Integrating AI, Digitalization, and the European Product Passport for Sustainable Trade and Circular Economy

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**Abstract.** Global supply chains and trade networks are undergoing rapid transformation under the combined pressures of sustainability imperatives, evolving consumer expectations, and accelerating digitalization. This paper examines how the European Product Passport (EPP)—enhanced by artificial intelligence (AI) and other digital innovations—can advance a circular economy and enable more transparent, efficient, and eco-friendly logistics. It describes how EPPs serve as repositories of comprehensive product data, extending from raw materials to end-of-life disposal, and illustrates how AI can translate this data into actionable insights that reduce waste and support compliance. The discussion also considers customs clearance processes, highlighting how AI-driven risk management and real-time verification can streamline operations while furthering sustainability goals. The paper then offers a vision for customs authorities as proactive enablers of resource efficiency and decarbonization. By outlining key opportunities, challenges, and policy recommendations, it provides guidance for policymakers, manufacturers, logistics providers, and regulators aiming to construct sustainable, resilient supply chains in an increasingly complex global context.

**Keywords:** European Product Passport, AI, Custom Clearance, Circular Economy, CBAM

1. Introduction

The logistics and supply chain landscape is in flux, influenced by intensifying environmental regulations, stronger consumer demands for accountability, and major technological breakthroughs that promise unprecedented data visibility (Frick, J., & Steger-Jensen, K. /2024). Within the European Union (EU), these shifts coincide with strategic frameworks such as the European Green Deal (European Commission/ 2019), the Circular Economy Action Plan (European Commission /2020), and sector-specific directives like the EU Battery Regulation (Establishing a framework for the setting of ecodesign requirements for sustainable products (2024/1781) and the EU Strategy for Sustainable and Circular Textiles (European Commission (2022). These policy instruments collectively advocate digital-first solutions that can orchestrate materials, information, and capital flows more sustainably and transparently.

A key element of this approach is the European Product Passport (EPP), also called the Digital Product Passport (DPP). The passport catalogues every product’s lifespan, covering design, manufacturing, transportation, and end-of-life handling (Grünewald, L., & Huvermann, F. /2024), (Stretton, C, Buzeti, Z /2024) While product passports are not entirely novel, recent advancements in artificial intelligence (AI) and data analytics have greatly expanded their scope and influence. These technologies may in future support the monitoring, prediction, and optimization of various parameters—ranging from raw material sourcing to carbon footprints—while maintaining robust regulatory compliance. (Adisorn, T., Tholen, L., & Götz, T. /2021).

1.1 Background

In 2015, United Nations Member States agreed on the 17 Sustainable Development Goals (SDGs) (Sustainable Development Goals (SDGs) /2025). Based on these SDGs, several international and national laws, standards, and procedures have been established and implemented in legislation.

Customs action at the external border is essential in protecting citizens and the internal market against safety and security threats. Border control and customs are among those facing major changes in enforcing and complying with the many new laws and technological developments. Customs systems must evolve to integrate these laws and digital solutions to support the process effectively.

However, the increased focus on SDGs standards and laws has led customs authorities to reassess their roles and responsibilities, as they no longer efficiently support these issues. Today, many customs processes are fragmented, manual, and blindly based on the importer's trust in providing the correct information. To reduce the carbon footprint, the control task has become more difficult for customs and precisely because it is based on trust and because the task and responsibility are shared between several actors in the distribution chain.

Focusing on the challenges of declaring CO2 at EU imports, the following customs-related tasks and reporting requirements are necessary for the importer to get the goods free for trade in the EU. Once the goods have cleared customs, they are released for free circulation and consumption by the importer.

1. **Customs Declarations at Import:** If no free trade agreement exists, duties and taxes must be paid. In the case of international trade, trade and freight documentation is required for customs declarations, and all prior advice must be prepared before transport. The importer reports manual and specifies their commodity code (titled HC-Code), which is the basis for calculating customs duty.
2. **Carbon Border Adjustment Mechanism:** The EU's Carbon Border Adjustment Mechanism (CBAM) is a tool to put a fair price on carbon emitted during the production of carbon-intensive goods entering the EU and to encourage cleaner industrial production in non-EU countries (EU's Carbon Border Adjustment Mechanism (CBAM) /2025). By confirming that a price has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU, the CBAM will ensure that the carbon price of imports is equivalent to the carbon price of domestic production and that the EU's climate objectives are not undermined. The CBAM is designed to be compatible with WTO rules.

There are several critical areas where both the importer and the owner of the goods are dependent on border and customs controls being implemented. A high quality of the control is vital for obtaining the implemented SDGs in legislation, etc.

In connection with imports and within the EU customs borders, EU's emissions trading system (ETS) is used (EU Emissions Trading System (EU ETS) /2025). All transport and production units must report CO2 via the EU Corporate Sustainability Reporting Directive (CSRD) (EU Corporate Sustainability Reporting Directive (CSRD) /2025) and when importing, the importer must indicate CO2 via CBAM.

Thus, many stakeholders depend on this being done adequately and fairly. If this customs control is not implemented appropriately, it will not be possible to ensure proper tax payment and determine the company's CO2 footprint.

In this connection, importers must use their available resources to the best of their ability to obtain actual data on embedded emissions. In cases where actual data cannot be obtained, the CBAM report must state that all available options have been explored. This includes the importer attaching documentation of previous unsuccessful attempts to obtain data in his report and describing the measures taken.

If we go all the way and look at the circular economy and CO2 of goods subject to the EU's Ecodesign for Sustainable Products Regulation (European Commission Ecodesign /2022). requirements, the CO2 of the goods will be based on either the import CBAM of a good and/or the CSRD data of a company. This good can subsequently be sold as an export good and must again be subject to border control for CO2 accuracy.

1.2 Motivation

To date, there has been insufficient research into which technological solutions are needed to solve this border and customs control fairly and satisfactorily, partly to ensure SDGs and partly to ensure tax and duty payment that affect the company's competitiveness.

The EU Single Window Environment for Customs (EU Single Window Environment for Customs /2025) is designed to streamline and enhance the digital cooperation between customs and non-customs authorities across the EU. The system aims to facilitate the electronic exchange of documents and information required for goods clearance, improving efficiency and reducing administrative burdens.

The European Maritime Single Window environment (EMSWe) is a framework designed to simplify and harmonize the reporting obligations for ships arriving at, staying in, and departing from EU ports. The EMSWe aims to reduce the administrative burden on shipping companies by providing a single-entry point for all reporting requirements. (European Maritime Single Window environment (EMSWe) /2025),)

Even though the EU Maritime Single Window (EMSWe) and the EU Customs Single Window are designed to streamline reporting and data exchange processes, they operate in different domains and are not directly integrated.

2. AI and the European Product Passport (EPP)

2.1 Defining the European Product Passport

The European Product Passport (EPP) provides a dynamic digital record of a product’s core attributes over its entire life cycle, covering material composition, manufacturing inputs, usage history, and end-of-life specifications (European Commission Ecodesign /2022). Its principal objective is to function as a single source of accurate information for diverse stakeholders—such as manufacturers, logistics firms, regulators, and consumers—who require data-based insights on sustainability, compliance, and product lifecycle management. (EU Corporate Sustainability Reporting Directive (CSRD) /2025) As a digital platform, the EPP incorporates features that allow real-time data updates, standardized documentation formats, and secure access protocols to protect the integrity and confidentiality of stored information. (Langley, D. J et al /2023)

2.2 The Power of AI for EPP Data

Artificial intelligence is critical for extracting actionable intelligence and insight from the extensive datasets contained within an EPP. It is expected to fulfill multiple functions broadly categorized as follows. First, automated compliance monitoring involves continuously matching product data against an up-to-date repository of regulations (e.g., REACH chemical restrictions, energy efficiency standards) and flags discrepancies that may indicate restricted substances or carbon emissions exceeding legal thresholds. Second, AI may facilitate predictive maintenance and lifecycle analysis by analyzing historical component performance and environmental data to forecast potential failures, encouraging manufacturers to design for durability and minimize resource extraction. Third, AI may support real-time supply chain optimization through route planning and scheduling that reduce energy usage and inventory management that more accurately balances supply and demand. Fourth, AI is expected to strengthen consumer engagement and personalized recommendations by examining usage patterns—such as how often consumers operate specific devices or in what mode—and suggesting ways to lower resource consumption, possibly incorporating gamification elements to encourage sustainable behavior (EU Emissions Trading System (EU ETS) /2025). By processing large and complex data flows, AI converts the EPP from a passive database into an active decision-making resource that maximizes circular economy advantages and promotes sustainability throughout the product life cycle (Zhang, A., & Seuring, S. /2024).

3. Customs Clearance in a Digital Era

In recent years, customs agencies have assumed responsibilities beyond collecting tariffs and preventing contraband. As regulations now incorporate environmental standards, labor rights issues, and broader supply chain transparency, customs authorities have had to verify revenue and safety compliance, product ethics, and sustainability. (Vorotyntseva, T., et al /2020,). This expanded role necessitates coordination with various specialized agencies, including environmental protection agencies and labor ministries. It highlights the significance of emerging digital tools in facilitating more streamlined and responsible border checks. (Eezyimport /2025)

3.1 Evolving Customs Responsibilities

Although safeguarding national revenue and security remains vital, policymakers have introduced various customs requirements for climate protection, ethical labor practices, and hazardous material handling. This shift means customs officials increasingly check whether incoming products meet specific carbon emissions thresholds, adhere to sourcing guidelines prohibiting forced or child labor, and comply with labeling or handling protocols for toxic substances (EU Single Window Environment for Customs /2025). The overall effect is that customs checkpoints function as compliance nodes in a global network concerned about sustainable production, workplace ethics, and public welfare.

3.2 Digitization and AI in Customs

To cope with the mounting responsibilities of verifying a product’s ethical sourcing and environmental footprint, customs authorities deploy digital solutions such as blockchain-based ledgers, electronic consignment notes (e-CMR), and the Internet of Things (IoT) for real-time cargo tracking. (Jane, F /2025)

Digital tools significantly decrease delays and lower costs, providing a foundation for seamless supply chain management. AI can improve customs clearance and enhance border security through “intelligent customs inspection” (ICI) while expediting legitimate trade, offering lessons for global moves toward “smart customs” (European Commission /2019). Digital product passports (EPPs) are a means to advance the digital circular economy (DCE) in the emerging context of Industry 5.0 (I5.0). Key technological enablers are data collection (e.g., IoT devices, digital twins), data curation (e.g., AI-driven preprocessing, digital threads), and data leverage (e.g., blockchain-based smart contracts) (Voulgaridis, K., et al /2024), Cao, Q., & Zheng, X. /2024).

By incorporating AI-driven analytics, ICI can further refine these processes. AI systems are expected to automatically reconcile shipping documents—purchase orders, invoices, bills of lading—with EPP data, alerting officers when discrepancies arise. Risk profiling then comes into play, wherein machine learning evaluates previous infractions, smuggling routes, or forged documentation to score the likelihood of problematic current shipments. Concurrently, blockchain keeps immutable records of product and shipping details, swiftly raising alarms if unauthorized changes or alterations in the documentation occur (Voulgaridis, K., et al /2024). By uniting these innovations, customs authorities can expedite legitimate commerce while insisting on sound ecological, social, and safety practices. As a result, customs evolve from a revenue-focused checkpoint into a modernized entity that upholds sustainability and ethical standards, reflecting society’s increasing emphasis on socially responsible global trade. (RTSlabs /2024), PWC /2024)

4. Digital Product Passports, the Circular Economy, and the Role of AI

A transition from the linear “take–make–dispose” paradigm toward a genuinely circular economy demands mechanisms capable of tracking products at every stage. (Gligoric, N., et al /2019) Digital Product Passports (DPPs) fulfill this need by consolidating key details on materials, manufacturing techniques, usage histories, and pathways for recycling or disposal. Merging DPPs with artificial intelligence heightens their impact by enhancing transparency, minimizing waste, and facilitating compliance with regulatory requirements.

4.1 Linking DPPs to Circular Economy Principles

The circular economy (CE) framework (Zhang, A., & Seuring, S. /2024) focuses on extending the value and lifespan of resources by promoting reuse, repair, remanufacturing, and recycling to eliminate waste. DPPs are aligned with this philosophy through the detailed record-keeping of product composition, hazardous substances, and step-by-step repair or maintenance instructions, all stored from inception to end-of-life. The result is comprehensive traceability, enabling stakeholders to make informed decisions about repairs or recycling. This approach boosts consumer trust by evidencing higher product quality, simplifying identifying optimal moments for refurbishment, and ensuring materials remain in use as long as possible (Establishing a framework for setting ecodesign requirements for sustainable products /2024).

CE will impact future products in many ways and challenge how customs handle taxes on products and taxing the environmental impact (e.g. CO2) not to mention how they control whether the reported information in the DPP. For example, cotton fibers may either stem from a new product or remanufactured textile waste, which is currently way more expensive but intentionally more environmentally friendly. Products may therefore pass the border with a more environmentally friendly registration than what is correct, if not, they are divided into two different product IDs and HC codes. The more complicated products we deal with (e.g. a car or a machine consisting of many items), the more complicated the tax and control procedures are. Further, some products such as brake components in cars, can only be refurbished a limited number of times, and this needs to be strictly identified. This may require Internet of Things and SmartTags or printed sensors on textile products to store information (Gligoric, N., et al /2019).

4.2 Expanding Opportunities with AI

Although DPPs already enhance transparency, their effectiveness is greatly magnified when combined with artificial intelligence. AI-driven systems analyze large volumes of product-specific data to bolster efficiency, advance sustainability, and unlock new collaborative possibilities. For instance, AI can manage material tracking and recovery by parsing product diagrams and bills of materials, then pinpointing components suitable for reuse or recycling. It can also recommend real-time recovery routes based on geolocation and facility capacity, thereby cutting costs and emissions. In the financial arena, AI offers lenders and investors verified sustainability metrics by parsing the information in DPPs for carbon intensity or recycled content, influencing loan terms and investment strategies. Additionally, AI encourages multi-stakeholder collaboration by automating surplus-material trading platforms and coordinating a network of repair workshops, recyclers, and raw material suppliers in real time. This way, DPPs shift from static data repositories into dynamic platforms that reduce waste, enable circular business models, and improve overall economic competitiveness.

4.3 Policy Support and Regulatory Alignment

The European Union increasingly views Digital Product Passports as central to its sustainability agenda. Through policies like the Ecodesign for Sustainable Products Regulation (European Commission Ecodesign /2022). and the EU Strategy for Sustainable and Circular Textiles (European Commission /2022), the EU has identified product categories where DPPs are either mandatory or strongly recommended (European Commission /2019). AI aids in meeting these requirements by automating documentation, reducing manual input errors, and aligning product data against official templates. Machine learning can also pinpoint anomalies—such as unexpectedly high emissions or unexplained discrepancies in durability—thereby allowing regulators to target audits more effectively. Through this cycle, AI lightens administrative burdens for manufacturers and governments, but more importantly upholds overarching EU objectives of waste reduction, climate change mitigation, and public health protection.

5. Need for verification in the customs process

The Danish Energy Agency hosts the digital CBAM solution in Denmark and is responsible for the ETS systems shared with the Danish Business Authority. (Danish Energy Agency /2025)

The Danish Energy Agency ensures that the annual CO2 emissions for ETS are quality assured by an independent third party in connection with the calculation of CO2 used in the context of the ETS. This quality assurance is a verification carried out by a verifier accredited for the task according to common EU rules. The accredited verifier checks that the approved monitoring plan calculates CO2 emissions.

The monitoring plan and emission permit are one coherent document. The emission permit is granted based on the operator's description of the production unit in the monitoring plan. The operator must comply with the legislation, including that the monitoring plan is correct and up to date.

**Verification and accreditation of Verifiers**

Per Commission Regulation No. 2018/2067 rules on verification and accreditation, a production unit's CO2 emissions and activity level must be verified by an independent third party called a verifier. Verifiers must be accredited by an accreditation body from an EU member state.

The scope of the accreditation is indicated using several activity groups that cover the activities covered by the quotas in the quotas directive. When choosing a verifier, the company must be aware of whether the verifier's accreditation covers all the quota activities your company covers.

Verifiers can be found on the websites of the national accreditation bodies, which you can find via this link to the organization EA (European Accreditation, which is Europe's cooperation organization for accreditation bodies).

When customs carry out border and physical checks on imported goods, they have no guarantee that the way CO2 is calculated is valid and correct. Unlike CO2 emissions in ETS, no verifier is accredited by an accreditation body from an EU member state.

Investigating whether the verifier role and task could be expanded with a compliance task of the SDGs data, would be relevant. This would ensure that the importer and product owner's data are correct and stored/master data in a digital tool and used in connection with e.g. the customs border control. It would also reduce the possibility of cheating, uncertainty, data quality, and the basis for calculation for CO2, etc. To ensure a harmonized digital tool and data, DPP and AI are obvious candidates to build on, together with SDG data, to be used for e.g. customs and border control.

6. The Future Role of Customs

Owing to intensifying consumer, regulatory, and environmental factors, customs agencies are transitioning toward more strategic functions. While they still oversee tariff collection and security, they enforce labor rules, ethical sourcing, and sustainability benchmarks. (PWC /2024) By merging AI tools with European Product Passport (EPP) data and SDGs data, customs authorities are positioned to facilitate a more transparent and circular supply chain system. (Morgan A /2024), (Veenstra, A., & Heijmann, F. /2023), (World Economic Forum /2025)

6.1 Need for SDGs data verification and compliance

Customs agencies stand at the intersection of multiple regulatory frameworks designed to reduce greenhouse gas emissions and protect labor rights. They can rapidly detect compliance or spot anomalies by melding EPP data with AI analytics. Upon a shipment’s arrival, AI platforms match declared product metrics—including carbon footprint or recycled content—with established standards, flagging deviations such as unexpectedly high emissions. This approach deters greenwashing by preventing unverifiable environmental claims, fosters more uniform application of sustainability rules across importers and exporters, and expedites clearance for traders that comply.

Inter-agency collaboration also emerges as an asset. Customs may consult with environmental bodies, labor ministries, or human rights commissions to scrutinize EPP information, particularly when issues like forced labor or carbon leakage arise. By automating these checks, the system reduces clearance delays and lowers the administrative load on compliant traders (European Commission. Sustainable Products Initiative /2025).

6.2 Risk Management

Balancing trade facilitation with regulatory rigor remains a core challenge for customs authorities. AI-driven risk management clarifies this balance, as algorithms assimilate new data on smuggling networks, commodity risks, and compliance patterns to refine threat assessments. High-risk consignments undergo deeper inspection, whereas lower-risk shipments supported by trustworthy EPP data receive swift clearance. This selective focus diminishes congestion at ports, cuts logistic expenses, and fosters predictable shipping timelines. Scalability is another benefit, as AI architectures can handle expanding trade volumes without matching increases in manual oversight, and logs detailing risk evaluations give both authorities and companies insights into why certain cargoes earn “high-risk” designations.

6.3 Green Incentives

Rather than purely policing regulations, customs authorities can also motivate circular and ethical excellence by employing policy levers. Under “green lanes,” goods meeting predefined sustainability criteria—such as low carbon footprints or validated ethical sourcing—enjoy prioritised clearance. Similarly, certain tariffs or taxes may be waived or diminished for shipments surpassing sustainability thresholds, offering clear financial benefits and prompting more organisations to invest in eco-friendly supply chains. Recognition initiatives, including official certificates or online databases listing “green” importers or exporters, further enhance brand differentiation and market trust. Interventions are often part of larger strategies coordinated among customs, taxation, and environmental agencies. AI regularly updates performance metrics (e.g., reduced carbon intensity, increased recyclability) to keep these incentives relevant and impactful.

6.4 Data Hubs for a Circular Economy

Given their broad oversight of incoming and outgoing products, customs authorities are uniquely qualified to act as data hubs, aggregating and disseminating key supply chain information from EPPs. In a circular economy, this role is instrumental for reducing waste and improving resource use, as data on reusable or recyclable components can be shared with sectors in need of such materials. A product no longer useful in one domain (e.g., textiles) might supply valuable materials to another industry (e.g., automotive). By leveraging centralised digital platforms under customs oversight, surplus parts or end-of-life items can be traded, aiding the creation of localised circular clusters. Efficient routing, whether for specialised e-waste or metals, lowers carbon emissions by cutting transport distances, while strict data governance maintains trust by restricting access to sensitive commercial information. This end-to-end visibility allows countries to adapt to growing trade volumes without compromising speed or accuracy in analysing product complexity. (Jones, C /2024)

Ultimately, customs shift from being a gatekeeper to becoming a catalyst for circularity and ethical commerce. By verifying sustainability claims, managing risk, offering green incentives, and sharing data, customs authorities align trade with global markets' rising environmental, social, and economic expectations. (Plociennik, C., et al /2022).

7. Conclusion

7.1 Summary of Key Insights

This paper has demonstrated how the synergy of artificial intelligence, digital product passports, and forward-thinking customs operations can create global supply chains that are more efficient, responsible, and conducive to circularity and SDGs goals. By integrating AI into European Product Passports (EPPs), static data archives transform into robust systems capable of managing risk, tracking compliance, forecasting maintenance, and engaging consumers. Concurrently, digitalized customs processes enhance real-time visibility, reduce bottlenecks, and expedite adherence to advanced sustainability and social standards.

7.2 Customs as a Linchpin for Circular Trade

Looking to the future, customs authorities have an opportunity to pioneer more circular global logistics. Merging product passport data with AI-driven insights enables them to pivot from traditional policing to sustainability facilitation. This approach includes verifying sustainability claims, concentrating resources on high-risk cargoes, incentivizing eco-friendly measures, and sharing valuable data with other stakeholders like recyclers, financiers, or refurbishment specialists. By performing these roles, customs authorities are pivotal partners in fostering environmental stewardship and bolstering economic durability.

7.3 Recommendations for Policy and Practice

Harmonised policy frameworks are essential for ensuring that sustainability standards and definitions are not fragmented across different regions or agencies. Encouraging investment in digital infrastructure, including secure data platforms and scalable AI tools, is vital for handling complex supply chain data while maintaining speed and reliability. Comprehensive training should target customs professionals, industry operators, and small and medium-sized enterprises (SMEs) to foster AI literacy and data management skills. Governments can also employ incentive mechanisms, such as tax benefits or recognition programs, to promote innovation in recyclability and low-carbon solutions. Finally, continual innovation and cross-sector collaboration must be nurtured through public-private partnerships and multi-stakeholder forums, ensuring that the supply chain ecosystem remains agile in the face of rapidly changing challenges.

7.4 Concluding Thoughts

In sum, aligning AI-driven insights with the European Product Passport framework offers a powerful catalyst for more responsible and resource-efficient supply chains. By ensuring product data integrity, streamlining customs checks, and strengthening circular practices, this integrated approach meets evolving regulatory and consumer demands and paves the way for next-generation logistics models. As pressures on global trade intensify, leveraging AI and digitalization alongside robust product passports will be essential for building sustainable, transparent, resilient supply networks.

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