

BLOCKCHAIN TECHNOLOGY EMPOWERING DIGITAL PRODUCT PASSPORTS FOR SUSTAINABLE SUPPLY CHAIN MANAGEMENT: A CONCEPTUAL FRAMEWORK

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Abstract

Purpose

To address the challenges of efficient and sustainable supply chain management, the EU has introduced the concept of "Digital Product Passports" (DPP) as a potential tool for promoting traceability, transparency, and sustainability throughout supply chains, while enhancing waste management (WM) processes. Therefore, the DPP is a novel project for the EU, engaging both academics and practitioners. The successful implementation of DPP relies on the integration of new information technologies, such as Blockchain Technology (BT). Previous research has shown that this technology has the potential to revolutionize supply chain management, primarily due to its ability to enable transparency, traceability, and accountability, which are essential resources for supporting the DPP and effectively managing product waste. Furthermore, the transparency and visibility provided by BT could enhance the legitimacy of DPPs. This transparency can be further enhanced using global, mutually acceptable, standards that allow the unambiguous identification of the different stakeholders and traceable units of interest. The purpose of this study is to discuss and assess the use of BT in conjunction with global standards to achieve an interoperable, immutable DPP implementation in the EU.

Design/methodology/approach

The authors have conducted an extensive literature review to develop a conceptual framework, which shows how BT empowers the DPP, leading to improved sustainable performance, better waste management, and the creation of social value within supply chains. By drawing upon the Legitimacy and Stakeholders' Theories, the proposed framework emphasizes the significance of transparency and traceability, which ultimately contribute to the creation of social value. It provides a foundational starting point, both to academics and practitioners, for future research and real-world applications, promoting the adoption of sustainable and transparent practices.

Findings

This study contributes to the literature review by offering insights into the integration of BT, appropriate standards and DPP within supply chains, addressing the pressing need for sustainability and efficient waste management. It shows that BT's capabilities enable the DPP to provide verifiable information on product origin, lifecycle, and environmental impact, empowering companies to take informed decisions and consumers to make sustainable choices. The study's findings and proposed framework can form a base for future research on the analysis of the above technologies and on their application to real use case scenarios.

Originality/value

The use of global standards in conjunction with BT, to achieve an interoperable, immutable DPP implementation in the EU, which can serve as an adoption model for other supply chains globally.

Keywords: Blockchain Technology, Digital Product Passport, Supply Chain & Waste Management, Sustainability, Standards

Introduction

In today's globalized and interconnected world, the need for efficient management of supply chains and the adoption of sustainable policies and practices are necessary. To address these challenges, the European Union (EU) has introduced the concept of "Digital Product Passports" (DPP). These types of passports serve as a powerful tool for facilitating traceability and transparency, throughout the supply chain, as well as for improving sustainability and waste management (WM) processes. DPP is a relatively new concept

and project for the European Union, allowing academics and researchers to propose solutions related to its implementation and contribution to companies and society.

This paper suggests that BT can provide a possible solution for the implementation of DPP. During the last decade companies and academics are becoming more interested in this new technology. BT was primarily used in the financial industry and specifically in the cryptocurrency of Bitcoin, but subsequent research (Stroumpoulis and Kopanaki, 2022) and business applications have shown that it could also transform and improve logistics and supply chain management. Due to its structure, it can lead to transparency and traceability and play an important role in supporting the DPP and controlling the waste and loss of products. The paper also suggests that the exchange of information between different companies in a supply chain requires the use of appropriate standards to ensure common understanding of data, such as those contained in the digital product passport.

The authors develop a conceptual framework to explore how BT and appropriate global data standards can empower the implementation of DPP. They show that this combination can lead to transparency, traceability, social value, sustainable performance, and better WM. A literature review analysis (Jia *et al.*, 2020) and conceptual framework, based on the Legitimacy and Stakeholders' Theories are also included. Specific technological solutions are considered and their combination for the implementation of DPP is examined. A theoretical framework is then developed which examines the effects of specific technologies on sustainable supply chain management.

Sustainability and new technologies in Supply Chain Management

Sustainable development was first defined in 1987, as "the ability to make development sustainable, to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland, 1987 p.16). Many years later, at the World Summit on Sustainable Development, the three pillars of sustainable development (social, environmental, and economic) were introduced (Roberts and Dowling, 2002).

The supply chain involves various organizations, human activities, information, data, and resources for the delivery of goods or services (Bhuniya *et al.*, 2021). It aims to integrate an organization's social, environmental, and economic goals for long-term economic performance (Carter and Roger, 2008) can lead to a sustainable supply chain. So, Sustainable Supply Chain Management (SSCM) is an extension of the traditional supply chain management, which combines environmental and social issues (Stroumpoulis *et al.*, 2021). Information systems (IS) play a significant role in the management of supply chains. Information technology (IT) is the foundation of supply chains (de Camargo Fiorini and Jabbour, 2017), enabling and supporting the development of an effective and efficient supply chain. Similarly, IS are one of the most important factors in achieving sustainability (Wang *et al.* 2015).

Waste management and circular economy

The Circular Economy is an imperative trend of the time. As the human population grows, so does waste and resource consumption. The Circular Economy is open to various interpretations. It is described based on the philosophy of material cycles, such as processes of recycling, reconstruction, renovation, reuse, and restoration. It involves management practices, such as the reverse supply chain. Basically, it is a business and social philosophy of keeping as much materials as possible (thus constantly feeding back the material in various forms through recycling policies) in the supply chain (Papadakis, 2020).

"Waste management is the set of activities that enable the systematic organization of waste collection and treatment in the so-called reverse chain" (Liu *et al.* 2020). As a result, any information from the forward chain, which includes the stages of product production and consumption, should be usable by the WM system (Liu *et al.*, 2020). WM systems vary based on waste type, disposal strategy, country, and regulations. The Circular Economy model aims to reduce waste by reprocessing products and materials at

the end of their life cycles. Full traceability and new manufacturing processes are essential for a successful CE (Shojaei *et al.*, 2021).

Information tracking in the WM process is difficult due to various partners and lack of technology, resulting in manual data collection and digital storage (Baralla *et al.*, 2023). BT could address the aforementioned issues through its decentralized system and smart contracts.

Blockchain technology and sustainable supply chain management

The visibility of demand, orders, and supply is currently a problem for the majority of organizations (Banerjee, 2018). They are often unable to see the entire picture of their supply chain due to lack of information regarding the location of their products, outside of the network of their company (Banerjee, 2018). According to Nayak and Dhaigude (2019), this problem is related to the fact that supply chains rely heavily on systems like Enterprise Resource Planning Systems (ERP), which store all information in one central location/server. These centralized systems seem insufficient because their primary goal is to enhance internal organizational operations, with a secondary goal of establishing connections with other stakeholders (Banerjee, 2018). Moreover, their design makes it simple to attack, corrupt, and hack (Dong *et al.*, 2017). The lack of trust between partners is a further issue (Nayak and Dhaigude, 2019).

The demand for better information sharing in supply chains has increased due to significant issues in data exchange, security, robustness, and process integrity. Transparency is becoming a more pressing need, and BT (Saber *et al.*, 2019), a distributed database of records, can provide a solution to these issues (Crosby *et al.*, 2016). BT's design incorporates non-localization, non-centralization (decentralization), security, auditability, and smart execution, making it different than other technologies. It can support any processes and the management of goods inside the supply chain, connecting physical products with their virtual identity inside the blockchain (Abeyratne and Monfared, 2016). Blockchain can assist supply chains in identifying dishonest vendors and fake goods (Saber *et al.*, 2019).

In conclusion, BT is a ground-breaking decentralized system. However, for the time being, its energy-intensive nature and the requirement for widespread use by many users keep it in the realm of debate and assessment in terms of application. It has the advantage of ensuring the integrity of exchanged data and emanating credibility as users of the technology network have complete transparency and decide on the transactions that take place (Papadakis, 2020). DPP tracks products from start to finish, preventing waste and fraud, making supply chains more transparent and providing accurate information for sustainable choices. It serves its purpose immutably (Papadakis, 2020).

Global data standards as a common language for sustainable supply chains

In a digitalized supply chain landscape, with various stakeholders and IT systems involved for operations management, a need for using a "common digital language" for unambiguous exchange of information is of high importance. This is vastly needed for the "Twin Transition", where sustainable practices co-exist with digital technologies, accelerating any sustainable transition (Muench *et al.*, 2022). Standards are agreements for products and services that govern processes or improve behaviours used by organizations to demonstrate consistency with business practice. "Standards" and "standardization", which are frequently used interchangeably, are two complementary concepts. (Papadakis and Kopanaki, 2022). Standardization is the process of creating standards, while standards are the results of this process. The use of Standards in Business Operations offers several advantages and measurable benefits for companies that implement them (Papadakis, 2020). Using standards in operations leads to higher customer trust, adherence to laws, lower costs, less waste, greater efficiency, and access to new technology (European Committee for Standardization, 2013).

Presently, companies are using various sustainability standards to guide their practices and demonstrate their commitment to environmental and social responsibility. One widely used standard is the Sustainable Development Goals (SDGs), which build on the "Millennium Development Goals" and aim to end poverty,

fight inequality, and address climate change by 2030 (Kamalam, 2017). The SDGs encompass economic, social, and environmental pillars, emphasizing the interconnectedness of these elements for sustainable development. “BCorp certification”, another known standard, is awarded to profit-oriented businesses that meet rigorous standards in environmental and social performance, accountability, and transparency (Stubbs, 2019). The Global Reporting Initiative (GRI) is also widely accepted as a standard for sustainability reporting (Agrawal *et al.*, 2023). It recommends that companies proactively consider sustainability in their decision-making and provide a framework for reporting on sustainability practices (Agrawal *et al.*, 2023). ISO 14001 is an international standard for environmental management systems that helps organizations manage environmental risks and commit to quality improvement (Sidjabat and Febrian, 2020). The above standards provide companies with guidelines and frameworks to integrate sustainability into their operations, decision-making processes, and reporting practices.

DPP as a tool for circular economies

A DPP is a digital collection of product-related data that combines different data sets about a product from every stage of its lifecycle (Kopelaar *et al.*, 2023). It is a key tool to create product transparency (Walden *et al.*, 2022) and accelerate the transition to a circular economy (Maayke *et al.*, 2022). There are two types of DPPs: static and dynamic. Static passports can only be read by actors who are involved in the life cycle of the product, whereas dynamic passports allow stakeholders from the entire life cycle to read and write the contents (Plociennik *et al.*, 2022). Technically, both online and offline methods of accessing the information in DPPs, (e.g., data carriers on physical product labels), are available (Gligoric *et al.*, 2019) which allows, if needed, to track a product's lifecycle history and trace it at any given time in the broader supply chain (Papadakis, 2015).

The EU has introduced policies to establish sustainable products, reduce waste, and apply circular economy policies globally. These policies include voluntary tools such as the “European Ecolabel” and the “Green Public Procurement Criteria” (European Commission (EC), 2020 and EC, 2022). Given the wide scope of regulation and the size of the EU market, DPP has significant potential to increase the circularity of products and materials (Kopelaar *et al.*, 2023). However, in most cases, the technology required for a circular economy is expensive, and the lack of financial resources hinders the successful implementation of a circular economy. The stakes of the circular economy are many (Kouhizadeh *et al.*, 2019). The subscription model in the “Circular Economy Action Plan” described as “Take - Make - Use - Dispose” (EC, 2019) is a linear consumption and production model that discourages manufacturers from creating more sustainable products. The DPP is one of the most important components for the establishment of a Circular Economy, the foundation of the EU's “Green Deal” and the “Twin Transition” (Berg *et al.*, 2021). The DPP has significant potential to increase the circularity of products and materials, but the technology required is expensive and the lack of financial resources hinders successful implementation.

Sustainable supply chains of various products and the DPP

DPP initiatives are mostly in Central and Northern Europe, with private and public sector efforts. Some Nordic countries also engage in DPP, but it is not seen as an important growth factor for Circular Economy (Jenssen *et al.*, 2022). Nevertheless, the complexity and necessity of the product supply chains where DPP will be implemented (electronic products, batteries and vehicles, plastic packaging, textiles, construction materials, food waste, water, and nutrients) has already initiated several piloting implementations across the EU. The “Keep Project” and “R Cycle Initiative” are two projects that aim to provide traceability solutions for electrical and electronic products to keep them in a circular system. The “Keep Project” tracks materials and components and it is funded by Sweden's Innovation Agency, while the “R-Cycle Initiative” supports the DPP idea and develops a cradle-to-cradle recycling system. Both projects provide trustworthy information about recycled plastic used in packaging (Patorska *et al.*, 2022).

Proposing global data standards for successful DPP BT implementation

Global standards are a key enabler, and this is outlined in the DPP initiative which recognizes as expected outcome the need of standards to ensure interoperability, security, and acceptance by all the stakeholders

and as such be implemented in other value chains (EC, 2019). One of the key benefits of using global data standards in the EU DPP initiative is the improved consistency, dependability, and transparency of data flows throughout the supply chain network (Çetin *et al.*, 2021). Global data standards enable consistent and standardized data exchange, ensuring that the information recorded in the passport is accurate, reliable, and easily understandable by all stakeholders involved (Lövdahl, 2023). This transparency and reliability of data flows enable effective collaboration and decision-making across the value chain, leading to more sustainable and informed choices (Lövdahl, 2023). The EU's DPP initiative uses global data standards to ensure non-European market participants can access the EU market and promote sustainable practices (Bendiek and Römer, 2019). Lastly, standards facilitate interoperability and compatibility between different systems and platforms (Papadakis, 2020). By adopting standardized data formats and structures, the EU DPP can seamlessly integrate with existing digital technologies and platforms, such as building information modeling (BIM) and material databanks (Çetin *et al.*, 2021). This interoperability ensures that the passport can effectively communicate and exchange data with other systems, enabling a holistic and comprehensive view of a product's lifecycle (Adisorn *et al.*, 2021). Global Standards like ISO/IEC 15459-6 (Global Trade Item Number) for products, ISO/IEC 6523 (Global Location Number) for physical/digital locations, ISO/IEC 15459-1 (Serial Shipping Container Code) for shipments, ISO/IEC 15459-4 & 5 for assets (individual/returnable), ISO/IEC 15418 (Global Document Type Identifier) for operational documents, ISO/IEC 16022 and ISO/IEC 18004 (for 2D data carriers placed on products and encoding the data of interest), ISO/IEC 19987 (EPC Information Services (EPCIS)) together with ISO/IEC 19988 (GS1 Core Business Vocabulary (CBV)) and GS1 Digital Link standard together with 2D Data Carriers can be exploited for a data quality based DPP supply chain when deployed via a BT ledger.

Impact of DPP on SSCM

For a long time, businesses believed that social and environmental issues were not as significant as financial ones because they were difficult to quantify. Additionally, they thought that corporate social responsibility was primarily linked to financial success. However, this viewpoint has gradually changed as businesses and shareholders have realized how crucial and relevant the aforementioned issues are to sustainability-related issues (Al Amosh and Mansor, 2018). So, nowadays, stakeholders expect companies to be more sensitive to both social and environmental issues (Duker and Olugunna, 2014). In order to better understand the contribution of the implementation of DPP, based on BT and Global standards, specific theories, such as the legitimacy and stakeholders' theories, can be considered and used.

Legitimacy Theory

Based on this theory, companies and organizations should realize that they are part of a broader ecosystem and that they are not the only ones having the right to use the resources (Deegan, 2019). To get the recognition of legitimate, organizations must prove to the society that they are capable to use these resources in a legitimate way (Mathews, 1997). Therefore, managers should ensure that their organization is functional in a way that there is alignment with the different social groups and the society in general. Sustainability policies led to the development of DPP, supported by BT and appropriate standards. Product traceability improves waste management, legitimacy, business performance, information visibility, and reduces fraud, leading to increased social value (Deegan, 2019). To sum up, legitimacy has a significant contribution in the way that companies handle their operations.

Stakeholders' Theory

According to this theory, the company's and all other stakeholders should benefit from the existence of the company. According to Freeman and Reed (1983), stakeholders are social groups that without their support, an organization or company would cease to exist. Based on this theory, the different groups of stakeholders have the right to be informed about the environmental and social issues (Ali and Rizwan, 2013), associated with the operation of a company. Nevertheless, as stated in the literature, there are not many companies or organizations, that clearly examine their social and environmental impact in a holistic way (Duker and Olugunna, 2014).

Conceptual Framework

The conceptual framework for blockchain-based DPP revolves around the integration of Legitimacy Theory, and Stakeholder's Theory. BT serves as a strategic resource that enhances data security, privacy, traceability, and transparency (Saber *et al.*, 2019). Through its decentralized and immutable nature, BT reduces the reliance on centralized authorities, allowing for trustless verification of digital passport data (Niranjanamurthy *et al.*, 2019). This, in turn, enables the reduction of resource consumption and waste by streamlining processes, improving supply chain traceability, and supporting sustainable sourcing and production practices (Kshetri, 2017). Furthermore, the transparency and visibility provided by BT could enhance the legitimacy of DPPs. When stakeholders can trust the information contained within digital passports, it increases social performance by facilitating informed decision-making, reducing inefficiencies, and promoting responsible practices (King *et al.*, 2023). By actively engaging stakeholders, BT-based DPPs create a collaborative environment where collective efforts contribute to the circular economy and sustainable supply chain management.

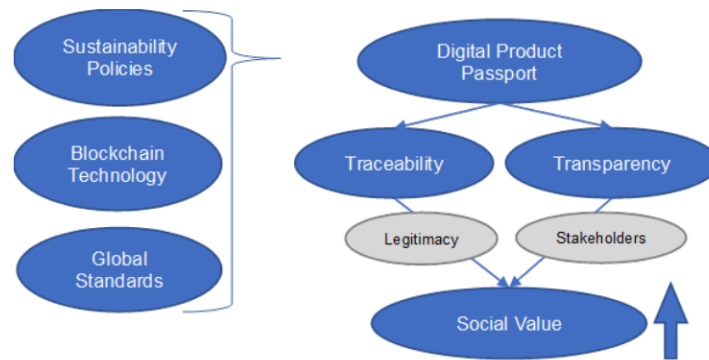


Figure 1, Impact of DPP on SSCM

As shown in the framework (Figure 1), Sustainability policies led to the development of DPP, supported by BT and appropriate standards. Product traceability improves waste management, legitimacy, business performance, information visibility, and reduces fraud, leading to increased social value.

Discussion and conclusions

The EU DPP initiative aims to enhance sustainability and circularity by providing comprehensive product information throughout the lifecycle of a product. To ensure the effectiveness and interoperability of this initiative, the use of global data standards is highly recommended. Utilizing various policies and incentive tools, such as public and private financing mechanisms, regulatory controls, and institutions to reduce initial economic compliance barriers and increase the benefits of certification for producers and value chain actors may be necessary to achieve such targeting (Smith *et al.*, 2018). The EU, as the largest consumer market globally, has the ambition to set global standards and regulations (Bendiek and Römer, 2019). In conclusion, the use of global data standards is highly recommended in the EU DPP Passport initiative. These standards enhance transparency, reliability, interoperability, and compatibility, ensuring effective collaboration and decision-making across the value chain. Furthermore, global data standards facilitate global trade and market access, promoting the adoption of sustainable practices worldwide. By adopting global data standards, the EU can establish a robust and effective DPP system that contributes to the circular economy and sustainability goals in the built environment. Further benefits can be achieved by the adoption of BT. However, BT has certain drawbacks related to complexity, network size, transaction costs, network speed, and political implementation concerns (Papadakis, 2020) that need to be addressed. Furthermore, it should be taken into consideration that most businesses or business collaborations, even if they do act in favor of circularity and subsequently sustainability, do so primarily out of self-interest and profit-orientation or with an eye toward potential regulations (Jensen *et al.*, 2022). Therefore, business

models must be tested not only from a technological, but also from a business point of view, so that a successful application of DPP is achieved (Mullhall *et al.*, 2019).

The study evaluated technologies for DPP implementation and proposed a framework for assessing their social impact. To achieve wider adoption, more pilots, governance, auditing protocols, and a framework should be established for interoperable and sustainable supply chains.

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