

Review

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Posted Date: 17 July 2025

doi: 10.20944/preprints2025071385.v1

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Review

Textile Materials Information for Digital Product Passport Implementation in the Textile and Clothing Ecosystem: The Role of Raw Fibres in a Substantial Transition

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Abstract

The Textiles and Clothing sector is increasingly focused on transitioning towards circular production, with industrial companies striving to integrate sustainable practices. Achieving this goal can involve rapidly adopting innovative materials, meaning using innovative raw ones and maximising the use of recycled and recyclable fibres. This implicitly means acting on the total transparency of information along the entangled supply chains in this sector. It is precisely this complexity that hampers efforts to track and disclose material usage accurately. To address this issue, this paper presents a systematic literature review to explore the main challenges in adopting technologies like digital product passports, which can help track materials information along supply chains to support sustainable transitions. The review's findings are discussed, focusing on identifying key material-related data that should be monitored to ensure responsible material use and strengthen sustainable production practices in the textiles and clothing sector to guarantee control over the use of materials and prevent their early dismissal.

Keywords: textile materials; digital product passport; raw fibres circularity; literature review

1. Introduction

The Textiles and Clothing (T&C) ecosystem is in the spotlight for the transitional transformation of industrial companies towards circular production, and this is a consolidated reality. The T&C ecosystem, by definition, "*encompass[es] all activities that help transform natural and manmade fibres into yarns and fabrics and use these to produce a range of final products – from clothes, carpets, home textiles to industrial filters and medical textiles*" [1].

This production-oriented configuration makes the consequences of producing goods in this sector [2]: the fashion industry is estimated to be responsible for 10% of global carbon emissions [3,4]; 80% of all clothing is landfilled or incinerated [5]- 87% in EU [4]- and only 1% of used clothes are recycled into new clothes -since technologies that would enable clothes to be recycled into virgin fibres are only now starting to emerge [4]-; 35 % of microplastic pollution in the oceans comes from microfibrils shed by synthetic fibres [6] -the majority of which are released during the first few washes [4]- while textile production is estimated to be responsible for about 20% of global clean water pollution from dyeing and finishing products [4].

At the social level, studies and news events underlined the industry's negative impacts (i.e. poor working conditions, health and safety issues, and human rights abuses)[7], and it has been estimated that 20- 50% of living wage are legal minimum wages [8].

At the economic level, the rapid rise in recent years of “fast fashion” businesses and their uncontrolled production methods increased both the negative environmental and social sustainability measures [9].

This profile made the fashion industry one of the most polluting [10] and problematic; therefore, solid governmental intervention has been planned. Regulations and directives in the EU (Table 1) are intended to cover macro themes such as Respectful and Secure Work Environments, Better Wage Systems, Resource Stewardship, Smart Material Choices and Circular Systems.

Table 1. Sustainability regulations impacting fashion and textiles are on the horizon from [8,11].

Jurisdiction	Status	Regulations and directives	
EU (EU Strategy for Sustainable and Circular Textiles implements the commitments of the European Green Deal and the Circular Economy Action Plan to reinvent the entire lifecycle of textile and footwear products).	Adopted In the EU, adopted directives still need to be translated into national law by each member state within a two-year period. Adopted regulations go into force immediately.	Waste Framework Directive: Mandates Extended Producer Responsibility (EPR), requiring brands to pay for end-of-life waste treatment	
		Corporate Sustainability Reporting Directive: Requires companies to report on environmental and social activities using a standardised methodology	
		Corporate Sustainability Due Diligence Directive: Requires environmental and human rights-diligence and improvements across the value chain	
	Proposed	Eco-design for Sustainable Product Regulation (ESPR): Mandates ecological design and circularity requirements to be practised at the product level, supported by digital product passports	
		Waste Shipment Regulation: Facilitates the transportation of waste for recycling and reuse in the EU and bans illegal waste shipments to the Global South	
		Ban on Destruction of Goods: Limits destruction of unsold or retained textile products, encouraging the repair or reuse of goods	
		Green Claims Directive: Addresses “greenwashing” and introduces requirements on various aspects of consumer-facing product claims	
	Draft	Microplastic Legislation: Aims to reduce the release of microplastics into the environment across manufacturing stages	
		Revision of the Textile Labelling Regulation: Streamlines physical and digital product label requirements on composition and origin of textile products	

In European jurisdiction, different actions have been promoted over the years and are constantly being updated.

Starting from ratifying the Paris Agreement and subsequent Fashion Industry Charter for Climate Action [12], the European Union converged its efforts in defining a set of sustainability strategies, policies and action plans [13]. In 2015, the European Commission adopted the first circular economy action plan [14]. Still, in 2020, with the New Circular Economy Action Plan (CEAP) [15], a more operative version of the first document, the T&C sector started to gain particular attention. With the premise that textiles are one of the most polluting production categories, in this document, the European Union starts highlighting actions that need to be taken to change assets in T&C production modes. The proposed strategy focused on the sustainability and circularity of textiles, centring this topic from the industrial competitiveness and innovation perspective. In particular, actions to boost the adoption of textile reuse and recycling practices, suggesting four precise actions:

1. New textile products must be conceived according to eco-design measures (i.e. fit for circularity, ensuring the uptake of secondary raw materials, boosting the market for sustainable and circular textiles, tackling the use of hazardous chemicals and materials, facilitating access to reuse and repair by users);
2. Provide incentives and support product-as-service models, circular materials and production processes and increase transparency through international cooperation;
3. Achieve high levels of separate collection of textile waste;
4. Increasing the sorting, reuse and recycling of textiles through innovation, encouraging industrial applications and regulatory measures (e.g. extended producer responsibility).

To get even narrower, in 2022, the European Commission adopted a sector-oriented package of measures (proposed in the CEAP), named the "EU Strategy for Sustainable and Circular Textiles" [16]: a document that underlines the significant impact of the production and consumption of textile products on the environment and precisely addresses sectorial production and consumption, due to

the considerable footprints of the T&C ecosystem in the environmental, social and economic perspective. Stressing the accent on durability, repairability, recyclability and recycling of fibres, the strategy also claims the urgency for avoiding the use of hazardous materials, minimising incineration and landfilling, as well as increasing the respect for the environment and social rights in the productive chain. In fact, in this document, a consistent space is dedicated to producers' responsibility for their activity and products throughout the value chain, underlining the necessity of significant control in the journey from fibre-making to the final product's end-of-life management. This document also declares specific actions, and the Digital Product Passport (DPP) as a tool first appears in T&C sector-oriented actions (Table 2).

Table 2. Actions of the EU strategy for sustainable and circular textiles according to <https://environment.ec.europa.eu/>.

Objectives <i>[The Strategy aims to create a greener, more competitive sector that is more resistant to global shocks.]</i>	Actions <i>[The Strategy lays out a forward-looking set of actions.]</i>	Implementation
All textile products placed on the EU market are durable, repairable and recyclable, to a great extent made of recycled fibres, free of hazardous substances, produced in respect of social rights and the environment	Set design requirements for textiles to make them last longer, easier to repair and recycle, as well as requirements on minimum recycled content	The Ecodesign for Sustainable Products Regulation, proposed in 2022, creates a framework to set ecodesign requirements for products, including textiles.
"fast fashion is out of fashion" and consumers benefit longer from high quality affordable textiles	Introduce clearer information and a Digital Product Passport	The Empowering Consumers in the Green Transition Directive and Green Claims Directive , proposed in 2022 and 2023, aim to tackle greenwashing.
profitable re-use and repair services are widely available	Reverse overproduction and overconsumption, and discourage the destruction of unsold or returned textiles	The " Reset the Trend " campaign (#ReFashionNow) was launched in 2023 to raise awareness about sustainable fashion.
the textiles sector is competitive, resilient and innovative with producers taking responsibility for their products along the value chain with sufficient capacities for recycling and minimal incineration and landfilling	Address the unintentional release of microplastics from synthetic textiles	The Waste Shipment Regulation , proposed in 2021, will help restrict the export of textile waste.
	Tackle greenwashing to empower consumers and raise awareness about sustainable fashion	Transition Pathway for the Textiles Ecosystem , published in 2023, and the European Circular Economy Stakeholder Platform (since 2018) promote and foster cooperation between industry, public authorities, social partners and other stakeholders.
	Introduce mandatory and harmonised Extended Producer Responsibility rules for textiles in all Member States and incentivise producers to design products that are more sustainable	Calls have been launched under Horizon Europe to further develop technologies and processes increasing the circularity and sustainability of the textiles sector.
	Restrict the export of textile waste and promote sustainable textiles globally	In 2023 the Commission proposed a revision to the Waste Framework Directive to introduce mandatory and harmonised Extended Producer Responsibility (EPR) schemes for textiles in all EU Member States.
	Incentivise circular business models, including reuse and repair sectors	In 2023 the Commission launched a plan to update and revise the Textile Labelling Regulation .
	Encourage companies and Member States to support the objectives of the Strategy	

Lastly, in 2023, the European Commission published the "[Transition Pathway for the Textiles Ecosystem](#)", co-created by the Commission and relevant actors in the sector [17] and adopted a proposal for a targeted revision of the Waste Framework Directive [18], introduced mandatory and harmonised Extended Producer Responsibility (EPR) schemes for textiles in all EU Member States. In these two documents, the Commission sets a roadmap to support the transformation of the T&C sector, considering stakeholders, economic resilience and sustainable requirements in its plan. The Transition Pathway, in particular, defines a framework to facilitate the transition of the textile ecosystem towards greater circularity and sustainability by 2030 and, to this end, announces actions

along the textile value chain, including fifty actions divided into eight building blocks. In the document, competitive strengths and challenges are declared, and a focus on different topics is provided.

Among others, guaranteeing a high quality and valuable production is the starting requirement. Companies can reach this performative objective, is said, e.g., through the rapid integration of innovative materials (also meaning to not rely only on innovative raw ones, but trying to integrate at best recyclable and recycled fibres), increasing experiences of businesses based on reuse, repair, recycling and circularity (e.g. maintaining strong leadership in segments of the value chain, tackling overproduction or premature dismiss of the final product, experiencing product-as-service practices) and rely on design and creativity to synthesise these objectives in economic resilience.

The plan is ambitious but efficient; the only concern still uncovered relies on the difficulty in mapping all the information on the material origin and end of life because of the T&C supply chains: the high level of complexity and entanglement in supply chains affects the control and the information disclosure concerning materials usage in the T&C. Therefore, a systematic literature review is here proposed to understand and define which are the main difficulties in the adoption of the digital product passport as a tool for the T&C ecosystem and, specifically, how the materials must be supervised all along the T&C supply chain to guarantee sustainable transition objectives. This analysis can provide an essential baseline for homogenising information already adopted in T&C DPP research activities and case studies, focusing on material-related information for transforming T&C production.

2. Methodology

A systematic procedure for the literature review [19] has been adopted to guarantee rigour and repeatable procedures for analysing the literature, offering a critical assessment of extant literature[20].

Systematic reviews aim to collect and analyse all research addressing a specific topic. Therefore, a variation of the PRISMA statement [21] has been adopted (Figure 1).

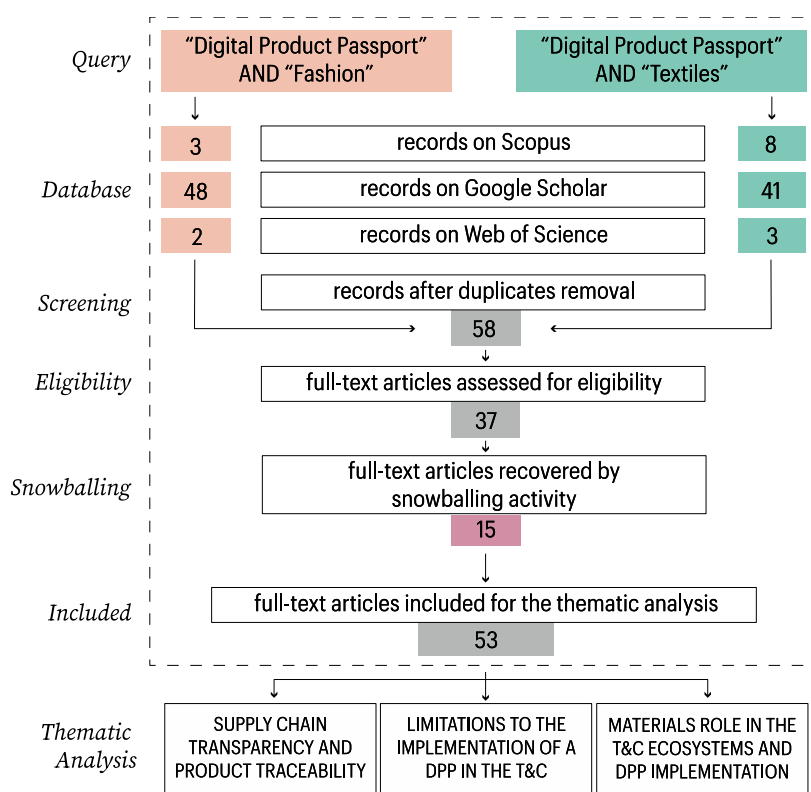


Figure 1. Methodology adopted for the literature review. Queries latest update 24.09.2024.

Two different queries have been explored in principal literature databases (i.e. Scopus, Google Scholar, Web of Knowledge) maintaining the same nomenclature (i.e. "Digital Product Passport" AND "textiles"; "Digital Product Passport" AND "fashion"). The emerging results have been filtered, excluding irrelevant records (i.e., in Google Scholar, just scientific articles in English have been filtered to be displayed).

At this point, results have been compared to remove duplicates from the counting. Subsequently, eligibility criteria have been defined and applied to the selection to limit the selection to relevant literature. Respectively, the selection has been refined by the following a priori criteria:

1. Exclusion of student thesis works;
2. Exclusion of non-retrievable articles;
3. Exclusion of papers describing case studies that are too narrow or have a different focus from the T&C ecosystem.

From the reading of the literature review obtained, some lacks emerged. Relevant articles have been cited in the works but have not been retrieved through the queries. Therefore, it has been felt necessary to introduce some additional literature to complete the analysis through a snowballing activity [22]. The resulting amount of studies has been then analysed according to thematic analysis [23] to understand and deep dive into three main topics:

1. Supply chain transparency and product traceability in the T&C;
2. Limitations to the implementation of the DPP as a tool in the T&C;
3. Materials role in the T&C ecosystem and the DPP implementation.

A total of 53 articles and reports have been analysed, and the complete list is available in Appendix A. The amount of contributions collected is composed of 31 journal articles, nine proceeding papers, three books or book chapters and 10 reports, mainly retrieved by the snowballing activity.

The bibliography reflects an interdisciplinary approach, drawing insights from environmental science, business management, technology, and policy studies. This broad perspective allows for a comprehensive understanding of the implementation of DPPs in the T&Cs at hand and encourages collaborative solutions.

After the first lecture, an in-depth focus on the role of material-related information in the literature analysed has been extrapolated to narrow the spotlight on prime matter's role in the DPP. Therefore, case studies have been retrieved to highlight the state of the art.

3. Results

From the analysis, three main themes are recurring:

1. It is necessary to increase transparency in information disclosure to implement technologies such as the DPP and share information along textile supply chains.
2. The limitations of the introduction of DP technologies have been analysed according to the provided literature.
3. The role of materials in the T&C ecosystems and DPP implementation is crucial from the perspective of a sustainable transition; therefore, it has been analysed as a topic to highlight minimum material-related information that should be considered in design and production.

3.1. Supply Chain Transparency and Materials Traceability: The Challenge

The T&C transition presents specific problems linked to the "shape" and the "nature" of the ecosystems themselves. First, one of the critical discussions in this transition concerns the long and globalised supply chains characterising the fashion sector, which usually involve relationships between companies at the opposite edges of the planet, with a high level of intercrossing [24]. Due to the wideness and capillarity of the T&C ecosystem worldwide, coping with the T&C's current activities with Circular Economy and Sustainable Development strategies opens an intricate environment of work [25]. According to Stridland et al. characterized T&C "is characterised by low supply uncertainty and high demand uncertainty, short product life cycles (especially in fast fashion segment),

tremendous product variety and complex as well as fragmented supply chains." T&C supply chains are usually defined as "a complex multi-actors buyer-driven production chain." Where, e.g., retailers sell apparel but rarely produce goods, manufacturers have different functional capabilities, but every company adopts methods and tools that are not standardised, hence difficult to track [26]. Since traceability is crucial for sustainability and material use monitoring, allowing companies to assess their products' environmental and social impact is essential for aligning with circular economy principles, emphasising the lifecycle of products and the importance of reclaiming and recycling materials [27]. Objectives, scopes, and actions to implement traceability in T&C supply chains have been recently explored and systematised [28]. However, the disclosure of information in this production ecosystem is still very low.

Supply chain transparency is crucial since every previously mentioned action by the European Union and the implementation of technologies (such as the DPP) is based on the assumption that data availability is easy and accessible. Traceability practices allow companies to "follow" products from their origin to the end consumer, which can help in verifying sustainability claims and reducing fraud [29–31]. Increased transparency can lead to improved sustainability practices because when companies disclose their supply chain processes, they are more likely to adopt innovative materials and practices that are sustainability-oriented, as they are held accountable by consumers and regulators [13,32]. Companies that adopt transparency measures, such as traceability, can leverage these initiatives as a competitive advantage, e.g. enhancing brand reputation and consumer trust, reducing the risk of greenwashing -mainly unintended[7] - especially as sustainability and transparency are becoming increasingly important to consumers [27,33–35].

In real life, data sharing is not yet a common practice for several profit-related reasons, and the implementation of the DPP in general is somehow threatened. Despite the benefits, several challenges hinder the implementation of transparency initiatives, including data fragmentation (even more underlined due to the lack of transparency throughout the supply chain), lack of standardisation, and high costs associated with tracking and reporting [24]. This is true at all levels, including material-related information. While technology can facilitate and support transparency, there are challenges related to cultural aspects of data sharing among different stakeholders in the supply chain. Companies may be reluctant to share sensitive information due to competitive concerns or fear of liability [36,37]. Moreover, ensuring data quality and accuracy remains a critical challenge [38,39]. Joint initiatives can help to standardise practices and enhance the overall transparency of the supply chain [40,41]. Diverse attempts from non-governmental organisations emerged over the last few years, engaging a considerable number of enterprises in the T&C sector and demonstrating the importance of monitoring and traceability in the transition of T&Cs [42].

In the last version of the Fashion4Good report (2023) [42], the authors declare that from the beginning of their monitoring activity, there is still a need to be more performing for what concerns transparency in T&C, and this indirectly means that information disclosure is the first mandatory step also to guarantee material recirculation.

Even though the transparency level of principal fashion brands worldwide could perform better, as the report says, the reason is not due to the lack of tools for monitoring and tracing supply chains in the sector[43]. Physical tracer technologies relevant to the textile industry to create an open-source guide are already available in the market, and all interested parties can identify which tracer technologies are best suited for their traceability motivations, use cases, and scope (**Figure 2**).

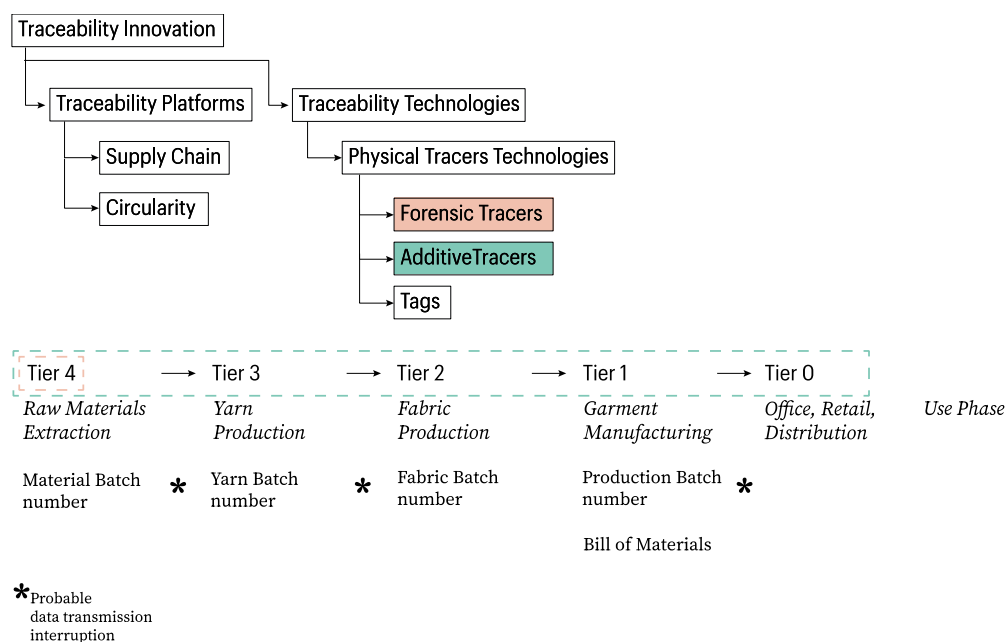


Figure 2. According to [34,44], traceability technologies for the fashion sector.

The use of physical tracers, which are in conjunction with digital technologies such as blockchain and the DPP, can significantly enhance transparency by providing reliable records of transactions and product histories [31], being collectors of reliable and verifiable information, including those on materials and their origin. Theoretically, DPP technology enables all stakeholders to access reliable information about the supply chain [45,46], and advances in digital technologies allow real-time tracking of products throughout the supply chain, enhancing traceability: this ability could provide advantages for companies in terms of monitoring and tracking [45]: using technologies such as blockchain's system could help in accurately track waste from its source through recycling, ensuring accountability and reducing contamination.

In summary, achieving transparency for the T&C supply chain is a significant challenge: cultural changes within organisations are mandatory and required, as well as economic investments.

Companies must foster a culture of openness and accountability, which may require training and changes in internal processes [47]. Supply chain transparency requires collaboration among stakeholders, including suppliers, manufacturers, and retailers. Building a transparent T&C ecosystem must be seen as a collective effort demanding engagement across the supply chain [48,49]. Addressing these challenges through collaboration, regulatory frameworks, and cultural shifts is essential for creating more transparent and sustainable information management (including materials) with companies in the first line encompassing tangible actions.

3.2. Limitations to the Implementation of a DPP in the T&C

According to the thematic analysis of the literature, implementing DPP in the T&C ecosystem is a topic of growing interest [29] that faces several similar limitations. The DPP is a core component of the European Union's Eco-design for Sustainable Products Regulation (ESPR) since the vision is to make it easier for consumers, businesses, and regulators "to access product-specific information related to sustainability, circularity, and legal compliance" [29].

Integrating the DPP into existing company systems is complex since many manufacturers and retailers need to update or replace their IT infrastructures to support the new system, which can incur into significant costs and resistance to change [50], and staff need to be trained on the new practices associated with the DPP. The need for specific skills in digital and sustainable practices can hinder the adoption and effectiveness of the system [47]. Moreover, changing established habits in the fashion sector takes much work. There is a specific cultural resistance to adopting new practices,

especially in an industry known for its traditional and often fast-paced approach [37]. Finally, managing and protecting data associated with the DPP are significant concerns. Companies must ensure that sensitive information is protected, further increasing the system's complexity [49], even though the disclosure of production data may enhance sustainability and generate a significant reduction in environmental impacts [51]. This uncertain panorama can be summarised into three main concerns regarding adopting DPP in the T&C ecosystem.

3.2.1. Lack of Standardization

More standardisation is needed for data formats and information sharing, especially in material-related data, an issue that can hinder interoperability among different stakeholders. Not having industry-wide standards for the data formats and types to be included in DPPs drives different companies using different formats and criteria, making it challenging to create a unified system that works for all [46,52]. This inconsistency can lead to confusion and inefficiencies, hindering the adoption of DPPs across different companies and regions [49]. Different areas and countries may have varying regulations regarding sustainability reporting and product transparency. This regulatory variability can affect how data is collected and shared across the supply chain. If companies are required to comply with different standards in different jurisdictions, they may need help creating a cohesive DPP that meets all regulatory requirements. Currently, there is yet to be a universally accepted framework for what should be included in a DPP, leading to significant discrepancies in what different companies report. Some companies prioritize environmental impact data, while others focus more on social responsibility metrics. A unified approach must be revised and shared to maintain the credibility of DPPs [32,41].

3.2.2. Data Fragmentation and Privacy

The T&C supply chain is often fragmented, stratified and globalised, making it challenging to gather and maintain accurate data across all levels. It follows a tangible difficulty in consolidating and standardising data necessary for effective DPP implementation [53]. This blurry environment immediately raised concerns over data privacy and security and can deter companies from fully participating or sharing sensitive information, as mentioned in 3.1.

Implementing DPPs necessitates collecting and storing a wide range of data, including product specifications, supply chain logistics, sourcing information, and potentially sensitive business information. This raises concerns about the types of data being collected, who has access to this data, and how it can be used. Companies may hesitate to share detailed information about their supply chains, production processes, or proprietary technologies for fear of exposing themselves to competitive disadvantages or intellectual property theft [46]. Again, even if some tools already exist and are on the market (previous Figure 2), a consolidated material-information structure is still unavailable nowadays.

3.2.3. Investments in Technology and Employees' Education

The implementation of DPP in T&C ecosystems necessitates significant investments in technological infrastructure. This includes acquiring advanced tracking and tracing technologies, data management systems, and communication networks to facilitate real-time data sharing across the supply chain. Investments in Internet of Things (IoT) devices, blockchain technology, and cloud-based platforms are critical for ensuring that DPPs can function effectively and provide accurate and up-to-date information [49,54]. Artificial intelligence (AI), machine learning, and big data analytics offer great potential. These technologies can enhance the functionality of DPPs by enabling predictive analytics, improving supply chain visibility, and facilitating data-driven decision-making. However, integrating them requires substantial financial resources and expertise, making it essential for companies to invest in both technology and skilled personnel to manage these systems effectively [37,55], creating an urgent need for workforce training and development.

Employees at all levels must understand how to use DPPs, interpret data, and respond to the evolving technological landscape. Companies should invest in training programs focusing on digital literacy, data management, and sustainability practices [56]. By equipping the workforce with the necessary skills, organisations can ensure a smooth transition to a more technology-driven and sustainable operating model [13,41].

Beyond internal workforce training, there is also a need for consumer education regarding the benefits and functionalities of DPPs. Educating consumers about accessing and interpreting DPP information can drive greater engagement and trust in the products they purchase. This can involve marketing campaigns, workshops, or community outreach initiatives aimed at raising awareness about sustainability, transparency, and the importance of informed purchasing decisions [57,58].

However, in the European environment, T&C ecosystems are mainly composed of small and medium-sized enterprises (SMEs) [59] that may struggle to secure the necessary resources to adapt, making the system more accessible to larger companies [32]. However, while the upfront costs of investing in technology and education can be substantial, companies must conduct thorough cost-benefit analyses to understand the long-term advantages of these investments. DPPs can lead to improved operational efficiency, reduced waste, enhanced brand reputation, and greater consumer loyalty, which can result in significant financial returns. Companies should assess the potential benefits of DPP implementation against the costs to make informed decisions about their investments [36].

3.3. Materials Role in the T&C Ecosystems and DPP Implementation

Downstream from the above analysis, the literature underscores the central role of materials in implementing DPP and their significance in promoting sustainability and transparency in the T&C sector.

Because T&C ecosystems profit mainly from physical artefacts, the choice of materials directly impacts the circularity of fashion products. Understanding the entire lifecycle of materials (from extraction to disposal) and creating a digital version of them is therefore essential in achieving sustainable value creation and improving product lifecycles in the T&C sector [60]. The contribution of material traceability towards achieving sustainability in the textile sector is substantial, and DPPs can be used to document material information effectively [30]. The DPP, in fact, theoretically facilitates the identification of materials used in products, forces them to be sourced sustainably, and can provide information on the recyclability of materials and the proper disposal methods at the end of a product's life cycle. This is crucial for promoting circular economy practices and reducing textile waste [61,62].

The information included in the DPP can, in fact, be used for lifecycle assessments (LCA), enabling companies to evaluate the environmental impact of materials throughout their life. This helps in optimising material choices for sustainable product design [55]. Moreover, by documenting the materials used, the DPP supports brands in substantiating their sustainability claims. This transparency can help mitigate greenwashing and build consumer trust [7,63], as well as helping consumers and stakeholders make informed decisions [49,64–66].

In addition, the DPP encourages the use of innovative, sustainable materials by providing a framework for sharing best practices and research on new materials with lower environmental impacts [38,67]. Innovation in the introduction of new low-impact materials or with recycled content and regenerative imprinting may lead to a significant reduction in, e.g., GHG emissions currently spent for fibre production (Figure 3), and in general, the use of organic cotton, recycled polyester, and biodegradable fabrics play a crucial role in helping to minimise environmental footprints at all levels (water pollution/usage, soil degradation, biodiversity maintenance...) [38,68,69].

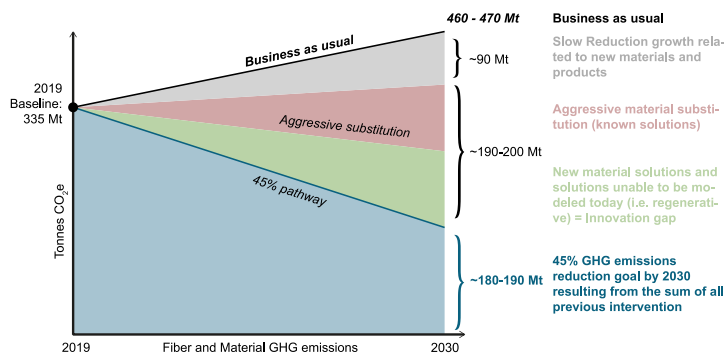


Figure 3. Modelling of interventions needed in the apparel and footwear raw materials extraction phase to achieve the 45% goal, re-elaboration of the author from TextileExchange¹. The industry must reduce its GHG emissions related to fibre and raw material extraction and initial processing to 180 – 190 MT CO₂e by 2030.

On the other hand, the DPP promotes collaboration among various stakeholders by standardising materials-related information. This collective effort can enhance the overall sustainability of materials used in fashion products [40] and subsequently assist companies in meeting regulatory requirements related to material sourcing and sustainability standards - this can be particularly important as governments implement stricter regulations regarding environmental impact [70]. However, as already stated, ensuring accurate traceability of materials throughout the entire supply chain is challenging despite the intense governmental commitment to monitoring activities [53]. Data must be collected and verified at every production stage, from raw materials to the end consumer, requiring close collaboration among all stakeholders [30]. A lack of available and accurate information can be easily defined as one of the main barriers to the current limited development of textiles' end-of-life treatment in the industry [29].

From this perspective, the role of material in the definition of a DPP starts to appear as intrinsic information that crosses the production chain. However, if, in some cases, the implementation of material information is relatively easy to follow (e.g., products with monomeric components), materials become a very tricky concern when it comes to the T&C ecosystems. Materials selection in the design phase may significantly affect DPP by influencing the quality and accuracy of the data recorded and the final product's environmental footprint [71].

Sustainable and easily recyclable materials can enhance traceability [72–74], as well as products implementing innovative manufacturing technologies that preserve the structure of fibres [64,66]. In contrast, complex or mixed materials may complicate the definition of a DPP and finally undermine successful end-of-life treatments and circularity practices and hinder effective information sharing.

In summary, materials play a crucial role in the DPP and vice-versa by enhancing traceability, supporting sustainability claims, facilitating recyclability, and promoting innovative practices. This comprehensive information can significantly impact the fashion industry's move towards a more sustainable and circular economy. All along the path, material-related information has started to be significantly present in tackling the sustainability (mainly environmental) of the T&C sector, and preliminary DPP attempts have begun to appear in literature starting from them [75]. Properly documented materials can improve and enable better recycling and circularity. However, since there is no universally accepted standard format for textile data sheets, several initiatives aim for standardisation. Formats and certifications like the International Organization for Standardization (ISO) standards and the Global Organic Textile Standard (GOTS) provide frameworks for documentation. Additionally, the use of the Material Declaration (MD) format and standards (e.g., the Higg Index, the OEKO-TEX, and the EU Ecolabel) are becoming more common for sharing material information, though industry-wide adoption is still evolving. Unfortunately, these schemes risk being exploited as sustainability decoys for brands, enabling greenwashing on a massive scale [7,76].

¹ <https://textileexchange.org/app/uploads/2023/05/GHG-Modelling-FAQs-2.pdf>, Consulted lastly on 14th March 2025

Therefore, due to the centrality of material-related information in the T&C sustainable transition, supply chain transparency and DPP definition for this sector, state of the art concerning the typologies of information currently inserted in DPP for the T&C sector was essential to understand if a common ground for standardising material-related information for T&C's DPP is emerging.

4. Discussion

Examining DPP technology across various industrial sectors, it can be summarized that the minimum data categories necessary to define a DPP to monitor in general include the followings.

General Information: Data that identifies the product and the manufacturer, general physical characteristics of the product (such as weight, volume, colour), and information related to the geographical location of the selling facility.

Material Information: Details regarding the type and origin of the materials used in the product, any information about chemicals, end-of-life treatment, and other specifics related to the physical attributes of the product and its components.

Environmental Impact: Data relating to the ecological footprint of the product.

Ownership: An example is the clothing and luxury goods sector, where ownership can be transferred through the digital passport application.

Repairability: Information on the repairability features of a product and the 'events' of repair that have occurred throughout its life. This may include details about the location or outlet that performed the repair, information on the nature of the repair, costs, and additional notes to contextualize the reason for the repair. For example, a luxury watch owner initiates a repair after accidental damage, with all details recorded in the associated digital passport.

Documentation: Warranty, service, insurance, and guarantee documents that can be immutably stored within the digital passport and accessed by all relevant parties.

Instructions: The DPP will store instructions and protocols for various operations such as disassembly and recycling, end-of-life management and disposal, along with procedures on how to repair, refurbish, upgrade, or reuse the product. This combined data will inform relevant stakeholders on the steps to take in order to effectively transition the product into the remanufacturing process to aid circularity.

For it concerns the T&C sector, a tailored DPP would undoubtedly contain a consistent section regarding material-related information, being one of the main topics to secure sustainability objectives in the T&C. According to the literature analysed, a list of the necessary information for materials in use in the T&C are generically described in Figure 4.

MATERIAL INFORMATION IN T&C DPP	
Material Composition:	Fiber origin (geographical) Fiber/Yarn Composition (physical/chemical) in % Textile Composition (physical/chemical) in % Fiber/Yarn/Textile Sourcing (trade)
Material Origin:	Virgin/Recycled/Regenerative (eventually in %)
Treatments:	Fiber/Yarn/Textile Pretreatment (chemicals/technologies) Fiber/Yarn/Textile Dyeing (chemicals/technologies) Fiber/Yarn/Textile Printing (chemicals/technologies) Fiber/Yarn/Textile Finishing (chemicals/technologies)
Environmental Impact:	Production (Cradle-to-Gate) [Soil, Water, Energy, Climate Change, Toxicity, Eutrophication ...]
Certifications:	Organic standards: ISO 9001; GOTS; OCS; RWS; GREEN SEAL Fair Conditions: RDS; FLOCERT; FWF; SA8000; SFA Chemical Control: REACH; OEKO TEX; RESPONSIBLE CARE; BLUESIGN Overall: CRADLE TO CRADLE; FAIR TRADE; RCS; LEED
Material Maintenance:	Fiber/Yarn/Textile washing/ironing/drying Fiber/Yarn/Textile Durability Fiber/Yarn/Textile Microplastics release
End-of-Life information:	Fiber/Yarn/Textile Recyclability Fiber/Yarn/Textile Biodegradability/Compostability

Figure 4. Summary of material-related information to be included in the DPP for the T&C sector.

This kind of information related to materials must be produced and is interesting for numerous actors in the whole supply chain, from Tier 4 to 0. However, standardization of information display has not currently reached a significant level, resulting in a fuzzy environment of material information disclosure that makes the material selection activity difficult and relies, de facto, on the textile producers' selling abilities.

At the end of the analysis, if some topics are well envisioned (e.g., introducing technologies such as blockchains for data protection), specific questions remain uncovered: Are European companies ready to introduce the DPP? Do they preview some courses or specific activities to educate their employees to improve their working routine to align with EU objectives quickly? Are designers, the actual game changers, aware of their heavy responsibility in introducing innovative materials in the envisioned products?

Therefore, further implementation of the work will be driven through assessments with T&C companies to highlight and underline opportunities, obstacles and eventual difficulties in the mapping and sharing of material-related information.

5. Conclusions

The presented work demonstrated that recent literature is rapidly exploring the possibility of implementing transparency, cooperation and information sharing across the T&C supply chains. Although the premises in this direction are vast and concordant, the difficulties in implementing tracing technologies rely on multi-level reasons, from privacy and intellectual property protection to economic investments, from the education of personnel to the mapping of the supply chain itself, from the flexibility of industrial asset to the control of the whole actors participating at the supply-chain worldwide. This intricate environment, coupled with the small-medium dimension on average of industries involved in the T&C ecosystem, is not easy to tackle and modify. In addition, in order to reverse the tendencies in the use and dismissal of T&C products, a focus on materials is mandatory. Mono-material components and products are pretty rare in this sector. At the same time, the prime matter deployed to the T&C product's realization is one of the primary activators of the emissions and sustainable production-related challenges for this sector. It follows that keeping an eye on existing materials and how they are used in this environment becomes essential.

The minimum information concerning materials to be added to the fashion products has been mapped. The missing information is how this kind of material information, even once mapped, can and must be used by companies themselves to reverse the current production models. How this information will be embedded in the working routine of companies in the T&C ecosystem is still an uncovered concern.

The following steps of the work will explore some intervention areas with companies to facilitate the collection and archive of material-related information in the daily practice of T&C industries in order to highlight opportunities to speed up conversion. According to the authors' previous works [77], the necessity of introducing material-related information management inside industrial companies must be faced by understanding the material properties and the reverberation that material choices rebound to production. And due to the amount of information to manage, this process must permeate the industrial companies in their everyday work, considering industrial companies as a dynamic and intelligent system.

Author Contributions: Conceptualisation, F.P.; methodology, F.P.; writing—original draft preparation, F.P.; writing—review and editing, F.P. & B.D.C.; supervision, B.D.C.

Funding: This study was carried out within the MICS (Made in Italy—Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR)—MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3—D.D. 1551.11-10-2022, PE00000004). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Data Availability Statement: Data available on request. Most data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Literature review analysed

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