DEVELOPING A DIGITAL PRODUCT PASSPORT (DPP) FRAMEWORK FOR CIRCULAR SUPPLY CHAINS: EVIDENCE FROM THE NATURAL LATEX MATTRESS INDUSTRY

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ABSTRACT:

Amid increasingly stringent sustainability regulations, such as the European Union's Anti-Deforestation Regulation (EUDR) and Eco-Design Regulation (ESPR), the Vietnamese natural latex mattress industry, and exporting sectors more broadly, faces mounting compliance pressures. These challenges necessitate comprehensive business restructuring and a decisive transition toward circular, environmentally sustainable production models. This study proposes a Digital Product Passport (DPP) framework tailored to the natural latex mattress industry to address the tension between fragmented smallholder supply networks and the rigorous data requirements of the European market. Adopting a document-based research design and comparative analysis grounded in leading standard frameworks, including CIRPASS and GPSNR, the study develops an integrative model that consolidates upstream data into unified product profiles to support circular supply chains. The findings establish a minimum data architecture capable of meeting EU regulatory requirements for traceability through shipment-level identifiers. Overall, the study provides both theoretical and practical contributions to support the rubber industry's proactive adaptation to green technical barriers and its transition toward a sustainable circular economy.

Keywords: Digital Product Passport (DPP), natural rubber mattress, EUDR, GPSNR.

1. Introduction

The natural latex industry plays a critical role in global material supply chains, particularly in emerging economies such as Vietnam, where it represents a strategic export commodity and a key source of rural livelihoods. Moving downstream, the natural latex mattress segment represents a high-value application that contributes to value-added upgrading and sustainable product innovation within the rubber sector. Indeed, the natural latex mattress industry plays a key role in the high-end bedroom furniture ecosystem due to its elasticity, durability, and health benefits. However, supply chain transparency remains a major challenge. The industry is highly fragmented, with 80–85% of production coming from smallholders, combined with multi-layered collection and raw material mixing, which disrupts data traceability from the origin (Fischer, 2023; Lachaux, 2025; PEFC, 2023). This characteristic limits businesses' ability to verify origin, assess risks, and meet sustainability standards.

At the same time, the EU is strengthening transparency through regulations such as the ESPR, which require lifecycle data traceability (European Parliament and Council of the European Union, 2023, 2024). However, DPP adoption is still limited in developing countries like Vietnam, creating a gap between regulatory requirements and supply chain capabilities. This lack of reliable data and connectivity increases compliance, legal, and reputational risks for Vietnamese companies when participating in the global supply chains (Kandaswamy, 2026; Legardeur & Ospital, 2024).

Therefore, this study proposes applying the DPP model to the natural latex industry to support meeting European product requirements. Specifically, the study aims at the following objectives: (1) proposing a DPP model suitable for the fragmented nature of the latex supply chain; (2) identifying the necessary data requirements for an effective traceability system. The research uses secondary data alongside European policy frameworks and focuses on designing the data architecture of both the upstream and midstream stages, including production, collection, and processing.

2. Literature review

2.1. Definition and architectural nature of DPP systems

According to the Eco-Design for Sustainable Products Regulation (ESPR 2024/1781), DPP is defined as a specific set of data associated with the product lifecycle (European Parliament and Council of the European Union, 2024). Along with the Anti-Deforestation Regulation (EUDR), supply chains are now facing digital pressures, a strong transformation, shifting from static record management methods to dynamic, systematic data streams (European Parliament and Council of the European Union, 2023; University of Cambridge Institute for Sustainability Leadership (CISL) & Wuppertal Institute, 2020).

Beyond the generality of the legal text, reports from the European Parliamentary Research Service (EPRS 2024) (Legardeur & Ospital, 2024) and the methodology of the Joint Research Centre (JRC) (Kandaswamy, 2026) affirm that, instead of operating as a centralized archive, the DPP system architecture is based on the following core principles:

- Distributed data: data is not centralized at a single point
- Data detail: information is managed at multiple levels (products, batches)
- Interoperability: uses standard data formats and APIs

Technologies such as blockchain, decentralized identities (DIDs), and IoT play a crucial role in supporting DPP deployment.

2.1.2. History of development and related works on DPP

Traceability systems have evolved alongside technological advancements. Early approaches relied on barcodes and RFID, enabling SKU-level tracking but offering limited data integration and sharing capabilities (GS1 in Europe, 2022; Langley et al., 2023). Standards such as GTIN and EPCIS improved event-based data exchange, yet systems remained linear and fragmented. The subsequent adoption of cloud computing enabled large-scale data processing through centralized platforms, though it introduced risks related to data monopolies, limited interoperability, and single points of failure (GS1 in Europe, 2022; Langley et al., 2023). Since 2019, driven by policy frameworks such as the European Green Deal, research has increasingly shifted toward distributed architectures supporting lifecycle transparency, exemplified by DPPs. Technologies including blockchain, decentralized identities (DIDs), and IoT have been integrated to enhance data accessibility and sharing.

Initiatives such as Catena-X and CIRPASS demonstrate the feasibility of this approach (Bendzuck et al., 2024; Wenning et al., 2024). Additionally, advanced methodologies such as model-based systems engineering (MBSE) and knowledge graphs (ontologies) have been proposed to improve interoperability and data synchronization (Juresa et al., 2026). Nevertheless, most existing models are designed for discrete products with clearly defined identities, and thus remain inadequate for supply chains characterized by continuous and blended material flows.

2.1.3. Research gaps

Studies on Digital Product Passports (DPPs) and traceability systems have been predominantly developed and implemented in the European context, while in Vietnam they remain at an early stage. Some pioneering firms, such as Dong Nai Rubber Corporation (Donaruco), have introduced EUDR-compliant traceability solutions using GIS and QR codes at purchasing points (ISCC System GmbH, 2021). However, these initiatives mainly address local spatial tracking rather than full integration into standardized DPP architectures. A significant gap persists regarding data reconciliation mechanisms for continuous raw material flows. This research aims to address the lack of integrated solutions capable of harmonizing the conflict between the lot-level tracking requirements of EUDR and the product-centric structure of ESPR. Through conceptualizing a multi-tiered integration framework for the latex supply chain, the research contributes a new traceability logic and structured data model that reconciles the physical constraints of lot blending with legal spatial requirements, thereby promoting practical application in complex agricultural networks.

3. Methodology

This study employs a qualitative approach, focusing on conceptual design and document analysis to develop a Digital Product Passport (DPP) model. A comparative strategy is applied by reviewing architectures from leading DPP initiatives and adapting them to the Vietnamese natural latex supply chain.

The research relies on secondary data from two groups. The first includes technological and regulatory frameworks such as CIRPASS (Bendzuck et al., 2024; Wenning et al., 2024) and - Global Platform for Sustainable Natural Rubber (GPSNR) (Fischer, 2023), which provide standards for system architecture, traceability, and compliance. The second covers operational data, including industry reports, FSC standards (Sukkaneewat & Utara, 2022). This data helps to reconstruct the entire supply chain from upstream (planting, latex harvesting) to downstream (finished product manufacturing).

Data analysis combines content analysis with supply chain mapping. Standard data fields are extracted, aligned with lifecycle stages, and refined by integrating industry-specific indicators (e.g., EUDR, DRC). The results form the proposed DPP framework presented in Section 4.

4. Research results

4.1 Description of natural latex supply chain

The supply chain management (SCM) of the natural latex mattress industry spans upstream raw material sourcing, midstream processing, downstream manufacturing, and distribution to end-users and export markets. Upstream, latex is extracted from rubber trees and sourced from two main groups in Vietnam: large-scale plantations with centralized management and easier access to sustainability certifications, and smallholder farms that contribute a significant share of total output but present challenges in traceability due to their fragmented nature (Fischer, 2023; Lachaux, 2025). In the midstream stage, harvested latex is transported to processing facilities where it undergoes centrifugation to remove water and impurities, producing concentrated latex with standardized dry rubber content (DRC), which is then stored, batched for traceability, and delivered to manufacturing plants (Dunuwila et al., 2023; Sukkaneewat & Utara, 2022). Downstream, this concentrated latex is transformed into solid foam blocks through blending technologies involving additives such as vulcanizing agents, activators, fillers, and foaming agents, followed by washing, pressing, and drying processes to ensure product quality and safety standards, including compliance with physical, mechanical, and chemical requirements (Sukkaneewat & Utara, 2022). Environmental management is also critical, with wastewater treated through biological systems to reduce ecological impact (Dunuwila et al., 2023). Finally, latex mattresses are distributed through OEM manufacturers and domestic brands to both local and international markets, where increasing consumer demand for environmentally friendly and traceable products is driving the adoption of transparency systems such as Digital Product Passports (European Parliament and Council of the European Union, 2024; University of Cambridge Institute for Sustainability Leadership (CISL) & Wuppertal Institute, 2020).

4.2 Data requirements for natural latex supply chain

Based on previous studies and recent reports, Table 1 is developed to outline the data requirements across the natural latex supply chain. It categorizes data into key groups (e.g., origin, materials, environmental impact, compliance, and lifecycle) and links them to relevant regulatory frameworks such as EUDR, ESPR, and REACH, while also specifying the roles and responsibilities of stakeholders, from upstream actors and customs authorities to downstream partners and consumers, in providing and accessing these data.

This table presents a structured data model for the Natural Latex Digital Product Passport (DPP), organized along four key life cycle stages: sourcing, production, usage, and end-of-life. It specifies the types of information required at each stage-ranging from origin traceability and legal compliance to chemical data, environmental attributes, and circularity indicators-along with concrete examples to ensure transparency and standardization. Overall, the table highlights how multi-dimensional data can be systematically captured and shared among stakeholders to support regulatory compliance, sustainability, and circular economy objectives.

Figure 2 illustrates the data flow architecture of the Natural Latex Digital Product Passport (DPP), showing how information is generated from different sources (upstream producers, manufacturers, and downstream recyclers) and structured into key data categories. It also highlights how these data are selectively accessed by various stakeholders, such as manufacturers, customs authorities, downstream actors, and consumers, ensuring transparency, traceability, and regulatory compliance across the supply chain.

Figure 1. Quality and environmental management in natural latex supply chain

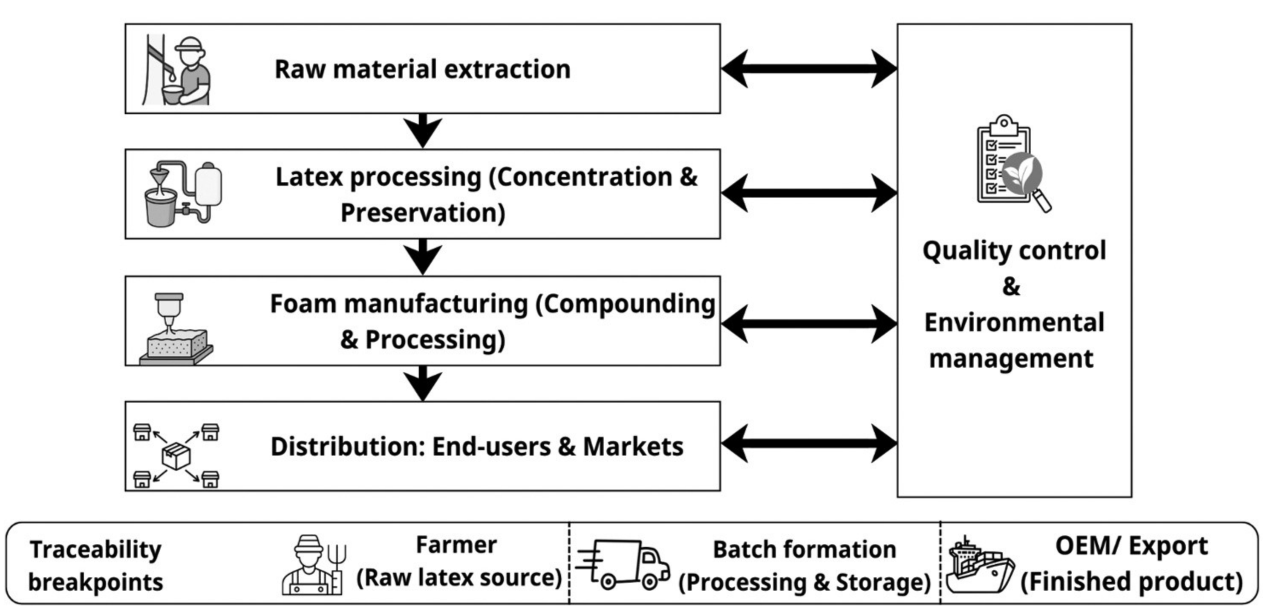


Table 1. Data requirements for natural latex supply chain

Data Groups and Data Points	Legal Basis	Up-stream	(OE-Ms)	Customs Agency	Down-Stream	Consumer
Product Origin and Identification						
Geo-coordinates (GeoJSON)	Mandatory (EUDR)	*	✓	✓		
Land Use Right Cert. (LURC)	Mandatory (EUDR)	*		✓		
Batch ID	Mandatory (EUDR / ESPR)	*	✓	✓		
Product Code / GTIN / SN	Mandatory (ESPR)		*	✓	✓	✓
Materials and Structures						
Material Comp. (Nat/Syn)	Mandatory (ESPR)		*	✓	✓	
Chem. Classification	Mandatory (REACH/ESPR)		*	✓	✓	
SVHCs & eSDS Data	Mandatory (REACH)		*	✓	✓	
Static design parameters	Voluntary/Compulsory depending on the type		*			✓
Environmental impact						
Carbon Footprint (GWP/PEFCR)	Mandatory (ESPR)		*			✓
Renewable energy & Biocarbon ratio	Voluntary participation (Bonus points awarded)		✓*			
Instructions and Technical Documentation						
Disassembly Docs.	Mandatory (ESPR)		*		✓	
Maintenance guide	Mandatory (ESPR)		*			✓
Compliance and Legal						
DDS & Non-Deforestation Proof	Mandatory (EUDR)	*	✓*	✓		
Working Conditions (ILO/FPIC)	Mandatory (EU CSDDD/ILO Standard)	*	✓	✓		
Risk assessment report	Mandatory (EUDR)		*	✓		
Recycled material content ratio	Mandatory (ESPR)		*		*	✓

Data Groups and Data Points	Legal Basis	Up-stream	(OE-Ms)	Customs Agency	Down-Stream	Consumer
Operation and Lifecycle (Dynamic Log)						
Agri-chemical History	Voluntary/Recommended (PEFC Certification)	*		✓		
Lifecycle log	Partially Mandatory (ESPR - Towards Circular Economy)		✓		*	✓

✓: Can be used by   * : Provided by

Note: Agri: Agricultural; Cert.: Certificate; Chem.: Chemical; Comp.: Composition; CSDDD: Corporate Sustainability Due Diligence Directive; DDS: Due Diligence Statement; Docs.: Documents; eSDS: extended Safety Data Sheet; FPIC: Free, Prior and Informed Consent; GeoJSON: Geographic JavaScript Object Notation; GTIN: Global Trade Item Number; GWP: Global Warming Potential; ILO: International Labour Organization; LURC: Land Use Right Certificate; Nat/Syn: Natural/Synthetic; OEMs: Original Equipment Manufacturers; PEFC: Programme for the Endorsement of Forest Certification; PEFCR: Product Environmental Footprint Category Rules; REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals; SN: Serial Number; SVHCs: Substances of Very High Concern.

Table 2. DPP Data framework by life cycle stage

Life cycle stage	Type of information	Example of detailed information
Stage 1: Sourcing & processing raw materials (From small farm to primary processing plant)	Origin & Geography Information	- Geographic coordinates (GeoJSON) accurate to 6 decimal places, or spatial polygons for plantations larger than 4 hectares. - Land use rights certificate. - History of the use of agricultural chemicals.
	Legal Compliance Rating (EUDR)	- Assessment Statement (DDS Reference Number). - Evidence proving that there was no deforestation activity after December 31, 2020.
	Processing Information & Material History	The unique Batch ID assigned to each standard latex block (TSR/RSS) package includes the complete identification list of the farmers contributing the raw materials.
	Social sustainability	Legal information demonstrating the absence of child labor abuse, forced labor, and Indigenous rights abuses (FPIC).
Stage 2: Production and design (Original equipment manufacturer - OEMs)	Technical Specifications & Ingredients	-
	Chemical Information (REACH)	- Extended Safety Data Sheet (eSDS) and exposure scenarios. - Identification of antioxidants, plasticizers, and international chemical classification codes (CAS, IUPAC). - The warning threshold is reached when Substances of Very High Risk (SVHCs) exceed 0.1% by weight.

Life cycle stage	Type of information	Example of detailed information
Stage 2: Production and design (Original equipment manufacturer - OEMs)	Environmental attributes (LCA/PEFCR)	- The Carbon Footprint (GWP) uses primary datasets. - Energy efficiency index, renewable energy ratio at the vulcanization plant, and biocarbon management formula.
	Product identification	The GS1 GTIN code is combined with a serial number for each individual product.
Stage 3: Product usage phase (Consumer & Maintenance)	Maintenance/ Service Log	Lifecycle log
	Product description	The web interface (scanning the QR code) displays the indicators to consumers.
	Technical documentation	Maintenance instructions for consumers/third-party service providers.
Stage 4: End of life cycle / Post-use processing (Downstream recycling enterprise)	Technical data for waste scenarios	Dismantling and structural separation documents.
	Toxicology and Safe Handling Information	The access code provides detailed chemical composition information according to the REACH standard to identify hazardous additives.
	Characteristics of the circular economy	Data on the percentage of recyclable materials. Recycling process log.

5. Discussion

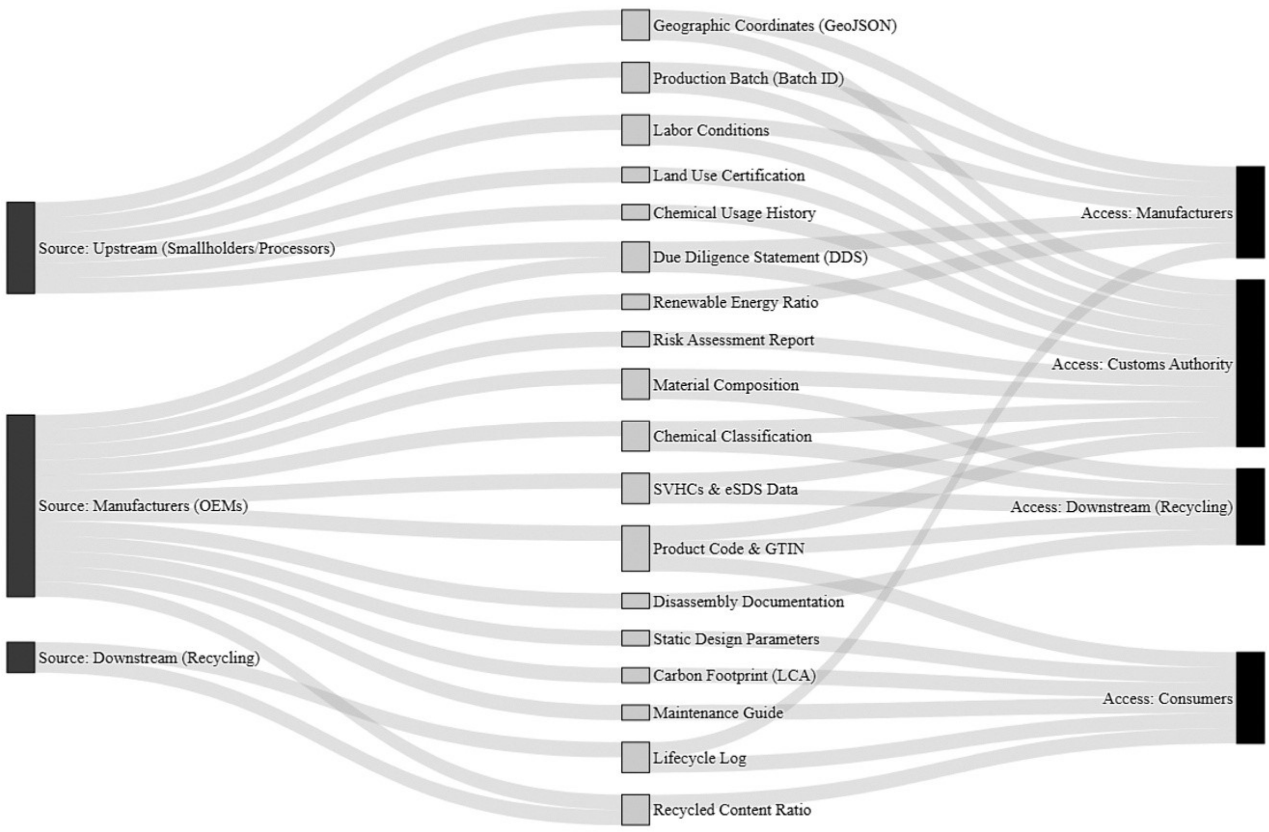
5.1 Comparison with existing systems

The core difference between the proposed DPP model and existing traceability systems in Vietnam lies in its ability to address the "architectural friction" between spatial identification requirements and the continuous production process. While current solutions from domestic businesses only go as far as localized digitization at collection stations to meet EUDR requirements (European Parliament and Council of the European Union, 2023), this model goes further by establishing a data reconciliation mechanism that allows the conversion of blended raw material flows into specific product information packages. This is crucial for maintaining transparency throughout the entire process, from smallholder rubber tapping to the formation of foam structures in mattress manufacturing plants. Furthermore, integrating chemical data layers (REACH) and carbon footprint (LCA) into a single identifier eliminates fragmentation in information governance, creating a more open and interoperable data ecosystem compared to traditional centralized repositories, which are prone to security risks and data exclusivity (GS1 in Europe, 2022; Langley et al., 2023).

5.2 Policy implications

From the above analysis, it is clear that implementing DPP is not only a technical challenge but also a matter of policy synchronization. To bridge the gap between the actual capacity of the domestic supply chain and stringent international standards (European Parliament and Council of the European Union, 2023, 2024), a data standardization roadmap at the industry level is needed, instead of allowing businesses to operate their own individual systems. This requires policymakers to build a legal framework that supports secure data sharing among links in the chain, while prioritizing low-cost technological solutions to suit the specific characteristics of small-scale farmers. From a governance perspective, mattress manufacturers need to recognize DPP as a

Figure 2. Multi-party DPP data access and authorization scheme



tool to optimize the value chain and affirm their reputation in the global market. Transparent lifecycle information not only helps overcome EU technical and legal barriers but also opens up opportunities to access green capital and build sustainable relationships with consumers who are increasingly concerned about the ethical origins of products.

6. Conclusion

The study developed a multi-layered integration model to address overlapping regulations for digital product passports in the latex industry. It identified four core data groups: origin, chemical safety (REACH), environmental footprint (LCA) (Dunuwila et al., 2023), and end-of-life. Integrating eSDS data and carbon indices into QR codes is essential for Vietnamese latex mattresses to meet ESPR requirements. A multi-stakeholder interface was also shown to be feasible, reducing inspection costs and increasing consumer trust. However, the study focuses mainly on model design and lacks detailed analysis of implementation costs and user adoption barriers. Future research should test automated authentication technologies and expand to recycling and end-of-life stages to complete the material lifecycle ■

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PHÁT TRIỂN KHUNG HỘ CHIẾU SỐ SẢN PHẨM (DPP) CHO CHUỖI CUNG ỨNG TUẦN HOÀN: TRƯỜNG HỢP NGÀNH NỆM CAO SU THIÊN NHIÊN

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TÓM TẮT:

Trong bối cảnh các quy định về phát triển bền vững như Quy định Chống phá rừng (EUDR) và Quy định Thiết kế sinh thái (ESPR) của Liên minh Châu Âu ngày càng thắt chặt, ngành nệm cao su thiên nhiên Việt Nam nói riêng và các nước xuất khẩu nói chung đang đối mặt với áp lực lớn, đòi hỏi các doanh nghiệp phải tái cấu trúc toàn diện, chuyển dịch mạnh mẽ sang mô hình sản xuất tuần hoàn và thân thiện với môi trường. Nghiên cứu này đề xuất mô hình Hộ chiếu số sản phẩm (Digital Product Passport - DPP) dành riêng cho ngành nệm cao su thiên nhiên nhằm giải quyết mâu thuẫn giữa đặc thù phân mảnh của mạng lưới hộ tiểu điền và yêu cầu dữ liệu nghiêm ngặt từ thị trường Châu Âu. Bằng phương pháp nghiên cứu tài liệu và phân tích đối chiếu dựa trên các khung tiêu chuẩn tiên phong như CIRPASS và GPSNR, nghiên cứu đã xây dựng một khung hướng dẫn cho phép tích hợp đa dữ liệu từ thượng nguồn đến hạ nguồn vào hồ sơ sản phẩm hướng tới chuỗi cung ứng tuần hoàn. Kết quả nghiên cứu then chốt xác lập được mô hình hệ thống thông tin dữ liệu yêu cầu tối thiểu đáp ứng quy định của EU nhằm truy xuất thông tin thông qua mã định danh lô hàng. Đây là cơ sở lý thuyết và thực tiễn quan trọng để ngành cao su chủ động thích ứng với các rào cản kỹ thuật xanh và chuyển dịch sang mô hình kinh tế tuần hoàn bền vững.

Từ khoá: Hộ chiếu Sản phẩm Kỹ thuật số (DPP), truy xuất nguồn gốc, chuỗi cung ứng cao su thiên nhiên, EUDR, GPSNR.