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DIGITAL PRODUCT PASSPORT AND BLOCKCHAIN: AN INTEGRATED APPROACH TO ENSURING PRODUCT TRACEABILITY

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Abstract
The growing demand for product transparency, sustainability, and circular economy practices has accelerated the development of Digital Product Passport (DPP) systems. This paper explores the integration of blockchain technology into DPP frameworks to enhance product traceability across the entire lifecycle — from raw material sourcing to end-of-life recycling. By leveraging blockchain's decentralized, immutable, and transparent nature, DPPs can ensure trustworthy data exchange among stakeholders while reducing the risk of fraud and data manipulation. The study analyzes the technical architecture, potential challenges, and real-world applications of blockchain-enabled DPPs, highlighting their role in promoting sustainable manufacturing, regulatory compliance, and consumer trust. Special attention is given to how this integrated approach can be adapted to emerging economies where digital infrastructure is evolving.

Keywords: Digital Product Passport (DPP), blockchain, Supply Chain Transparency, product traceability, circular economy, Smart Contracts, IoT, decentralization, sustainability

Introduction

In recent years, the push for sustainable development, circular economy models, and environmentally responsible consumption has led to the emergence of innovative digital tools for product lifecycle management. One such innovation is the **Digital Product Passport (DPP)**—a system designed to collect, store,

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and share critical information about a product's origin, composition, use, and end-of-life treatment. DPPs aim to increase transparency and traceability across supply chains, enabling consumers, regulators, and manufacturers to make informed decisions.

However, the effectiveness of DPPs depends largely on the reliability and integrity of the data they contain. Traditional centralized databases are vulnerable to data tampering, single points of failure, and limited interoperability across stakeholders. To address these challenges, blockchain technology has emerged as a promising solution. With its decentralized, immutable ledger system, blockchain ensures that data entered into the DPP cannot be altered retroactively, thus building trust among all participants in the product's value chain.

This paper investigates the **integration of blockchain with DPP systems** as a means to ensure secure, transparent, and verifiable product traceability. It examines the benefits, implementation challenges, and the broader implications for industries seeking to comply with sustainability regulations and enhance consumer confidence. Particular attention is given to how this technology can be adapted to the context of developing economies, such as Uzbekistan, where digital transformation is gaining momentum.

Literature Review

The concept of the Digital Product Passport (DPP) has gained increasing attention within the context of the European Green Deal and other global sustainability initiatives. According to the European Commission (2022), DPPs are expected to become a standard tool for tracking product-related data to enable circular economy practices, especially in sectors such as electronics, textiles, and batteries. Research by Moktadir et al. (2023) emphasizes the role of DPPs in improving supply chain transparency and facilitating eco-design by enabling end-users and regulators to access accurate, real-time product information.

However, many scholars highlight critical limitations in existing DPP frameworks, particularly regarding data security and interoperability. Traditional centralized systems are prone to single points of failure and limited stakeholder

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trust. To overcome these issues, blockchain technology has been proposed as a viable solution. Kim et al. (2024) present a blockchain-based DPP model that ensures data immutability and decentralization, significantly improving system resilience and credibility. Similarly, Lee and Choi (2022) demonstrate how smart contracts can automate the verification of product attributes in a DPP ecosystem, reducing the reliance on third-party audits.

In addition, Tan et al. (2023) explore the integration of Internet of Things (IoT) devices with blockchain-enabled DPPs, enabling real-time monitoring of product conditions such as temperature, usage, and handling throughout the supply chain. While these technological advances show promise, critics such as Zhao **(2021)** caution that high computational costs, regulatory uncertainties, and scalability issues may limit the widespread adoption of blockchain in DPP implementation, especially in developing countries.

Despite these challenges, a growing body of literature supports the notion that combining DPP with blockchain represents a foundational step toward achieving transparent, secure, and sustainable product systems. This review highlights the need for more context-specific studies, particularly in regions like Central Asia, where digital infrastructure is still emerging but presents significant potential for rapid transformation.

Methodology

This research adopts a qualitative, exploratory approach to analyze the integration of blockchain technology into Digital Product Passport (DPP) systems for enhanced product traceability. The methodology is structured around three core phases:

Literature-Based Framework Design. An in-depth review of peer-reviewed journal articles, policy documents, and technical whitepapers was conducted to establish a theoretical framework for DPP implementation using blockchain. This helped identify existing architectural models, technical requirements, and real-world use cases in both developed and emerging economies.

Comparative Case Study Analysis. Three real-world implementations of blockchain-enabled DPP systems—two from the European Union and one pilot initiative from Southeast Asia—were selected and analyzed comparatively. Each

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case was examined in terms of architecture, stakeholder roles, data management strategies, and outcomes related to traceability and transparency. This analysis served to identify best practices and context-specific challenges.

Applicability Assessment for Emerging Markets. Based on the findings from the above stages, a conceptual model was developed to assess the feasibility of applying blockchain-based DPP in emerging economies, with a particular focus on Uzbekistan. Factors such as digital infrastructure maturity, regulatory frameworks, technological readiness, and stakeholder involvement were evaluated using secondary data and policy reports.

The chosen methodology enables the identification of both technical and socio-economic barriers to DPP adoption in developing contexts while proposing adaptable, scalable models based on global experience.

Results

The integration of blockchain technology into Digital Product Passport (DPP) systems significantly improves product traceability and data integrity across the entire supply chain. Through the use of immutable ledgers and decentralized data architecture, blockchain allows secure and transparent information sharing among stakeholders, reducing the risk of fraud and ensuring regulatory compliance. Case studies from the European Union indicate that blockchain-enabled DPPs enhance trust by providing verifiable information about a product's materials, environmental impact, and lifecycle history. Moreover, when paired with Internet of Things (IoT) technologies, these systems enable real-time tracking of product conditions—such as temperature or location—which is particularly valuable in sectors like food safety, logistics, and pharmaceuticals.

Blockchain is a distributed ledger technology that enables the secure, transparent, and tamper-resistant recording of transactions across multiple nodes in a network. Unlike traditional centralized databases, blockchain operates without a single controlling authority, relying instead on consensus mechanisms to validate and permanently store information. Each record (or "block") is linked to the previous one, forming a chronological "chain" that is cryptographically secured and nearly impossible to alter retroactively.

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In the context of Digital Product Passports (DPP), blockchain offers several strategic advantages. It ensures data immutability, meaning once product information is recorded (such as origin, materials, environmental impact, or ownership history), it cannot be manipulated without detection. This is crucial for supply chain transparency and traceability, especially in sectors where regulatory compliance and consumer trust are critical, such as electronics, textiles, food, and pharmaceuticals. Furthermore, blockchain enables multi-stakeholder trust, allowing manufacturers, suppliers, regulators, and consumers to access verifiable product data without relying on a central authority.

Another key advantage is the potential for automation via smart contracts, which can trigger actions (e.g., certifications, alerts, or ownership transfers) when certain conditions are met, improving supply chain efficiency. When integrated with IoT devices, blockchain can support real-time data capture, enhancing monitoring and lifecycle documentation. However, while blockchain brings robust security and traceability, it must be implemented with consideration for interoperability, privacy laws, and technical scalability to be effective within the DPP ecosystem.

Implementing Digital Product Passports (DPP) using blockchain technology presents several significant challenges(fig.1). High technological and financial costs make it difficult for small and medium-sized enterprises (SMEs) to adopt blockchain solutions due to the resources required for development and maintenance. In many developing countries, including Uzbekistan, limited digital infrastructure—such as unreliable internet, inadequate server capacity, and the absence of secure digital identification systems—further hampers implementation. Although blockchain ensures data immutability, it cannot guarantee the accuracy of the input data, making the system vulnerable to the "garbage in, garbage out" problem. The lack of global standardization for DPP formats and blockchain protocols creates interoperability issues across industries and jurisdictions. Moreover, blockchain's transparent and permanent nature raises privacy and data protection concerns, particularly in the context of regulations like the GDPR. Regulatory uncertainty is another barrier, as many countries have not yet established clear legal guidelines for blockchain use in supply chains. Finally, public blockchains often suffer from scalability and

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performance limitations, including low transaction throughput and high latency, which restrict their effectiveness in large-scale, real-time industrial environments.

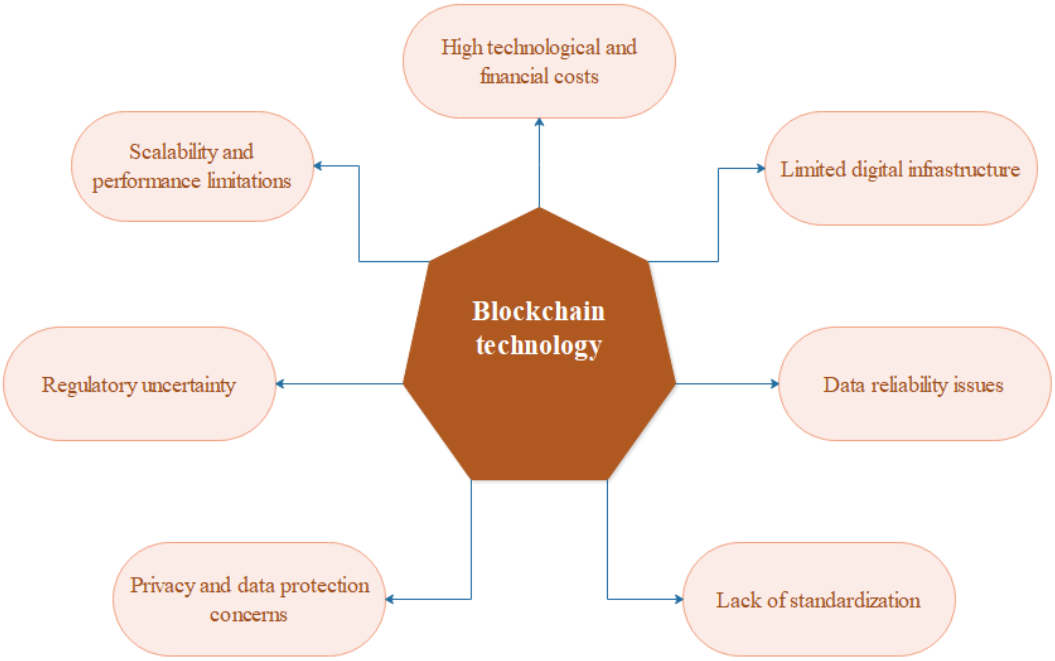

Figure 1. Challenges of implementing DPP using blockchain technology

Implementing Digital Product Passports (DPPs) on blockchain requires meeting several critical criteria to ensure a secure, efficient, and scalable ecosystem. Chief among these is safeguarding privacy and confidentiality, particularly for sensitive data like proprietary manufacturing details. To manage growing volumes of product and transaction data, scalability and operational efficiency are essential. DPP systems must also be interoperable, allowing seamless integration across various platforms and stakeholders in complex supply chains. Decentralization reinforces stakeholder trust by eliminating reliance on a single authority, while smart contract functionality automates workflows and minimizes manual errors. Equally important are data integrity and security, which ensure that all information is accurate, tamper-proof, and accessible only to authorized users. DPP systems should also be sector-independent, using standardized data formats for universal applicability, and must support event-

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based supply chain traceability, capturing what, who, when, where, and why details of each product interaction. A comparative evaluation of blockchain platforms highlights Secret Network as the most suitable for DPP deployment due to its strong combination of privacy protection, scalability, and smart contract features—setting it apart from alternatives like Ethereum, Hyperledger Fabric, and Corda.

Table 1. Comparison of blockchain platforms for DPP implementation.

Feature	Ethereum	Hyperledger Fabric	Corda
Type of Network	Public (permissionless)	Permissioned (private)	Permissioned (private)
Privacy & Confidentiality	Low (open to all)	High (fine-grained access control)	Very High (data shared only with parties)
Smart Contract Support	Yes (Solidity-based)	Yes (Chaincode – Go/Java)	Yes (via CorDapps)
Scalability	Medium (network congestion issues)	High (modular and optimized for enterprise)	Medium (optimized for peer-to-peer flows)
Transaction Speed	Slower (gas fee dependent)	Fast (parallel execution possible)	Fast (based on notary system)
Use Case Fit	Best for open, decentralized systems	Best for regulated industries and consortiums	Best for financial/legal private networks
Interoperability	Medium	High (pluggable architecture)	Medium
Data Immutability	Very High	High	Medium (uses states instead of blocks)
Developer Ecosystem	Large and mature	Growing enterprise ecosystem	Niche but strong in finance
Ideal for DPP	Open/global DPP systems	Enterprise-grade DPPs with compliance focus	Closed-network DPPs needing confidentiality

Conclusion

The integration of blockchain technology into Digital Product Passport (DPP) systems represents a promising and transformative step toward achieving transparency, traceability, and sustainability in global supply chains. By leveraging the decentralized, immutable, and transparent nature of blockchain,

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DPPs can provide trustworthy and verifiable product information throughout a product's lifecycle—from raw material sourcing to disposal or recycling. This fosters greater accountability among manufacturers and supply chain actors, strengthens regulatory compliance, and builds consumer trust. Moreover, the integration of IoT devices and smart contracts further enhances automation, real-time monitoring, and data accuracy, all of which are essential for efficient supply chain management in the circular economy.

However, the successful implementation of blockchain-enabled DPPs requires overcoming several critical challenges, including high technological costs, limited digital infrastructure, interoperability issues, and privacy concerns. The comparative analysis of blockchain platforms suggests that permissioned networks such as Secret Network and Hyperledger Fabric offer more suitable architectures for enterprise-grade DPP deployment due to their scalability, privacy, and modular design. For developing countries like Uzbekistan, tailored implementation strategies that account for infrastructural limitations and regulatory readiness will be crucial. Ultimately, a context-aware, phased approach—backed by international standards, public-private collaboration, and technological adaptability—will be key to unlocking the full potential of DPP systems powered by blockchain.

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