

Article

Circular Economy: Literature Review on the Implementation of the Digital Product Passport (DPP) in the Textile Industry

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Abstract: The development of a system to store and share key information about product lifecycles offers a key opportunity to improve the textile and apparel industry. The introduction of the digital product passport (DPP) serves as an inclusive tool that enables industry stakeholders—companies, suppliers, stakeholders, government organizations, public institutions, and consumers—to more accurately track the journey, characteristics, components, and environmental impact of products. This study explores the implementation and potential of the DPP, highlighting its transformative role as a bridge between technological innovation and sustainability in the textile and apparel sector. By providing unprecedented transparency and traceability, the DPP disrupts conventional industry paradigms and facilitates sustainable practices. The findings highlight the DPP's ability to consolidate disparate data into a unified system that provides stakeholders with actionable insights that were previously unavailable. In addition, the study identifies regulatory and operational gaps and positions the DPP as a pioneering solution to these challenges. This is significant progress toward operationalizing the principles of the circular economy and fostering innovation along the entire value chain. In line with the European Commission's 2020 Circular Economy Action Plan, the DPP complements initiatives such as the Ecodesign for Sustainable Products Regulation (ESPR) and improves product traceability. By providing stakeholders with reliable, comparable data, it supports informed decision making and promotes transparency, decarbonization, and sustainability. This analysis underlines the potential of the DPP to transform the sector into a better informed and environmentally conscious industry.

Keywords: circular economy; sustainability; digital product passport; textile industry



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1. Introduction

The aim of this study is to review the published literature on the digital product passport (DPP), fundamentally in the context of activity in the textile sector. Specifically, the aim is to gather information that will help companies and consumers themselves to perceive product(s) in a more sustainable way when making their choice. Thus, the study focuses on the analysis of concepts such as the circular economy and lifecycle; it considers the environmental impacts that the textile and clothing sector has on the surrounding environment; it identifies the measures recommended by the European Commission to minimise these impacts; it evaluates the results of implementing the DPP in the sector; it analyzes the advantages and disadvantages that it provides directly to consumers and companies; and finally, it establishes the information and data that should be included in

the DPP of a textile product. Considered one of the largest and most important industrial sectors in the world, textiles/clothing generate enormous revenues and provide employment for millions of people across Europe [1]. However, given its size and capacity to mobilize labor, it has huge impacts on the environment and social structure in general and is considered the second most polluting industry in the world [2]. By including very diverse processes in its activities (raw material management, spinning, weaving, dyeing, finishing, garmenting), involving polluting technologies, the use of chemicals and derivatives, and the involvement of vast human resources, the textile/apparel sector has harmful effects on the environment (water pollution, greenhouse gas emissions), while at the same time promoting labor exploitation [3,4]. In order to combat these harmful effects on the environment and people's quality of life, in 2020, the European Commission (EC) adopted a new Circular Economy Action Plan (CEAP), which established a set of sustainability principles, including the implementation of digital passports [5]. The set of principles proposed in the new Ecodesign for Sustainable Products Regulation (ESPR) in 2022 extends and repeals the current Ecodesign Directive established in 2009 [6]. The new regulation focuses mainly on the creation of the DPP and aims to increase the transparency of processes, both for companies in the supply chain and for the general public. On the other hand, it aims to promote greater efficiency in terms of information transfer [6], responding to the lack of supporting regulations in the sector. However, there are still many challenges facing the textile and clothing industry, which the sector wants to overcome with the fundamental contribution of DPPs, namely through the implementation of innovative approaches that facilitate the exchange of information on the sustainability parameters of products along value chains, such as their carbon footprint and recyclability. In a broader context, DPPs can also play a key role in defining the circular economy and carbon reduction strategies, targeting new markets and business models that respect social compliance reports. It is worth mentioning, however, that a DPP model has not yet been formulated to achieve the necessary breadth of application [7]. This is the context of this study, which aims to reflect on the potential of this tool to add value to an entire sector of activity. The aim is, through a generalized and systematic analysis of all of the parameters involved in the implementation of DPPs, to understand how this new approach can contribute to a more sustainable future for the textile/apparel industry—namely through the consolidation of a worldwide circular economy based on more transparent information and the idea of environmental preservation.

2. Methodology

For this article, a literature review was carried out on the study variables, including the ideas, experiences, and thoughts of authors investigating this field of research. In general, publications in books, scientific articles, and theses about DPPs were analyzed, more specifically for the textile sector. However, we first introduce concepts such as the circular economy, which is interlinked with sustainable design and product lifecycle analysis, as these are concepts that interact with the introduction of this digital tool, the digital product passport. These concepts are related to sustainable business models and the creation of ecological and durable products, and this information can be contained in the DPP. The aim of this method was to delimit the context of this research, and the theoretical framework is organized into theoretical and analysis categories to specify the domain of the concepts worked on in the empirical analysis. Thus, at this stage, a literature review was carried out with the aim of (i) framing and contextualizing the emergence of the DPP in the European Union's Sustainability Plans; (ii) establishing a definition of the DPP and the information that should be contained in this tool in order to create greater transparency in the process of creating and selling textile products; (iii) detecting

the opportunities and challenges in the development of the DPP in the political/fiscal context of countries, companies, and consumers; and (iv) providing a general framework and analysis of the solutions and projects created to meet the needs of creating a universal DPP. According to [8] bibliographical research is a fundamental skill in undergraduate programs since it forms the first step for all academic activities. Laboratory or field research necessarily involves preliminary bibliographical research. Seminars, panels, debates, critical summaries, and monographs do not dispense with bibliographical research. It is obligatory in exploratory research, in defining the subject of a work or research, in developing the subject, in citations, and in presenting conclusions. Therefore, while it is true that not all students will carry out laboratory or field research, it is no less true that all of them, without exception, will have to carry out bibliographical research to prepare various assignments [8]. However, during the development of the literature review, a systematic review was carried out specifically on the digital product passport, with the aim of identifying, selecting, evaluating, and synthesizing the relevant evidence available on this digital tool proposed by the EC. According to [9] showed a systematic literature review as a type of research that follows specific protocols and aims to understand and give some logic to a large corpus of documents, especially by checking what works and what does not work in a given context. It focuses on its reproducibility by other researchers, explicitly presenting the bibliographic databases that are consulted, the search strategies carried out in each research browser, the process of selecting scientific articles, the criteria for including and excluding articles, and the process of analyzing each article. It also explains the limitations of each article analyzed, as well as the limitations of the review itself [9]. The systematic review of the literature in this study is in line with updates from the European Commission's governing body and legislation that may be introduced in the future. To carry out this systematic review, we searched for the expression "passaporte digital de produto" or "digital passport product" or "passeport numérique des produits" in the search engines Google scholar, Scopus, Web of science, and Science Direct on 30 May 2024 (Figure 1). In the first selection, we found 130 articles from peer-reviewed international journals that mentioned this digital tool. We then analyzed 19 of these articles that developed the concept of DPP for further study. Due to the increasing development of this digital tool and the implementation of DPP in industry, there were already articles on this concept, but there were few bibliographical reviews on this concept because the legislation has not yet been defined by the EC. The inclusion criteria for this study aimed to select articles offering comprehensive insights into the concept and implementation of the digital product passport (DPP). Priority was given to peer-reviewed studies addressing the development, application, or challenges of DPPs in the textile and manufacturing industries, particularly those aligned with the European Commission's sustainability initiatives. Only articles in English, Portuguese, French, or Spanish were considered, focusing on the role of DPPs in product traceability, lifecycle analysis, and circular economy strategies, as well as their socio-economic impact on stakeholders like producers, consumers, and policymakers. Studies featuring innovative solutions or practical case studies enriching the research were prioritized. The exclusion criteria ensured relevance and quality by excluding articles without explicit references to DPPs, those unrelated to textiles or manufacturing, and non-peer-reviewed materials. Studies focusing solely on general sustainability concepts or digital tools without addressing DPP frameworks were also excluded. Older studies (pre 2010), duplicates, and those with incomplete data, inaccessible full texts, or ambiguous findings were removed. This rigorous selection process resulted in a robust dataset of high-quality studies.

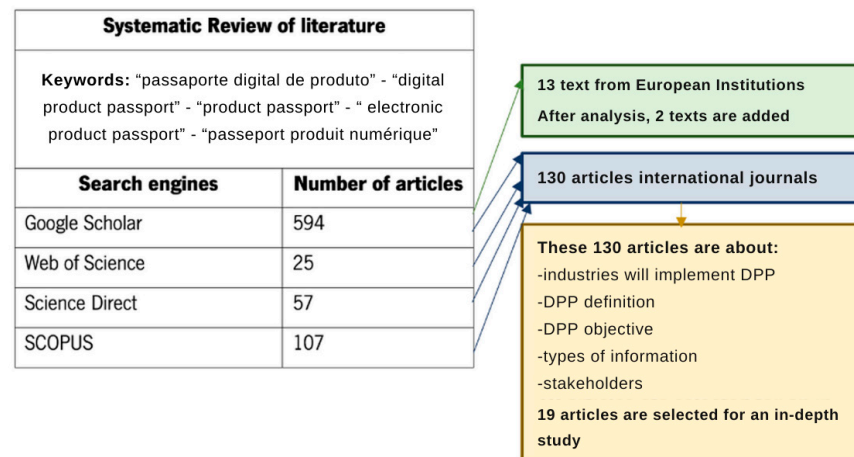


Figure 1. Systematic review of the literature carried out by the author.

3. State of the Art

3.1. Impact of the Textile Industry on the Environment

The fashion and textile sector is responsible for a significant environmental impact, being identified as the third largest cause of degradation of water resources and land use in 2020. In that year, to meet the demand for clothing and footwear for each citizen of the European Union (EU), an average of nine cubic meters of water, 400 square meters of land, and 391 kg of raw materials were needed [1]. It is estimated that production in this sector contributes to around 20 per cent of global freshwater pollution, mainly attributable to the chemicals used in dyeing and finishing clothes. In addition, the textile industry is responsible for approximately 10 per cent of global carbon emissions, surpassing the combined contribution of international air and maritime transport. According to data from the European Environment Agency, fashion and textile purchases in the EU in 2020 generated an average of 270 kg of CO₂ emissions per individual, totaling around 121 million tonnes of greenhouse gases [1]. Every year, the European population consumes around 26 kilos of textiles, discarding approximately 11 kilos of that total. Although used clothing can be exported outside the EU, the majority (87 per cent) is incinerated or sent to landfill. It is therefore imperative to promote the economic and environmental benefits of prolonged use of textile products, as well as raising awareness of repair and maintenance practices that favor durability. Using high-quality materials, carefully selecting finishes, and offering clear maintenance instructions on labels are essential to empower consumers to make informed decisions during the purchasing process [10]. Textile products, particularly clothing, are made up of a variety of fabrics, materials, and accessories, such as buttons and zips, which include combinations of natural and synthetic fibers, plastics, and metals [11]. This diversity makes sustainable disposal more challenging. The textile industry largely relies on synthetic fibers and petroleum-based polymers, such as polyester, polypropylene, nylon (polyamide 6-6), and acrylic, which account for 63% of global textile fiber consumption. The production and disposal of these fibers is directly related to significant carbon dioxide (CO₂) emissions. Natural fibers such as cotton, which account for around 26% of the clothing sector, are highly intensive in water and chemical inputs; the production of just 1 kg of cotton requires between 7000 and 29,000 L of water. In addition, the intensive use of pesticides and fertilizers in cotton cultivation harms biodiversity, impacts water quality, and compromises soil structure [12]. The solid and liquid waste generated by the textile production chain contaminates terrestrial and aquatic environments, with synthetic fibers persisting in the environment for millennia and releasing microplastics that disperse into both the soil and the oceans [13,14]. Textile processes often use highly toxic chemical compounds that pose sub-

stantial health risks to workers and aquatic ecosystems. The textile industry emits effluents that compromise water oxygen levels, negatively affecting aquatic biota [15–18]. In particular, wet processing—which includes fiber preparation, dyeing, printing, and finishing—as well as the production of yarns and fabrics, rely heavily on fossil fuels, contributing both to the emission of pollutants and to the increase in atmospheric CO₂. In 2015, the textile sector was responsible for the emission of approximately 1.2 billion tonnes of CO₂, with projections indicating an increase of 26% by 2050 [17,19]. The global production of textiles and clothing is on a steady growth trajectory, with an expected acceleration. Clothing sales have almost doubled in the last 15 years [15,18]. In 1975, the global production of textile fibers totaled approximately 23.9 million metric tonnes, rising to 98.5 million tonnes in 2017 and reaching 111 million tonnes in 2019 [10]. Projections suggest that annual consumption of clothing, which was 62 million tonnes in 2019, could reach 102 million tonnes by 2030 and expand to 160 million tonnes by 2050 [10]. According to data released by the European Parliament in 2024, less than half of used clothes are stored for reuse or recycling, with only 1% of used clothes being recycled into new products, given that the technologies that enable this recycling into virgin fibers are still in the development phase [11]. The role of legislators is crucial in promoting increased recycling. In 2022, the European Commission presented a Strategy for the Sustainability of Textiles, which includes extending the useful life of textiles by recycling and reusing materials in new quality products [10]. The Waste Framework Directive requires EU member states to establish separate collection systems for textile waste by the beginning of 2025 and imposes new textile recycling targets. To meet these new regulations, collection, sorting, and recycling infrastructures will need to adapt quickly [11]. In 2022, a McKinsey & Company report entitled “Scaling textile recycling in Europe—turning waste into value” indicated that closed-loop recycling—which involves reusing pre- and post-consumer textile waste to produce new yarns and fabrics—could be applied to between 18% and 26% of raw textile waste in Europe by 2030 [20]. Companies such as Renewcell, Ambercycle, Circ, Gr3n, and Worn Again Technologies are at the forefront of recycling textile waste into new products [21]. Between 2021 and 2022, Textile Exchange published an annual materials market report, highlighting that closed-loop reuse and post-consumer recycling increased from 0.06% to 0.18% of total material use (8623 tonnes) between 2018 and 2020 and to 0.6% of total material use (37,153 tonnes) between 2018 and 2021 [22]. The Sankey diagram shown in Figure 2 shows the division of materials into three main categories: conventional (virgin) materials (44 per cent), renewable materials (42 per cent), and recycled materials (14 per cent). Recycled materials are subdivided into textile and non-textile waste (mostly plastics). The share of recycled textile waste is segmented into pre- and post-consumer waste, with post-consumer waste accounting for 4% of the 14.6% of materials collected for reuse (5R’s strategy), and 0.6% cannot be reused for any purpose other than recycling [22] (Figure 2). The development of new business models within the textile industry that embrace circular economy practices is crucial for the use of more sustainable materials and the creation of timeless designs that can adapt to evolving fashion trends. Consequently, it is essential for companies to adopt sustainable design techniques aimed at reducing textile waste. Examples include modular design, design for longevity, and design for recyclability [23]. Designing for low environmental impact involves choosing materials and processes that minimize the ecological footprint. This includes selecting renewable, recyclable, or biodegradable raw materials and planning production processes to reduce water and energy consumption. Durable, resilient materials, along with provisions for maintenance and repair, are key to longevity-focused design, with the aim of developing high-quality, long-lasting products. Similarly, choosing materials that can be easily disassembled and recycled is essential for recyclability-focused design [23]. The need for secure and reliable information regard-

ing the sustainability of textile products is underscored by the substantial environmental impact of the sector and its effects on people's quality of life, particularly in developing countries where poor working conditions and widespread corruption are prevalent [7]. In conclusion, the textile industry faces significant challenges related to environmental impact, the increasing demand for sustainable products, and the urgent need to adapt to emerging legislation. Promoting circular economy practices, technological innovation, and consumer awareness are crucial steps in transforming the industry, not only to reduce its ecological footprint but also to contribute to a more sustainable and responsible future. Legislative initiatives alongside the development of new recycling technologies and sustainable design practices could represent an essential step toward creating a fashion industry that respects planetary boundaries and champions social and environmental justice [7].

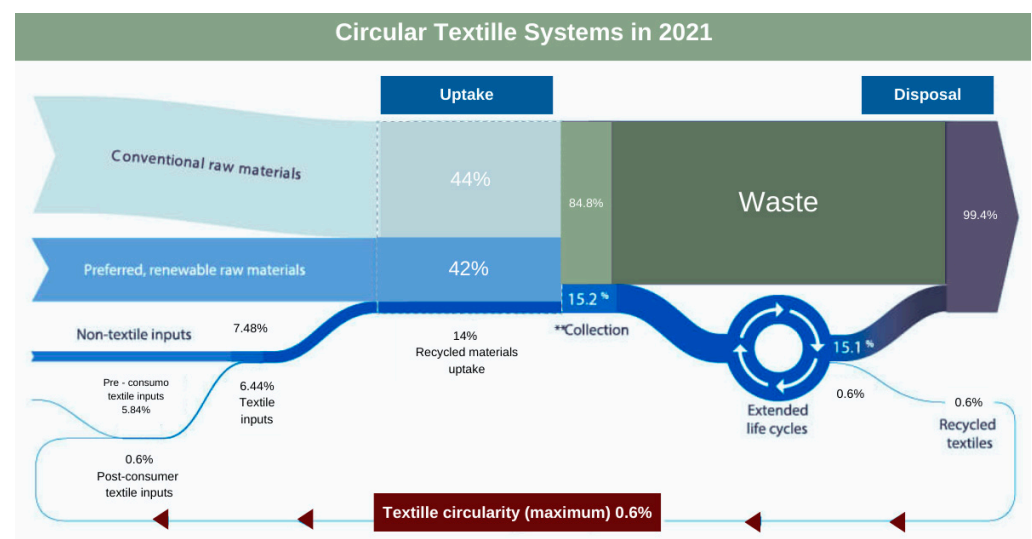


Figure 2. Flow of raw materials, including post-consumer waste, realised by the author of this article including information from ref. [22].

3.2. Circular Economy

Accelerated growth in resource consumption, driven by population expansion, has resulted in a substantial increase in waste generation in various economic sectors, concomitant with a worrying reduction in biodiversity and an intensification of pollutant emissions [24,25]. Since the Industrial Revolution, the global economy has operated under a linear model, characterized by the extraction of raw materials, transformation into products, and subsequent disposal after use [26]. The concept of the circular economy emerged in the 1970s and is often associated with various authors. [27–29] recognize the initial formulation by [30,31] described the circular economy as a closed economic model centered on waste prevention, job creation, energy efficiency, and dematerialization. Later, Ref. [31] emphasized the relevance of a business model based on selling the use of goods rather than ownership, allowing companies to generate profit without bearing the costs and risks associated with waste management [24,25]. Currently, the definition and practical application of the circular economy in economic and industrial systems has evolved, incorporating a wide range of complementary theories, all centered on the idea of closed resource cycles [26–28]. Among the most significant approaches are the 'cradle to cradle' theory [32], the laws of ecology [33], closed-loop and performance economics [34], regenerative design, industrial ecology [35], biomimicry [36], and the blue economy [37]. Various definitions of the circular economy have been proposed, but [32] suggest four fundamental criteria for a suitable formulation: (a) a focus on closing resource cycles; (b) an emphasis on optimizing rather than merely minimizing resource flows; (c) consideration of multiple

levels of action; and (d) a distinction between the ideal concept of the circular economy and a pragmatic version, which incorporates other approaches to achieving sustainability. The circular economy model proposes a transition from the linear system of production and consumption to a closed cycle in which the useful life of products is extended by reusing resources and conserving energy. This model contrasts with the linear logic in which products are discarded after use [38]. In this new paradigm, the longevity of products is maximized from the resource extraction phase to the moment they become waste, with the aim of minimizing environmental impact and optimizing reuse opportunities. As outlined by the Business Council for Sustainable Development (BCSD), the circular economy model proposes that at the end of a product's useful life, it is reintegrated into new production processes, generating new goods or materials [39]. The [19] broadens this perspective by defining the circular economy as an industrial system with a restorative and regenerative focus, geared toward the use of renewable energies, the reduction and control of harmful chemical substances, and the elimination of waste through meticulous design. According [40] characterize the circular economy as a mechanism that establishes closed material cycles. The [41] reinforces this view, considering that the circular economy, from design onward, is restorative, seeking to preserve products, components, and materials, ensuring that they remain useful and valuable for as long as possible. According to [42], the model focuses on creating a continuous flow of materials and reusing the same raw materials and energy throughout various production stages. The [43] points out that circular economy strategies are characterized by slower, closed, and limited processes. This system aims to decouple economic progress from dependence on finite natural resources, promoting a reduction in the extraction of virgin raw materials and driving new cycles of production, consumption, and recovery of materials [26] By minimizing resource use, waste generation, and greenhouse gas emissions, the circular economy proposes slowing down, closing, and restricting material and energy cycles. Its practical application can be fostered by initiatives such as the design of durable products, maintenance, repair, reuse, reconditioning, and recycling [43]. The fundamental principles of the circular economy can be summarized in three pillars: (a) preserving and enhancing natural capital by effectively managing finite resources and balancing renewable resource flows; (b) maximizing resource efficiency by ensuring that products, components, and materials remain in circulation and useful for as long as possible; and (c) promoting systemic efficiency by identifying and mitigating negative externalities [44]. This model presupposes an interconnection between production and consumption in a closed cycle that combines technology, economics, the social environment, and waste management to create products and services that are sustainable from both economic and ecological point of views. By encouraging reuse and recycling, the circular economy extends the added value of products while reducing the need for continuous extraction of new resources. Even with the gradual devaluation of materials over time, the circular economy avoids the unnecessary extraction of raw materials. Retaining products in closed production cycles provides economic and environmental advantages by reducing the exploitation of non-renewable resources, reducing dependence on imports of raw materials, and limiting the generation of waste and its associated emissions [43]. Although the circular system still involves the use of virgin resources and the production of waste, it differs from the linear model by promoting a significantly more rational use of resources and the sustainable disposal of products that cannot be reused. The transition to a circular economy has enormous potential to generate substantial savings, estimated at hundreds of billions of euros for the European Union, and mitigate negative impacts on the environment. This model is considered one of the most influential movements toward sustainability [44]. At the same time, growing consumer awareness of the need for responsible environmental practices has stimulated demand for products designed to mini-

mize environmental pollution. In the textile sector, there has been an increase in demand for products labeled as 'bio', despite the fact that these present significant environmental problems, such as water contamination. These 'bio' products are not necessarily safer for human health—contrary to what some non-specialist sources claim. However, their production and the preparation of raw materials must follow strict criteria for environmental preservation and protection. The central issue, therefore, lies not only in protecting individual health but in promoting a healthy environmental state, which is essential to collective well-being [45]. The transition from the traditional linear economy to a circular economy model is currently being encouraged by various European Union initiatives. The principle of circularity focuses on the optimized use of resources, especially secondary resources (waste), adopting the fundamentals of the 6Rs: reduce, recover, reuse, recycle, redesign, and remanufacture. Some future perspectives already envisage an evolution from a circular economy to a sustainable economy in which the 'battle for resources' will be replaced by the concept of resource sufficiency [45]. However, the shift to this new paradigm will be neither simple nor immediate, requiring substantial investment and profound transformations in the systems currently in place [46,47]. The European Commission (2015) emphasizes that this process will require a long-term commitment, with the active participation of all levels of society, from member states and regions to companies and citizens [46].

3.3. Textile Circular Economy

The textile industry employs more than 60 million people in its global value chain and, in 2016, generated revenues of more than 1.29 trillion dollars, based on commercial operations associated with the import and export of clothing and related products [48,49]. However, the current production model in this sector remains predominantly linear, characterized by the intensive extraction of non-renewable resources to manufacture products [49,50]. Research indicates that more than 50 per cent of garments produced for the fast fashion market are discarded by consumers after less than a year's use [51,52]. In 2020, textile consumption in Europe was identified as one of the main contributors to environmental impact and climate change, ranking fourth in terms of global impact throughout the lifecycle [53]. This sector is also the third largest consumer of water and soil and the fifth in terms of raw material consumption and greenhouse gas emissions. In addition, an analysis carried out by Business Insider revealed that around 85% of textiles purchased end up being discarded every year, with clothes washing releasing approximately 500,000 tonnes of microfibers into the oceans, equivalent to 50 billion plastic bottles year [48]. According to the Ellen MacArthur Foundation (2017), the economic loss associated with the non-recovery of clothing, which is incinerated or sent to landfill, amounts to around 100 million dollars a year [49]. In New York City, it is estimated that 20 million dollars are spent annually on incinerating or disposing clothing discarded by consumers [48]. Given the textile industry's position as one of the largest consumers of raw materials and its significant environmental and social impacts, it is imperative to promote the transition to a circular textile system, considering that less than 1% of the fibers used in clothing production come from renewable resources [49]. Over the last two decades, the average duration of use of garments has decreased by 36 per cent, with each item being used on average only seven to eight times [49,54,55]. Promoting a sustainable path requires the adoption of circular business models that encourage greater product longevity, as well as more sustainable consumption and lifestyles. The phenomenon of 'greenwashing' is currently a major challenge for the textile industry. Green marketing, which aims to reduce the environmental footprint of products through redesign and sustainable production, is trying to meet the growing demand for sustainable consumption practices. The main focus is on introducing environmentally friendly products and attracting consumers who value

environmental awareness [48]. A study conducted by [56] highlights the importance of cultivating an environmentally conscious image and offering high-quality green products as key factors for customer satisfaction. The study found a positive correlation between price and satisfaction, suggesting that consumers are willing to pay more for products that are both sustainable and of high quality. However, despite the benefits of green marketing, its implementation faces major challenge [56]. One major problem is ‘greenwashing’, a practice whereby companies misrepresent or exaggerate the environmental benefits of their products and practices, often without providing reliable evidence for these claims [47]. The report “Synthetics Anonymous: Fashion Brands’ Addiction to Fossil Fuels” analyzed 50 major fashion brands, including those that claim to be transparent, such as Zara, Primark, H&M, and Burberry. The study examined the use of fossil fuel-derived materials in their collections and their commitments to reduce this use. H&M, ASOS, and M&S were identified as the biggest offenders, with 96%, 89%, and 88% of misleading claims, respectively. In addition, H&M’s Conscious Collection was found to contain 72% synthetic fibers, compared to 61% in the main collection [46]. Despite the existence of sustainability certifications and initiatives, misleading practices, ambiguous wording, and lack of transparency continue to confuse consumers. This highlights the urgent need for greater accountability and a comprehensive review of the sustainability standards that currently govern the fashion industry [47]. Apparel brands need to collaborate with various actors in the value chain to develop innovative solutions that address supply challenges, particularly in relation to raw materials and the end of life of products [53]. In this context, the principles of the circular economy play an important role in the textile industry. They aim to preserve the value of fibers and clothing throughout their entire use cycle. The aim is to reintegrate products into the economy at the end of their useful life and avoid disposal in landfills or incinerators [49]. According to [50], implementation of a circular economy in the textile industry is feasible as long as companies make structural changes in the initial and final stages of their production chains, enabling a significant reduction in the sector’s environmental footprint. Circular design is also important to ensure the longevity and durability of products, as about 40% of the reasons why consumers throw away their clothes have to do with functional problems, such as tears, wear, loss of elasticity or shape, stains, and color changes [54]. In addition to using durable and sustainable materials, it is crucial to anticipate changes in consumer behavior [57]. To this end, developing timeless designs that counteract the fluctuations of fashion trends, together with providing detailed information on product care and offering repair services (either in retail stores or in partnership with local workshops), can play a crucial role in consumers’ emotional appreciation of clothing [52]. The DPP is a key tool for the transition to a circular economy. This mechanism will provide transparent and comprehensive information on products and their production processes, accessible to both consumers and businesses, in order to promote more sustainable practices and stimulate the formation of a more efficient and circular market [58,59]. The DPP will contain detailed data on the reuse, repair, and recycling of products and enable businesses and consumers to find new ways to extend the useful life of goods, reduce waste production and conserve natural resources. This tool will be crucial for promoting the circular economy and new, more sustainable business models by assessing the lifecycle of products and maximizing their durability, minimizing the need for frequent replacement [7].

3.4. Context for the Introduction of the Digital Product Passport (DPP)

The textile industry plays a central role in the global economy, both in terms of revenue generation and job creation, particularly in European countries and emerging economies. However, its impacts on the environment and society are profound and complex. Due to its resource-intensive production processes [2], which include high water

and energy consumption, the use of harmful chemicals, and the emission of significant amounts of greenhouse gases, the sector is considered the second largest source of pollution in the world. In addition to its impact on the environment, the textile industry is also characterized by critical social challenges, such as poor working conditions and low wages in many production regions, especially in developing countries. Labor exploitation, including child labor and lack of workers' rights, remains a pressing issue in the sector [3,4]. These issues highlight the need for a transition to more sustainable and ethical practices that promote a circular economy, the use of recycled and biodegradable materials, and more transparency in the supply chain (Figure 3). The European Green Deal, launched by the European Commission in 2019, is a strategic initiative to lead the European Union toward an ecological transition with the aim of achieving climate neutrality by 2050. A key element of this plan is the concept of the digital product passport (DPP), which will be developed to provide detailed information on the composition, origin, reparability, recyclability, and end-of-life options of products. The introduction of the DPP for the textile sector represents a valuable opportunity not only to inform consumers but also to improve communication between all stakeholders in the value chain, including post-sale, thus promoting a more circular economy [55]. The European Commission is currently preparing the Sustainable Products Initiative, which aims to extend the scope of the Ecodesign Directive to a wider range of products, alongside the introduction of the digital product passport (DPP). According to Saari et al. (2022), the DPP consists of two basic components: a unique identifier assigned to each product and the data associated with this identifier, which are collected by various actors throughout the supply chain. These data include key product characteristics and detailed information about the product's lifecycle [56]. For the circular economy to function optimally, comprehensive access to data on materials, components, products, and assets is essential. However, the lack of such easily accessible information remains a major obstacle. This lack of transparency not only leads to economic inefficiencies for consumers and manufacturers but also contributes to significant waste and pollution. The availability and proper management of product-related data are crucial for overcoming these challenges and for the success of circular economy initiatives [59].

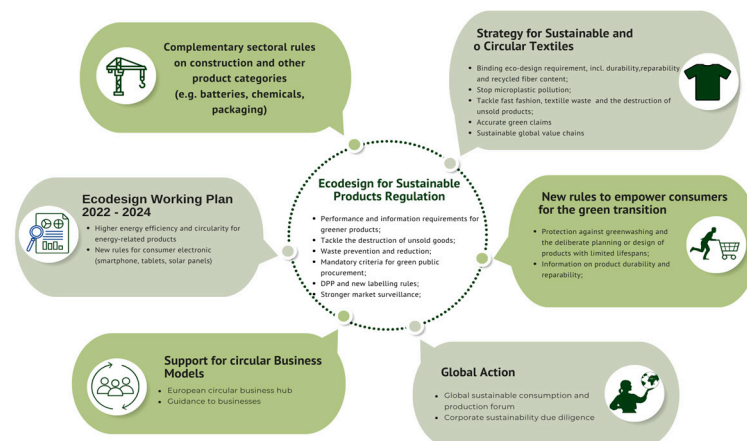


Figure 3. Ecodesign for Sustainable Products Regulation carried out by the author of this article with the information in ref. [3,4].

In 2022, the first phase of the CIRPASS (Collaborative Initiative for a Standard-Based Digital Product Passport for Product-Specific Data Sharing in a Circular Economy) was launched, lasting 18 months, following the proposal of the Sustainable Products Regulation (ESPR). The central aim of this initiative was to develop a structured concept for the digital product passport (DPP), establishing an inter-sectoral data model that promotes the circular economy. Initially, the project focused on three strategic sectors: electronics, batteries, and

textiles. The consortium leading the initiative consisted of 30 global partners, including industry organizations, digital companies, international standardization bodies, regulatory authorities, and NGOs, reflecting a collaborative and multi-sectoral approach. The DPP regulation is currently being drafted by the European Commission, with final approval expected in 2024 and implementation of the first product groups anticipated in 2026/27 (Figure 4) [54].

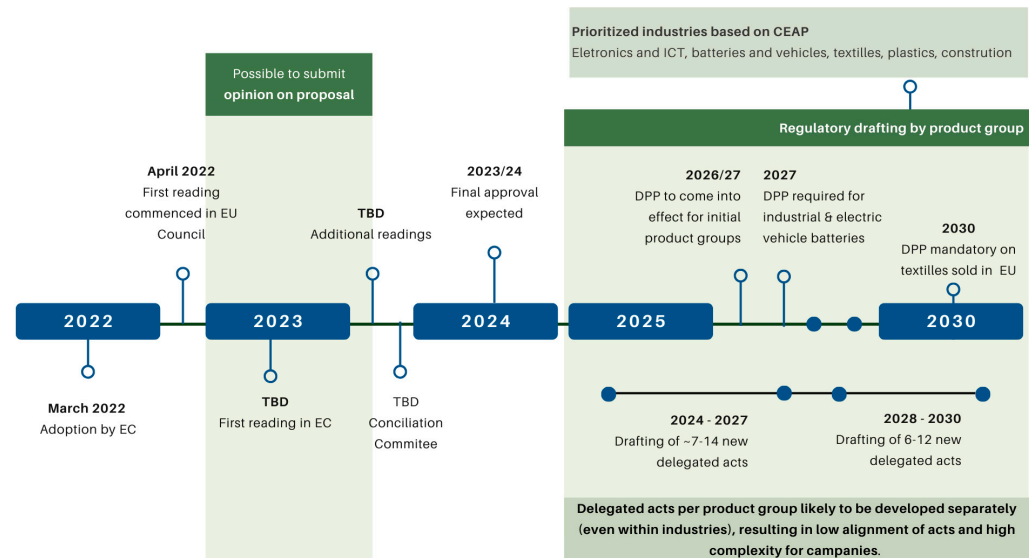


Figure 4. Timeline carried out by the author of this article according to the information in ref. [53].

Despite these advances, several aspects of the European Union’s digital product passport (DPP) remain undefined, including its scope (such as the level of application), technology (data storage, support, and access), and data governance (requirements and management). These variables render implementation a protracted process, as the European Commission is developing specific DPPs for different product categories to meet the unique requirements of each sector [57]. In accordance with the harmonized legislation of the European Union relating to the products covered by this regulation, they must comply with the requirements of the aforementioned EU standards from the moment they are placed on the market, throughout their availability and use, until the end of their lifecycle (Regulation (EU) 2023/988). Manufacturers, as well as other economic operators involved, are obliged to: “maintain the technical documentation, the declaration of conformity, and other necessary documents proving the product’s compliance with legal requirements for a period of 10 years from the date of placing the product on the market; ensure the inclusion on the product (or, where applicable according to specific regulations, on the packaging, in an accompanying document, or on the label) of information that allows for its identification; and ensure that the product (or, as described in specific regulations, the packaging, accompanying document, or label) contains the manufacturer’s name, the registered trademark (if applicable), and the address” [6]. The adoption of the DPP will have profound implications for global value chains, requiring international suppliers and manufacturers to capture and provide the necessary information to comply with the DPP [58]. The regulation will also mandate that a specific percentage of each product be composed of recycled materials, as well as impose restrictions on product disposal. This regulatory model could even serve as a reference for other regulatory bodies considering the implementation of DPPs in the future [59].

3.5. Definition of DPP

The deployment of this digital tool in the fashion and textile sector aligns with the EU's Strategy for Sustainable and Circular Textiles, spearheaded by the European Commission, and is expected to be fully operational by 2030. The European Commission defines the digital product passport (DPP) as a digital repository containing specific product data accessible via a data carrier. It serves to "record, process, and exchange information about products across supply chain partners, regulatory authorities, and consumers." Durand et al. (2022) describe the DPP as a structured collection of product data, specifying ownership, scope, and access rights for different users. It acts as a digital custodian for information related to the product. However, the exact scope of the passport, especially whether it will extend beyond sustainability and circular economy attributes, remains under consideration [58]. According to Adisorn et al. (2021), the DPP provides a dataset that outlines the components, materials, and chemicals involved in the product, offering guidelines for repair and recycling during its lifecycle [60]. King et al. (2023) describe it as a system offering data on sustainability, circularity, hazardous substances, and valuable materials shared among stakeholders within the value chain. This joint ownership facilitates informed decision making aligned with sustainability objectives [60]. The European Commission states that the DPP will utilize a unique identifier via a data carrier (e.g., barcode or QR code), which must be physically present on the product. The mandatory information requirements, as outlined in the Ecodesign for Sustainable Products Regulation (ESPR), include details on product composition, origin, environmental impact, and guidance for repair, maintenance, and recycling. Additional information may encompass lifecycle performance, hazardous substances, recycled content, and the product's estimated lifespan. The DPP will provide data on product origin, composition, and repair or recycling possibilities, potentially aiding circular economy practices like predictive maintenance, remanufacturing, and recycling. It also offers consumers and stakeholders insights into the sustainability attributes of product materials [60]. Moreover, the DPP could extend its functionality beyond the circular economy. With enhanced data transparency, it may incorporate details on greenhouse gas emissions, certifications, and other criteria valuable for customers, investors, and stakeholders, supporting reporting and audit processes. This broader application could further contribute to the industry's climate neutrality goals [61,62]. A primary objective of the DPP is product traceability, essential for several reasons. Traceability enhances transparency and accountability throughout the supply chain, allowing the tracking of a product from its origin to the end consumer (Figure 5). This increased transparency helps to build consumer trust, as it enables verification of the sustainability claims made by brands [55]. Traceability also plays a crucial role in ensuring compliance with legal and sustainability standards. The DPP will assist regulatory bodies in monitoring and enforcing compliance related to environmental impacts, labor conditions, and product safety, thereby supporting a more responsible and sustainable textile industry [63].

The DPP is a strategic instrument within the European Union's regulatory framework that aims to optimize value chains, improve data transparency, and promote sustainability. As outlined by the European Commission in 2022, pilot initiatives in the private sector are already demonstrating the potential benefits of the DPP in mitigating financial, operational, and reputational risks, while promoting more responsible business practices in line with the principles of the circular economy [6]. The application of the DPP will have a direct impact on various stakeholders and offer significant benefits at different stages of the product lifecycle. Studies and reports, such as those by Plociennik et al. (2022) and Re-Tek (2019), highlight the following specific benefits [61,62]:

- Designers and management: The DPP enables the inclusion of detailed feedback on the environmental impact and end-of-life disposal of products, facilitating the devel-

opment of design solutions that maximize recyclability and maintenance, contributing to product longevity.

- **Manufacturers:** By accessing a comprehensive digital archive of each product's lifecycle, manufacturers can effectively trace component provenance, improve accuracy in warranty claims and recalls, and implement predictive maintenance strategies by correlating failures with operational parameters.
- **Repairers and maintenance service providers:** They benefit from detailed technical information on spare parts, usage history, and maintenance logs, improving the accuracy and quality of the services provided.
- **Remanufacturers:** They gain access to important data on the condition of components, enabling them to optimize the remanufacturing and reuse of strategic parts. This improves the production cycle and reduces the need for new material resources.
- **Recyclers:** The availability of detailed data on product composition, including information on hazardous or valuable materials, will improve the efficiency and safety of recycling processes.
- **Consumers:** They receive comprehensive information about products, including the carbon footprint, the presence of allergens, and the availability of spare parts, so that they can make purchasing decisions based on environmental and sustainability criteria.

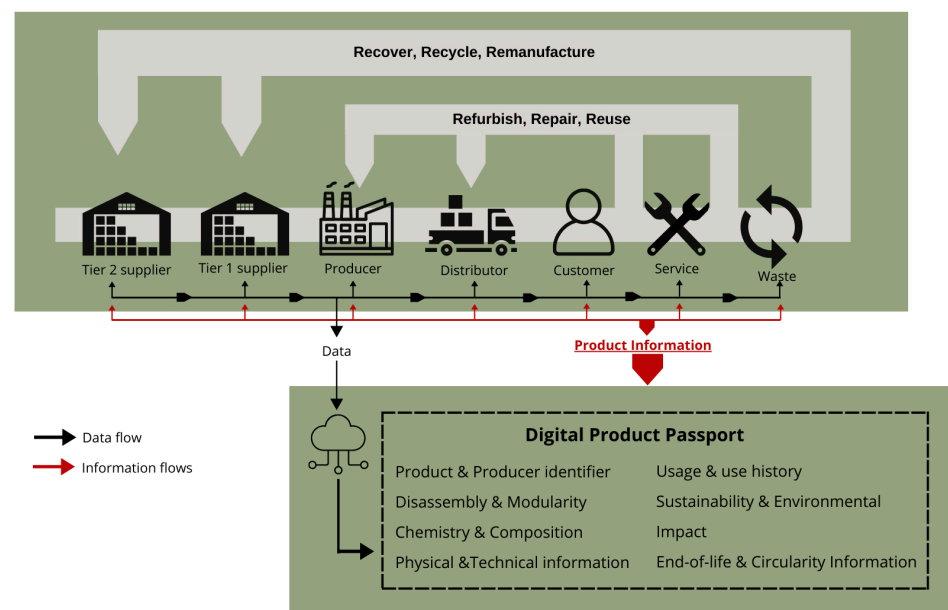


Figure 5. Illustration of the flow of data and information in a DPP carried out by the author.

Developing the DPP in these areas may initially pose significant organizational and economic challenges. However, once this system is properly implemented, it could function with minimal human intervention and be used in different sectors and industries, leading to cost reductions and reduced process complexity. The digital product passport (DPP) provides consumers with easy access to key information that enables them to verify the authenticity of products and make more sustainable consumption choices. It also limits data distortion in supply chains [54]. Similarly, companies that value sustainable development throughout the product lifecycle have the opportunity to provide reliable information on the best features of their products. The DPP has great potential to support the circular economy and enable circular business models, particularly by enabling consumers to better assess the sustainability of products and identify those with negative environmental impacts. However, the implementation of this system still requires considerable effort. These include standardizing mandatory information on products available on the market, supporting eco-

design, extending product lifetimes, and improving the efficiency of material recovery [7]. In addition, the DPP aims to facilitate access to information for consumers and market surveillance authorities and to promote more conscious and transparent consumption.

3.6. Objectives for Implementing Digital Product Passports (DPPs) in the Textile Industry

“The introduction of a digital product passport as a tool aimed at significantly improving the traceability of textile products throughout their value chain can empower consumers to make informed choices by providing better access to information about products concerning end-of-life management. It will also enable economic operators to accurately track the amount of textile waste produced and assist Member States in implementing and monitoring selective textile collection obligations for reuse, preparation for reuse, and recycling, in accordance with this regulation.”—EU to Directive 2008/98/EC on Waste (13 March 2024)—P9_TA(2024)0145.

The development of this passport should assist both consumers and businesses in making informed choices when purchasing products, facilitate repairs and recycling, and enhance transparency regarding the environmental impacts of products throughout their lifecycle (Figure 6). The DPP should also aid public authorities in conducting better checks and controls [58]. According to the authors Adisorn, Tholen, and Götz (2021), the objectives associated with the DPP can be identified as follows: The DPP is committed to offering clear and accessible information on the origin, composition, and lifecycle of products. This helps consumers to make well-informed decisions and builds trust across the supply chain [54].

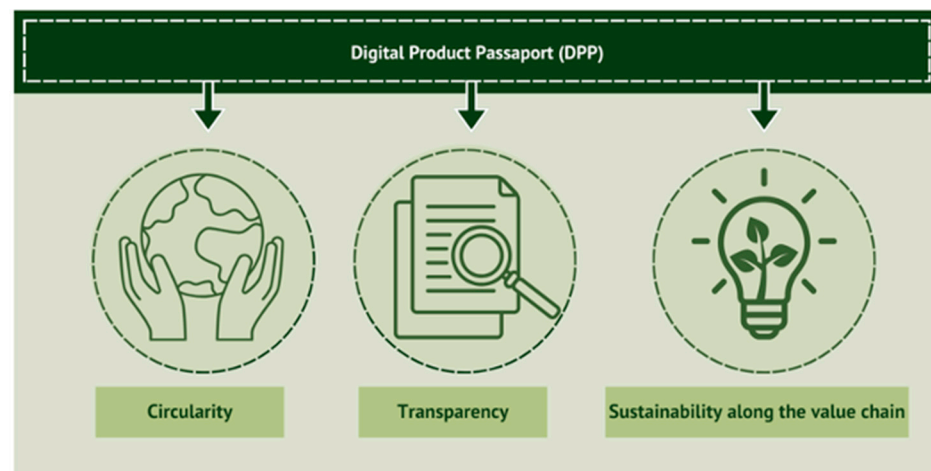


Figure 6. Characteristics and objectives of the DPP carried out by the author.

- **Facilitate Traceability:** The DPP supports product tracking throughout its lifecycle, helping stakeholders to verify authenticity, ethical sourcing, and regulatory compliance.
- **Support Circular Economy Initiatives:** The DPP encourages the circular economy by sharing details on repair, maintenance, and recycling, promoting the reuse and refurbishment of products to cut down on waste and resource depletion.
- **Promote Sustainable Practices:** The DPP champions sustainability by spotlighting eco-friendly materials and providing insights into the environmental impact of products, guiding consumers toward greener choices.
- **Ensure Product Safety:** The DPP provides critical safety details, including potential risks, recall notices, and certifications, to protect consumers and uphold safety standards.
- **Empower Consumer Choice:** By offering customized information on product usage, features, and personalization options, the DPP enhances the consumer experience and encourages active engagement.

- **Streamline Supply Chain Operations:** The DPP boosts supply chain efficiency by refining inventory management, curbing counterfeit risks, and improving communication among all parties involved in the product's lifecycle.
- **Foster Innovation:** The DPP creates a platform for innovative business models and collaboration, paving the way for sustainable solutions and new industry practices.
- **Simplify Regulatory Compliance:** The DPP helps meet legal requirements by providing a reliable, decentralized platform for accessing product data, easing the process of demonstrating regulatory compliance.
- **Build Trust and Responsibility:** The DPP enhances trust through greater transparency, traceability, and accountability, promoting responsible practices throughout the supply chain [59].

3.7. Requirements and Data to Be Included in the DPP

The creation of the DPP for the textile and fashion industry necessitates meticulous consideration of pertinent and suitable information requirements throughout the lifecycle of products [63]. Each item of information and data incorporated into this passport must be presented in a consistent, clear, and comprehensible manner to ensure that all stakeholders can utilize it effectively. Factors such as the complexity of the product, the intricacies of its lifecycle, ecological indicators, and potential for damage are among the considerations that should inform the information requirements for a DPP [61]. Furthermore, Hedberg and Šipka (2020) and Adisorn et al. (2021) suggest that a DPP should adopt a strategy that intelligently integrates information requirements with existing databases, leveraging the insights gained by companies from previously collected information [64,65]. Adisorn et al. (2021) underscore that this approach would initially lessen the administrative burden on manufacturers [55]. Conversely, the availability of comprehensive data and information for all stakeholders in the value chain is crucial for facilitating the transition to a circular economy [62]. Regardless of the specific design of a DPP and its accompanying information requirements, data should be gathered in a centralized location, with varying levels of access rights assigned to specific stakeholder groups. Ideally, the information captured in a DPP should be recorded at the item level, corresponding to each product whenever feasible. Nevertheless, certain types of data, such as general repair information, may be appropriately provided at the batch or model level [66]. Prior research indicates that some additional administrative burdens will be imposed on producers, while the European Commission consistently stresses in its proposal for the Ecodesign for Sustainable Products Regulation (ESPR) that it will seek to minimize unnecessary administrative demands on economic operators placing products in the market [6]. Nonetheless, some potential information that could be included in a DPP is organized as follows [63]:

- **Product Identification:** Implements distinct identifiers like serial numbers or QR codes, ensuring accurate tracking and identification of each product across its entire lifecycle.
- **Origin Details:** Provides precise information on the manufacturer, production site, and supply chain, enhancing transparency and supporting ethical procurement practices.
- **Material Composition Analysis:** Offers a detailed breakdown of the materials and components used, including their chemical makeup, relevant certifications, and associated environmental impacts.
- **Manufacturing Data:** Delivers insights into production methods, techniques, and energy requirements, shedding light on the processes involved and their environmental implications.

- **Repair and Maintenance Guidance:** Includes detailed instructions on repair procedures, spare part availability, and access to certified service providers to help prolong product use and minimise waste.
- **Performance Metrics:** Provides key data on product efficiency and performance, including energy ratings and testing results, allowing for informed and evidence-based consumer decisions.
- **Ownership Tracking:** Maintains a record of ownership history and transfers, ensuring full transparency and aiding in verification of authenticity.
- **End-of-Life Strategies:** Offers clear, practical guidance on the proper disposal, recycling, or repurposing of products, aiming to minimize waste and support sustainable practices.
- **Compliance and Certifications:** Lists the product's certifications and regulatory compliance status, ensuring it meets industry standards and legal requirements for safety and quality.
- **Warranty and Service Details:** Provides comprehensive information on warranty terms, service history, and access to approved repair providers, facilitating efficient product support.
- **Safety Alerts and Recalls:** Shares updates on any product safety issues, including potential risks and recalls, ensuring consumers are informed and protected.
- **Recycling and Disposal Instructions:** Offers detailed recommendations on the correct disposal and recycling methods, highlighting suitable facilities and designated drop-off points.
- **Intellectual Property:** Documents information on the product's patents, trademarks, and copyrights, protecting its intellectual property rights and ensuring proper recognition.

The information included in the DPP encompasses data related to the design, production, utilization, and disposal of the product. In the context of this project and article, the DPP is introduced as an effective tool for fostering transparency and accountability in production, enabling consumers to understand what they are purchasing and the processes involved in its production. At the same time, the DPP can be utilized by companies striving to demonstrate their commitment to sustainability and social responsibility. Thus, a solution that provides distributed traceability throughout the entire value chain is essential for tracking textile and garment products [64].

3.8. Brands and Initiatives Advancing Digital Product Passports (DPPs)

Discussions within the European Commission on the introduction of DPPs by 2030 in various product categories are continuing. The main objective is to significantly improve the sustainability and environmental responsibility of product lifecycles [55]. However, from the beginning, there have been some concerns about the implementation of this innovative tool, especially in terms of the necessary technological infrastructure, harmonization of regulatory standards, and stakeholder acceptance [65,66]. Despite these challenges, numerous projects funded by both the public and private sectors have been launched to facilitate the development of DPPs. This highlights their importance as a key tool for future sustainability, particularly in high-impact industries such as textiles [59]. A study conducted by [67] shows that digital identities, including DPPs, were largely well received by textile industry professionals. The results suggest that by 2035, 73% of textiles produced worldwide are expected to be digitally identifiable using solutions such as DPPs. This forecast underlines the industry's growing commitment to digitalization and sustainability, as these solutions improve traceability and transparency and enable companies to meet increasingly stringent regulations and consumer demands for responsible practices [66]. Nevertheless, the widespread introduction of DPPs faces challenges, particularly with

regard to the protection of intellectual property and the establishment of uniform global standards. In the context of the textile sector, the DPP is a transformative tool that can bring about significant structural change. By providing comprehensive information on the entire product lifecycle—from the sourcing of raw materials to their recycling or reuse—DPPs promote greater transparency and facilitate the adoption of ethical and more sustainable business practices [67]. With DPPs, both companies and consumers are able to make more informed decisions, helping to reduce waste, optimize resource use, and extend product life [54]. This approach supports the goals of a circular economy by promoting the reuse of materials and minimizing dependence on virgin resources. Furthermore, this innovation is a response to increasing regulatory requirements in Europe, such as the European Green Deal and the Sustainable Textiles Strategy, which aim to transform the sector and establish it as a global leader in sustainability [6]. By digitally identifying textile products, companies can demonstrate compliance with stricter environmental targets while improving their reputation with consumers, who are becoming increasingly aware of the social and environmental responsibility of brands (Table 1) [7]. Several leading companies have started to implement DPPs to position themselves ahead of future regulations and use this tool to differentiate themselves in the market. These companies are investing in traceability and digitization technologies to ensure that a digital record is available for every product that goes to market, which builds consumer confidence and promotes brand loyalty. In addition, DPPs offer benefits to the entire value chain, from suppliers to recyclers, by providing real-time insights into the sustainability of materials and processes. From a business perspective, the integration of this technology can lead to significant benefits, such as optimized inventory management, lower operating costs, and a reduced environmental impact. Companies using DPPs will be better able to respond quickly to market demands and offer products that meet the sustainability values desired by modern consumers [7]. To summarize, the digital product passport (DPP) has the potential to play a crucial role not only for the textile industry, but also for many other sectors. It promotes transparency, sustainability, and accountability throughout the value chain. While significant implementation challenges remain, including the need for a harmonized legal framework and advanced technological infrastructure, the evolution of DPPs is inevitable as businesses and governments recognize their essential role in facilitating the transition to a more circular and sustainable economy [54].

Table 1. Brands that have developed DPPs.

Brands	Innovation Projects
Patagônia	Patagonia was one of the first companies to implement DPPs on some of its products, offering consumers detailed information on the environmental and social impacts, from the origin of the materials to the production process. In this way, consumers have information about the development and creation of the brand's products [68].
Adidas	Adidas uses DPPs to increase transparency in the complex resource chain, offering consumers information about the materials used in products, such as the working conditions in factories and the environmental impact of their production [69].
H&M	H&M is adopting DPPs with the aim of providing consumers with more information about the origin, production, and environmental impact of products marketed by the brand. As such, it hopes that the PDP will help build a more sustainable and transparent resource chain [70].
Engie	Engie is using DPPs to track the environmental impact of work uniforms. The main aim of this initiative is to reduce the environmental impact of the company's supply chain and promote more sustainable practices [71].

The following table presents a series of projects funded by government bodies and digital platforms that develop similar solutions for implementing the DPP in the textile industry. It includes a description of the objectives of each project, the country of origin, and the technologies involved (Table 2).

Table 2. Projects that have developed DPPs.

Project	Country	Description	Technology
CIRPASS	Europe (financed by the European Commission)	It lays the foundations for the gradual implementation and piloting of DPPs. The first focus is on three priority areas, electrical devices and electronics, batteries, and the textile industry, while establishing the basis for a cross-sectoral DPP based on shared rules, principles, and taxonomy [72].	The technologies used in this DPP: cross-sector definition and description of the DPP; intersectoral product data model for DPPs; open DPP data exchange protocol; building consensus among stakeholders on essential data for circularity; development of use cases and roadmaps for piloting and deployment [72].
DPP 4.0	Germany	The aim is to create a concept for sharing product information so that it can be used to figure out the legal criteria needed to create DPPs and achieve circular economy objectives [73].	Creation of a demonstration website (front-end) that meets the data interface requirements of the stakeholders [73].
TRICK	Italian	This project aims to develop DPPs for textile articles and provide information on the environmental impact and sustainability of a product throughout its existence [74].	The core of the project is the development of complete, reliable access for PMEs and a standardized platform for data storage, protected by blockchain, to allow companies to obtain protected data for products, combined with a marketplace that includes the necessary services and the data generated [74].
STVgoDigital	Portugal	This project encompasses R&D initiatives with a strong collective character and high inductive and demonstrative effects, with the central involvement of companies in the textile and clothing sector, to promote the adoption and transition to the new Industry 4.0 paradigm in order to promote the digitalization of the entire value chain and increase the productivity and efficiency of each company, and consequently the supply chain, making them more transparent, agile, and flexible [75].	It aims to create an online platform with resources available for PMEs to begin their journey in adopting solutions based on artificial intelligence (AI). It is focused on an area that is representative of the interests of the national cluster, which is guaranteeing the quality of textile and clothing materials and products. It is an area that cuts across the cluster and makes intensive use of image processing and AI techniques and algorithms [75].

These projects demonstrate the variety of approaches and technologies being developed to promote sustainability and transparency in the textile industry through DPPs. The use of emerging technologies such as blockchain, IoT, and artificial intelligence plays a crucial role in creating innovative solutions that enable more efficient traceability and sustainable material management.

4. Discussion

4.1. Opportunities for Implementing Digital Product Passports (DPPs)

The implementation of DPPs offers significant opportunities, particularly through their ability to provide comprehensive and detailed insights into the entire production lifecycle of products [58]. This improved transparency enables companies, consumers, and policy-makers to verify sustainability claims and encourages the development of new methods and the introduction of innovative business models [59]. As Ref. [60] noted, DPPs can have a significant impact on design, raw material selection, sourcing, production, transportation,

and purchasing decisions. They are capable of evolving into advanced information systems that fulfill both policy and regulatory requirements. Digital passports are increasingly recognized as a strategic tool to motivate consumers to make more sustainable purchasing decisions. They allow consumers to evaluate the entire lifecycle of a product before making a purchase [60]. In this context, it is clear that DPPs can significantly improve sustainability practices throughout the product lifecycle by increasing transparency for consumers and companies alike, while enabling a centralized flow of information between stakeholders. This system reduces the risk of data loss during the lifetime of a product [56]. Furthermore, the availability of sustainability-related data in conjunction with changes in value chains provides consumers with the information they need to make informed and responsible purchasing decisions [64]. According to Götz et al. (2022), DPPs can provide additional reliable information about products, especially in terms of recycled content, raw materials, and options for recycling, repair, or reuse. As a result, every part of the value chain can benefit from greater transparency, traceability, and consistency [63]. Thus, DPPs improve visibility, accountability, and traceability for all actors in the value chain [61,62]. DPPs not only improve communication between the different stakeholders in the distribution network but also raise consumer awareness and facilitate more sophisticated purchasing decisions [55,63]. In summary, DPPs can act as digital compliance tools throughout the supply chain, enabling the monitoring and communication of key metrics, such as greenhouse gas emissions [57,58]. At the same time, they help to assess material value, reduce environmental impact, and create more sustainable and environmentally friendly solutions, thus improving sourcing, production, and purchasing processes [55,62]. These digital passports also enable more efficient resource management and significant energy savings, supporting the emergence of environmentally conscious businesses [63]. The following summary summarizes the opportunities that DPPs offer from both consumer and business perspectives in this sector (Table 3).

Table 3. Advantages of DPPs by the author.

Advantages for Companies	Advantages for Consumers
<ul style="list-style-type: none"> - Full traceability of product production, creating greater transparency in business models. - Detailed information on products—materials used, production processes, and environmental and social impacts—combating greenwashing. - Efficient management of resources and reducing waste. - Promotes the circular economy—more sustainable business models. - Compliance with environmental and social regulations. - Development of new, more sustainable, and personalized products. - Access to new markets that value transparency and sustainability. - Better collaboration between the different players in the value chain. 	<ul style="list-style-type: none"> - Greater transparency—it will be possible to know the origin of the products, the materials used, the production processes, and the environmental impact. - It will be possible to make more conscious choices, opting for products with a lower environmental impact and that promote the circular economy. - It will be possible to check the quality and durability of the items and safety/health standards. - Tracking the product’s lifecycle, from raw materials to disposal, facilitating reuse, recycling, and repair. - Access to complete product information by simply scanning the QR code, such as washing and drying instructions and composition. - Consumers will be able to make more informed purchasing decisions that contribute to a more sustainable future.

4.2. Challenges for Implementing the DPP

One of the main challenges in implementing the DPP is firstly to determine precisely which data should be included throughout the useful life of a product, covering processes such as reuse, recycling, and repair. This task is of great importance to ensure greater transparency in the development of this tool [57,58]. In theory, the principle behind the DPP is to provide comprehensive data on the trajectory of products, which will require different levels of inspection for an in-depth understanding of business models and the subsequent creation of more sustainable standards [67]. Another aspect to consider is the practical issues inherent in the nature of the data to be included in DPPs, as well as the information that should be collected and maintained after the product has been launched. This is crucial, as the level of specificity of the data will have to be determined and can range from the identification of the production batch to an individual item or specific model [67]. The existence of various levels of access to this data is also essential in order to guarantee the protection of company confidentiality, which makes the issue of transparency a central factor [53]. Although data aggregated at the model level can be useful for describing the diversity of articles available on the market, these data may not adequately reflect the size of the market in global terms. The process of keeping product passports up to date throughout their lifecycle is still in the development phase, and it is unclear whether industries would adopt this system, as there are significant concerns about the security of intellectual property and the protection of confidential company information [55,62]. Furthermore, defining the criteria that should govern DPPs remains a key unresolved issue. Consumers and recyclers should be free to choose the information they consider relevant, as advocated by various stakeholders in the industry [54]. An additional potential limitation lies in the need for policymakers, consultants, and academics involved in policymaking to have access to the data contained in the DPP database. In this context, the degree of specificity of the data will be decisive [55,62]. It is also essential that consumers clearly understand the instructions for recycling, reusing, or repairing products, as well as checking whether manufacturers or retailers accept products for recycling [76]. As far as the design and operationalization of DPPs is concerned, there are still a number of unresolved issues, such as the necessary data infrastructure, the possible regulatory repercussions, as well as the design and integration of these passports into production [57]. The fragmentation of the various policies regulating different aspects of sustainability information is another challenge to be overcome [77]. Table 2 summarizes the main obstacles to implementing DPPs (Table 4).

The textile industry is considered to be one of the biggest contributors to environmental degradation, with high water consumption, significant greenhouse gas emissions, and excessive waste production. This scenario highlights the urgent need to move toward more sustainable business models, as promoted by the circular economy. The circular economy is based on the efficient use of resources and advocates the extension of the lifecycle of products, the reuse of materials, and the systematic reduction of waste. In this scenario, the digital product passport (DPP) has proven to be an innovative and transformative tool for the textile sector. By providing detailed information on the origin, composition, and environmental impact of a product, the DPP facilitates traceability throughout the value chain, combats greenwashing practices, and promotes greater transparency for businesses and consumers. By promoting practices such as the reuse, recycling, and repair of products, the DPP is also directly in line with the principles of the circular economy and makes it possible to significantly reduce the amount of waste and promote more responsible and resilient business models. The SWOT analysis presented examines the strengths, weaknesses, opportunities, and threats related to the implementation of DPP in the textile sector (Table 5). The strengths include full traceability, efficient resource management, and the

promotion of cooperation between the different actors in the value chain, which are key factors in strengthening the circular economy. On the other hand, weaknesses such as the high initial investment and the complexity of technological integration highlight the practical challenges of implementation. The opportunities reveal significant potential for raising awareness among consumers, enabling them to make better-informed and more sustainable choices. However, threats such as the lack of global standards and the risks associated with data protection may limit the positive impact of the instrument. The effective implementation of DPP requires a coordinated effort between companies, governments, and consumers. If done well, this digital solution has the potential to transform the textile sector globally, reduce environmental impacts, promote the circular economy, and set new sustainability standards. Through collective engagement and innovative strategies, the DPP can act as a catalyst for the transition of the textile sector to a more sustainable and balanced future.

Table 4. Disadvantages of DPPs by the author.

Disadvantages for Companies	Disadvantages for Consumers
<ul style="list-style-type: none"> - The development and implementation of a DPP system requires significant investments in technology, employees, and the internal processes of the companies involved. - Integrating the tool with existing management systems can be complex and may take longer. - Storing and managing large volumes of data throughout the supply chain can be challenging, requiring the adoption of specialized tools and software. - The lack of legislation on global standards for DPP can make interoperability between different systems and companies difficult. - Companies in the sector can be resistant to change and hesitant to adopt innovative technologies. - The protection of sensitive data stored along the supply chain is essential to prevent the loss of information and fraud. - The growing threat of cyber attacks requires the implementation of robust security measures to protect DPP data. - Small companies may face difficulties in implementing the DPP due to a lack of financial resources and technical ability. - Consumers may be sceptical about the information contained in the DPP or feel that the amount of information available may be overwhelming. 	<ul style="list-style-type: none"> - Consumers may not have smartphones/tablets with internet, thus limiting their access to information in the DPP. - The amount of technical data in this tool may be difficult for the average consumer to understand. - The implementation of the DPP could increase the costs of products, which could reduce purchasing power. - There is concern that the storage of consumers' personal data could violate their privacy if there is not adequate security. - The lack of legislation on international standards for implementing the DPP could make it difficult to compare products.

Table 5. SWOT analysis of the digital product passport (DPP) by the author.

SWOT Analysis of the Digital Product Passport (DPP)	
Strengths	Weaknesses
<p>Complete traceability of product manufacturing</p> <p>Creating more transparency in business models.</p> <p>Detailed information about products, materials used, production processes, environmental and social impacts—combating greenwashing.</p> <p>Efficient management of resources and reduction of waste.</p> <p>Promotes the circular economy, encouraging more sustainable business models.</p> <p>Compliance with environmental and social regulations.</p> <p>Development of new, more sustainable, and personalized products.</p> <p>Access to new markets that value transparency and sustainability.</p> <p>Better collaboration between the different actors in the value chain.</p>	<p>The development and implementation of a DPP system require investments in technology, employees, and internal processes.</p> <p>Integrating the tool with existing management systems can be complex and take longer.</p> <p>Storing and managing large volumes of data throughout the supply chain require specialized tools and software.</p> <p>The lack of legislation on global standards for DPPs can make interoperability between different systems and companies difficult.</p> <p>Companies in the sector can be hesitant to adopt innovative technologies.</p> <p>The protection of sensitive data stored along the supply chain is essential to prevent the loss of information and fraud.</p> <p>The growing threat of cyberattacks requires robust security measures to protect DPP data.</p> <p>Small companies may face difficulties in implementing DPP due to a lack of financial resources and technical ability.</p>
Opportunities	Threats
<p>It will be possible to know the origin of the products, the materials used, the production processes, and the environmental impact.</p> <p>It will be possible to make more conscious choices, opting for products with a lower environmental impact and that promote the circular economy.</p> <p>It will be possible to check the quality and durability of the items and safety/health standards.</p> <p>From raw materials to disposal, facilitating reuse, recycling, and repair.</p> <p>Simply scanning the QR code will provide details such as washing and drying instructions and composition.</p> <p>Consumers will be able to make more informed purchasing decisions that contribute to a more sustainable future.</p>	<p>Consumers may not have smartphones/tablets with internet, thus limiting access to the information in the DPP.</p> <p>The amount of technical data in this tool may be difficult for the average consumer to understand.</p> <p>The implementation of the DPP could increase the costs of products, which could reduce purchasing power.</p> <p>There is concern that the storage of consumers' personal data could violate their privacy if there is not adequate security.</p> <p>The lack of legislation on international standards for implementing DPPs could make it difficult to compare products.</p> <p>Consumers may be sceptical about the information contained in the DPP or feel that the amount of information available may be overwhelming.</p>

5. Conclusions

Experts agree, and the industry accepts, that the transition to a consolidated sustainable economy will only happen with more intelligent management of product data during its lifecycle. Although much of this information exists, it is not made available to those who could best utilize it. However, thanks to digital technologies, the possibility of labeling, tracing, locating, and sharing this information along value chains, even at the level of individual materials and components, is now a reality. The introduction of the DPP can therefore make a decisive contribution to the development of more durable, circular,

energy-efficient, and environmentally friendly products, in line with the EU regulatory framework. By providing standardized information on the lifecycle of products regulated by the ESPR, this new digital tool will be an indispensable support for consumers to make informed and conscious decisions, while also enabling the creation of new business models aimed at extending the lifecycle of products. With regard to circularity, it should be noted that it plays a key role in the wider transformation of the industry toward climate neutrality and long-term competitiveness. The significant saving of materials during manufacturing processes and along value chains, the generation of additional value, and the unlocking of economic opportunities are examples of this contribution. As well as being an essential tool for supporting sustainable production and consumption, the DPP can also be an important vector for accelerating Europe's digital transformation in industrial, economic, and social terms. The different players in this industry will certainly be able to take advantage of transparent data sharing—and, in general, all of the other opportunities created by the DPP—to invest in technological innovation based on comprehensive, clear, and reliable information. Another aspect to consider, arising from the review of the existing literature, clearly shows that when the industry invests in greater circularity and economic neutrality, the DPP functions as an excellent digital tool in information-sharing processes, enabling the adoption of R cycles with a view to eliminating waste. It should also be noted that the DPP favors extending the lifecycle of products, giving producers and third parties more time to maintain and repair them. It also appears that, thanks to the use of the DPP, the recycling of end-of-life products is much safer, since access to the stored information associated with the product (composition, safety data) is fully available. It should be emphasized that recycling becomes more effective due to the increased flow of materials, as companies' dependence on natural resources and scarce materials decreases. However, despite the above, the academic literature on DPPs reveals a general lack of knowledge about the information they should collect, as well as the role they should play in a circular economy during the various phases that products go through. By focusing on how DPPs should transmit the information inherent in each textile product, this study has encountered numerous doubts, both about the data are to be collected and made available and how they will be updated in the future. There are many questions. How can we guarantee the reliability of the data collected on the production of textiles (or any other products) incorporated into DPPs? How will the repair, recycling, and reuse processes be carried out? What strategies and mechanisms should companies adopt to create a more transparent and circular market? This study clearly shows that extending the implementation of this tool to most industries will take a long time. However, in the case of the textile industry, it is expected to be implemented by 2027 and the European Commission is currently developing specific DPPs for various product categories in order to respond to the specific characteristics and needs of each sector of activity. Future research on digital product passports (DPPs) should focus on developing robust mechanisms to ensure the reliability, accuracy, and integrity of data captured throughout the product lifecycle. This includes investigating advanced methods for standardizing data collection, updating protocols, and ensuring seamless integration across different sectors, especially in industries with complex and fragmented supply chains, such as the textile industry. Investigations could look into the application of blockchain and distributed ledger technologies to improve the traceability and authenticity of data, as well as the use of artificial intelligence for predictive maintenance and optimized recycling strategies. In addition, it is essential to analyze the potential barriers to DPP adoption, including technological readiness, economic feasibility, and regulatory compliance, while exploring tailored solutions to address these challenges in different industries and geographical contexts. Another important starting point for research lies in assessing the socio-economic and environmental impacts of widespread

adoption of DPPs. Studies could examine how DPPs influence consumer behavior, particularly in promoting sustainable purchasing and disposal decisions, while assessing their potential to foster the development of innovative circular economy business models, such as product-as-a-service or repair-centric networks. Cross-industry comparative analyses of DPP adoption, capturing best practices and experiences, would provide invaluable insights to policymakers and industry stakeholders seeking to align their activities with circular economy objectives and sustainability requirements.

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