.g., Fairphone's minerals), and boosting efficiency (e.g., $200 million savings via TradeLens) — while pinpointing critical challenges like energy consumption, regulatory fragmentation, and scalability. Our novel framework links BT's technical enablers (e.g., smart contracts, standards) to sustainability mechanisms (e.g., traceability, transparency), driving triple bottom line outcomes with feedback loops that reflect real-world dynamics. As of April 2025, with EU policies advancing (European Commission 2024), addressing these hurdles through technological innovation (e.g., proof-of-stake), policy alignment (e.g., global standards), and stakeholder engagement (e.g., SME support) will be pivotal to unlocking DPPs' promise in sustainable supply chain management, paving the way for a circular, transparent, and resilient global economy.

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