Università degli Studi di Padova
Dipartimento di Scienze Chimiche
Corso di Laurea Magistrale in Sustainable Chemistry and Technologies for Circular Economy
Tesi di Laurea Magistrale

Exploring the Feasibility and Limitations of Digital Product Passports in the Textile Industry: A Critical Assessment of Current Models

Relatore

Proff. Anna Mazzi

University of Padova

Correlatore

Dott. Carla Joana Silva

CITEVE

Controrelatore

Proff. Alessandra Lorenzetti

University of Padova

Tutor Universitario

Eng. Elena Battiston

University of Padova

Laureando

Teresa Dianelly Flores Ramirez

Student ID 2043146

ANNO ACCADEMICO
2022/2023

To my family Rosalba, Demetrio, Erika, Vanessa
Mami Nina, Papi Nino, Abuelita Susana, Abuelito Pancho
My aunties, cousins
and to my dearest friends

Abstract

The European Commission defines the Digital Product Passport (DPP) as a structured collection of product-related data with a predetermined scope. It includes agreed-upon data ownership and access rights, facilitated by a unique identifier. This information is electronically accessible through a data carrier [1]. The DPP plays a crucial role in digitizing the industry along the value chain and has a broad impact on all life cycle stages. Its influence extends to shaping new legislative regulations, creating business opportunities, and refining strategies that contribute to a more effective circular economy. This involves determining how products are utilized, recycled, repurposed, and repaired.

The data collected serves a dual purpose: aiding customers in making informed decisions and helping companies identify opportunities within their supply chain to align strategies with environmental needs. Currently, the textile sector is actively crafting a proposal for the DPP that aligns with the European Commission's requirements. This initiative aims to identify the most suitable proposal, which will subsequently pave the way for defining the next steps for the broader industry. Notably, the textile sector, recognized as one of the most environmentally impactful industries, is slated to implement DPP regulations by 2027. However, it's noteworthy that France has opted for an accelerated implementation, planning to enforce these regulations by 2024. This decision reflects a commitment to expedite the adoption of DPP regulations across the entire industry.

This master thesis contributes to the ongoing discourse supporting the success of the DPP. The reader will gain insights into the DPP as both a system and a product. Additionally, the thesis delves into the definition of current data requirements for textiles, examines undefined elements, provides an overview of existing proposals and their distinctions, and proposes characteristics necessary for cohesive value propositions.

Contents

List of Figures

List of Tables

List of Acronyms

DPP Digital Product Passport

CIRPASS Collaborative Initiative for a Standards-based Digital Product Passport for Stakeholder-Specific Sharing of Product Data for a Circular Economy

ESPR Ecodesign for sustainable Products Regulation

GDPR General Data protection Regulation

UNEP United Nations Environment Programme

EU European Union

CEAP Circular Economy Action Plan

SMEs Small and Medium-sized Enterprises

SDG Sustainable Development Goals

SCP Sustainable Consumption and Production

be@t bioeconomy at textiles

EoL End-of-Life

CITEVE Technological Centre for Textile and Clothing

TRL technological readiness level

API Application Programming Interfaces

1 Introduction

The DPP is a technology concept for a digital policy instrument that collects information about the value chain, sustainability, raw materials, and safety of products across different sectors [2]. The European Commission is pushing the development of this initiative to support the most impactful industrial sectors toward a more sustainable and circular economy-inclined industry. The system will include environmental data from the product's value chain, certifications, product performance, substance of concern, and other information. The information could be of a product, batch, or product model [3].

In Europe, textile production has the fourth highest impact on the environment after food, housing, and transport [4]. The major delays for changes in the industry are the lack of transparency, standardization, data sharing [5], as well as traceability and collaboration. The textile sector has experienced multiple attacks in the past years mainly due to the negative environmental and social impacts within the sector, allegations like child labour, work environment injustice, waste generation, hazardous chemical use, and more. Customers and organizations have been the principal requestors for better products and for production changes to be more aligned with sustainable values. The main goal of DPP is to improve the circularity of products in terms of the R-strategies and to foster transparency and traceability of products, materials, and components [6]. In the latest recommendations by CIRPASS, the product certifications will be available on the DPP as well[7]; in addition, with the Green Claims directive proposed by the European Commission; the customer will be able to choose within the vast product selection which is the more sustainable options more accurately [8]. Additionally, and maybe most importantly, the companies will

be required to exchange specific information that will provide them with the ability to select the best companies with which to partner, and potentially put a stop to green-washing.

Multiple organizations and companies are working to achieve a DPP that will set the guidelines for the rest of the industry and be implemented internally. Others, are working to develop the DPP as a product to offer as a service to other companies. CIRPASS with its consortium is preparing the ground for the gradual piloting and deployment of the DPP, focusing on developing a roadmap for prototypes in three value chains: electronics, batteries and textiles [9].

The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible [10]. To change from a linear economy to a circular one, we need to understand where we stand in the different impact categories throughout the life of the textile article. To understand if the DPP will support the textile sector to achieve circularity we must first understand what circularity means in the textile sector. The Ellen McArthur Foundation defines circularity within the textile sector as In such a model, clothes, fabric, and fibres re-enter the economy after use and never end up as waste [11]. Additionally, digitization is essential due to the visibility and understanding it can provide. To understand better how, The Ellen McArthur Foundation also mentions that With current advances, digital technology has the power to support the transition to a circular economy by radically increasing virtualisation, dematerialisation, transparency, and feedback driven intelligence [11]. As a result, it is possible to suggest that DPP will play a crucial role in the shift towards a circular economy as it will provide the infrastructure to measure and the system to analyse the environmental and social impact of a product/textile product/article, providing an extended cradle-to-cradle perspective.

2 State of the Art

2.1 Digital Transformation

The concept of the circular economy has gained significant attention as a sustainable solution to address the challenges of resource depletion and environmental degradation caused by traditional linear economic models. A circular economy aims to create a closed-loop system, where products and materials are reused, refurbished, or recycled to maximize resource efficiency and minimize waste. In recent years, digital transformations have emerged as key enablers in facilitating the transition towards a circular economy.

The term Industry 4.0 stands for the fourth industrial revolution which is defined as a new level of organization and control over the entire value chain of the life cycle of products [12]. Industry 4.0 has paved the way for the emergence of digital transformation. This transformation entails a shift from industrial automation to enhancing performance through digitisation, achieved by deploying sensors and facilitating access to data for the identification of improvement opportunities. This progression has unlocked the potential to explore additional applications and enhance decision-making with precise and readily accessible information. The development of the Digital Product Passport owes its existence to these technological advancements.

The digital transformation can enable circularity by providing the information necessary to comprehend bottlenecks, inefficiencies, and areas for improvement, among other insights. Through the amalgamation of real-time data measurement and the utilization of extensive existing databases, the industry can access the information required for compliance with diverse legislation's.

Moreover, it presents an opportunity to enhance environmental impact, address social considerations, and identify avenues for improved economic outcomes. This synergy between data-driven insights and digital technologies not only contributes to circularity but also supports holistic sustainability efforts within the industry.

The Digital Product Passport represents a pivotal catalyst in propelling the entire supply chain further into the realm of digital transformation. It equips the supply chain with the necessary capabilities to achieve the digitalization essential for meeting the system requirements of the DPP. With the DPP as an integral component, the industry can harness data-driven insights, enhance sustainability, fully embrace the potential of circularity, and contribute to the fulfillment of the Sustainable Development Goals

2.1.1 What is Digital Product Passport

A DPP is a structured repository of product-related data, delineated by a predefined scope, agreed data ownership, and access rights, all facilitated through a unique identifier. It is accessible electronically via a data carrier. The primary focus of the DPP is to encompass information pertaining to sustainability, circularity, value retention for re-use, re-manufacturing, and recycling [13].

The full legislative rollout for the Digital Product Passport in the textile sector is expected to be completed by the year 2030 [14].

A well-implemented DPP holds the potential to significantly advance the circular economy [15]. It empowers supply chain stakeholders to pinpoint sustainability and social opportunities based on calculated data. Regulatory bodies can establish more informed and precise regulations with access to this data [16]. Moreover, by enabling post-consumer engagement and granting access to relevant data for those capable of adding value to textile articles, it extends their lifecycle. This initiative also opens up new markets centered around repairability, resale, and textile-as-a-service. Additionally, it offers brands and economic actors the opportunity to innovate and expand their services, providing an end-to-end solution for customers. These are the identified markets that can emerge from this technology, with the potential for more as the implementation evolves.

2.2 Elements conforming the DPP

The DPP consist of three important components: the DPP-system, the DPP itself, and the DPP-data.

The DPP-system incorporates a thorough framework of standards and protocols within the IT architecture [6]. This encompasses aspects like data carriers and unique identifiers, access rights management, interoperability (covering technical, semantic, and organizational aspects), data exchange protocols and formats, data storage, data processing (including introduction, modification, and updates), data authentication, reliability, integrity, and data security and privacy [17].

While specific details of the DPP for distinct product groups will be outlined in delegated acts, the general information requirements are delineated in Article 7 and ANNEX III, as specified in [7]. These requirements may include:

1. The unique product identifier at the level indicated in the applicable delegated act
2. The Global Trade Identification Number as provided for in standard ISO/IEC 15459-6 or equivalent of products or their parts;
3. Relevant commodity codes, such as a TARIC code;
4. Compliance documentation, such as the declaration of conformity, technical documentation or conformity certificates;
5. Requirements related to substances of concern;
6. User manuals, instructions, warnings or safety information;
7. Information related to the manufacturer;
8. Unique operator identifiers other than that of the manufacturer, in particular responsible for product certification tasks;
9. Unique facility identifiers;
10. Information related to the importer;
11. Voluntary EU Ecolabels;
12. Information on the performance of the product in relation to the product parameters;
13. Information for consumers and other end-users on how to install, use, maintain and repair the product in order to minimise its impact on the environment and to ensure optimum durability, as well as on how to return or dispose of the product at end-of-life;

14. Information for treatment facilities on disassembly, recycling, or disposal at end-of-life;
15. Other information that may influence the way the product is handled by parties other than the manufacturer;

Each of these integral elements encompasses its unique set of challenges, and the responsibility for addressing these challenges falls upon different actors within the ecosystem. A successful DPP implementation necessitates the active involvement and support of all stakeholders involved in the creation of textile articles, recognizing their interdependence in surmounting these challenges.

Among these integral elements, the DPP-data demands particular attention. The DPP's overarching goal is to empower customers and other users with the data they require to make informed decisions[18]. Therefore, it is imperative that the data within the DPP is not only comprehensive but also reliable. Presently, there is no standardized definition for data verification, nor is there a clear process in place to modify or update data as needed.

The European Commission has taken a significant step towards addressing these concerns with the release of the European Green Claim Directive. However, it's important to note that this directive is still in its early stages and has not been fully implemented [8]. To enhance the trustworthiness of the DPP as a tool, future iterations should consider the incorporation of data verification processes and mechanisms to certify data accuracy. This would enable customers and users to place their trust in the reliability and integrity of the information provided.

2.3 United Nations Environment Program

The United Nations Environment Programme (UNEP) stands as the foremost global authority concerning environmental matters and serves as a resolute advocate for the worldwide environment [19]

As articulated by UNEP, the fashion industry emerges as a significant contributor to the ongoing climate and ecological crises. This industry exhibits a substantial reliance on nature, extensive dependence on fossil fuels, pervasive pollution across its entire value chain, and an extraordinary degree of wastefulness. Moreover, it hinges upon a culture of excessive production and consumption while being facilitated by an underpaid workforce subjected to discrimination, hazardous working conditions, and harassment[20].

The fashion sector exerts a profound influence on a multitude of Sustainable Development Goals (SDGs), with the most prominently impacted goals including Clean Water and Sanitation (SDG 6), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), Life Below Water (SDG 14), Life on Land (SDG 15), Poverty Alleviation, Gender Equality, and Equitable Employment (SDG 1, 5, and 8)[20].

In light of these critical challenges, UNEP has crafted sustainable consumption and production policies, which we will explore in the following section, addressing the pressing issue of over-consumption within the textile industry.

Figure 2.1: Sustainable Development Goals [21]

2.3.1 Sustainable consumption and production

The major cause of the continued deterioration of the global environment are the unsustainable patterns of consumption and production, particularly in industrialized countries, which is a matter of grave concern, aggravating poverty and imbalances.[22]

Sustainable Consumption and Production SCP is about doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles. [23]

The policy focus on three main objectives [24]:

- Decoupling environmental degradation from economic growth: more goods and services with less impact, environmental degradation, waste, and pollution
- Applying life cycle thinking: Manage resources sustainably throughout their entire lifecycle, from extraction to disposal. This approach creates new markets, green jobs, and better resource management in developing countries, using environmentally sound technologies
- Sizing opportunities for developing countries and leapfrogging: Encourage innovation and sustainable practices in developing nations, promoting progress beyond traditional methods.

Despite the earnest endeavors and the formulation of fresh policies and regulations, there is a pressing need for more robust and impact measures to transition toward a mindset and lifestyle grounded in sustainable consumption. These emerging regulations should prioritize fostering the circular economy, eradicating modern slavery, and minimizing environmental degradation and pollution to the greatest extent possible.

2.4 Legal Origin and Institutions involved

The Digital Product Passport initiative is an integral component of the Ecodesign for Sustainable Products Regulation (ESPR) and a key action item within the European Union's Circular Economy Action Plan (CEAP)[15]. The European Union is resolutely committed to becoming a green economy, and as part of this commitment, it has introduced various proposals and initiatives.

Under the umbrella of the European Green Deal, Europe has set ambitious targets, including achieving carbon neutrality by 2050 [15]. This commitment has led to the development of numerous innovative approaches to enhance sustainability and foster a circular economy. The CEAP is one such initiative stemming from the European Green Deal, which has given rise to ESPR and the strategy for sustainable and circular textiles. These initiatives collectively enable the EU to address the multifaceted impact of the textile industry, with the Digital Product Passport playing a significant role in these endeavors[25].

2.4.1 Europe

Europe, driven by the ambition of fostering a greener and more digitally advanced economy, has initiated the European Green Deal and remains actively

engaged in ongoing discussions about effectively transitioning through the Digital Euro program. Europe aspires to position itself as a global benchmark for such initiatives. To achieve this, it is not only paving the way but also nurturing the market with diverse technologies and economic support mechanisms.

The DPP encapsulates both of these ambitious initiatives. It serves as a conduit for digitisation within a robust infrastructure that seamlessly integrates technology and data. This fusion of capabilities provides Europe with a unique opportunity to address specific environmental challenges and propel itself forward as a leader in sustainable and digital transformation efforts.

2.4.2 European Commission

As part of its commitment to make sustainable products the standard, the European Commission has introduced a Regulation on Ecodesign for Sustainable Products. This regulation establishes a framework for defining ecodesign requirements tailored to different product groups. These requirements aim to enhance various aspects of products, including [3]:

- durability, reliability, reusability, upgradability and reparability;
- possibility of maintenance and refurbishment;
- presence of substances of concern;
- energy use or energy efficiency;
- resource use or resource efficiency;
- recycled content;
- possibility of remanufacturing and recycling;
- possibility of recovery of materials;
- environmental impacts, including carbon and environmental footprint;
- expected generation of waste materials.

The European Commission plays a central role in the establishment and execution of the legal framework and regulations governing the DPP. Their responsibilities encompass overseeing compliance with these regulations and ensuring the effective operation of the system. The European Commission is the driving force behind the proposal, development, regulation, and international integration of the DPP.

2.4.3 Ecodesign for Sustainable Products Regulation

The ESPR establishes a comprehensive framework for defining ecodesign performance and information requirements based on the principles of product sustainability and circularity across a diverse range of products[3]. As an integral component, ESPR introduces the Digital Product Passport as a strategic tool for effectively managing these information requirements[15].

ESPR is driven by the overarching objectives of mitigating negative life cycle impacts associated with products and enhancing the functionality of the internal market[3]. It operates in harmony with various other regulations to ensure coherence with existing policy provisions and broader Union policies. Notable considerations include alignment with initiatives such as the European Green Deal[26], Industrial Strategy for Europe[15], Circular Economy Action Plan (CEAP)[26], EU strategy for sustainable and circular textiles[15], Green Claims [8], Corporate Sustainable Due Diligence, Market Surveillance Regulation[13], and Union legislation on waste, chemical, and food safety[7].

This integrated approach underscores ESPR's pivotal role in advancing sustainability goals while complementing and aligning with existing policy frameworks and strategic initiatives within the European Union.

2.4.4 CIRPASS

Funded by the European Commission under the Digital Europe Programme, CIRPASS is a collaborative initiative to prepare the ground for the gradual piloting and deployment of a standards-based DPP aligned with the requirements of the Proposal for Ecodesign for ESPR. Initially, CIRPASS focuses its efforts on the electronics, batteries, and textile sectors[9].

The project consortium is composed of 31 partners representing thousands of industrial, research, digital, and international, standards, organisations across Europe and beyond. The 18-month project will respond to the European Commissions call on creating a clear concept for the DPP, defining a cross-sectoral product data model and DPP system with demonstrated benefits for the circular economy as well as developing roadmaps for its deployment.[9]

CIRPASS plays a pivotal role in the development of the DPP. It serves as a hub for collecting proposals, acts as a communicator for legislative evolution, and provides a platform for collaboration and integration among stakeholders dedi-

cated to DPP development. Furthermore, CIRPASS actively fosters knowledge-sharing through information dissemination and seminars, ensuring continuous education and support for achieving the DPP proposal. This multifaceted role is instrumental in consolidating necessary information and support in a single space, thus fostering collaboration and driving development across sectors.

2.4.5 CITEVE

CITEVE, a technological institute that offers vital support and services to companies operating in the textile and clothing industry. This private non-profit organization is headquartered in Portugal, specifically in Vila Nova de Famalicão. CITEVE actively participates as a member in various international networks and engages in multiple technical working groups dedicated to research, product testing, and certification processes[27].

Among its wide-ranging activities, CITEVE provides crucial consultancy services to assist companies in achieving innovative objectives within the Textile and Clothing Industry. While offering a comprehensive array of services, including laboratory testing, certification, and research and development (R&D), CITEVE maintains a dedicated team focused on advancing the Digital Transition. This team's primary responsibility is to facilitate technology adoption through research and implementation, enabling companies to meet regulatory requirements and support their customers' visions.

These textile experts are at the forefront of innovation, not only driving the expansion of the digital transition but also aligning their objectives with those of their customers to place sustainability at the core of their endeavors.

BE@T PROJECT

The be@t project embodies a transformative synergy of sustainability and cutting-edge technology within the textile industry. At its core, this initiative leverages advanced technological solutions to drive sustainability, a central theme in today's global landscape. By exploring bio-based materials, innovative fabrication processes, and biodegradable technologies, the project not only elevates the environmental performance of textiles but also underscores the vital role that technology plays in reshaping the industry. Sustainability, as a guiding principle, is intricately interwoven with the deployment of state-of-the-art advancements, facilitating the development of textiles that are ecologically

responsible and economically viable. This harmonious convergence of sustainability and technology sets the stage for a profound re-imagining of how textiles are conceived, manufactured, and disposed of, fostering a more eco-conscious and resilient future for the textile sector. In essence, the BE@T project underscores the pivotal relationship between sustainability and technology as drivers of positive change within the industry.

The purpose of this initiative is to develop a pilot program that encompasses various aspects of supply chains, technologies, solutions, and approaches, all aimed at fostering greater transparency and traceability in textile products, as well as enhancing supply chain visibility. At the heart of this effort is the development of a comprehensive Product Curriculum Vitae (CV), which will comprise a rich set of data describing the properties of materials used in home textiles or clothing items, details of the manufacturing process, the companies involved in the supply chain, and information to facilitate end-of-life options such as repair or recycling. Key data points to be included in this CV encompass the composition of fibers, energy consumption, and the various companies contributing to the product's lifecycle. This initiative aligns seamlessly with the concept of a "digital product passport" as outlined in the European strategy for circularity and sustainability.

Given the close alignment with the BE@T project's objectives, the initiative's technological readiness level TRL is aimed to achieve TRL 8. The overarching goal is to deliver comprehensive digital solutions, exemplified by the deployment of a large-scale demonstrator covering the entire national and international supply chain of clothing brands. It is important to highlight that this initiative is primarily oriented towards research and demonstration, representing a significant stride in advancing sustainability and circularity in the textile industry within the context of the BE@T project. [28]

2.5 DPP BENEFITS

While the direct benefits of the DPP implementation remain speculative without real-world application, potential advantages can be gleaned from its development and deployment. The DPP has the potential to illuminate existing gaps in the textile industry's journey toward sustainability and a circular economy. It can serve as an educational tool and a repository of certifications or even stand as a final certification itself.

Additionally, the DPP possesses the ability to connect disparate proposals that contribute to circularity and may be less recognized within the system. Its information can foster the conceptualization and implementation of new businesses within the textile sector, fortifying existing ones. Simultaneously, it enables brands to explore expanded possibilities for post-consumer activities, adding value to garments through solutions like repair and resale.

The DPP will highlight areas of opportunity in the textile sector, allowing regulatory authorities to make informed decisions by examining the industry's current state. This serves as a crucial initial step for future innovation and regulation. To bring about significant changes and explore new solutions, an abundance of information and data is necessary. In this context, the DPP provides a valuable starting point by offering insights into the current state and potential pathways to achieve sustainability goals.

In alignment with its defined goal, the DPP will furnish customers with the information needed to make informed decisions about their garments and to track claims made by brands and the sector.

2.6 What does it represent for the textile industry

The Digital Product Passport regulations apply to all textile and clothing products within the EU, including those exported to the region. This legislation addresses three sectors initially: clothing and textiles, industrial batteries, and consumer electronics [14]. The textile industry's continuous growth raises concerns about its impact on water, energy consumption, and the environment.

The DPP holds potential benefits for the textile sector, acting as a standardized data record for each textile article. It encompasses information about origins, processes, materials used, sustainability aspects, usage, and everything in between, extending to the EoL. This centralized repository allows for easy localization, review, and monitoring of information, benefiting the industry, authorities, and customers.

Additionally, the DPP can enhance transparency and traceability throughout the supply chain. Detailed information about production methods, environmental impact, and social responsibility practices associated with a specific textile article would be accessible to manufacturers and consumers. This transparency empowers consumers to make informed choices, educates them, identifies areas of opportunity within the sector, and provides valuable information for the post-

consumer industry and the sector's focus on circularity, promoting innovation.

The DPP also serves as a proposal to advance circular economy objectives by offering essential data related to materials, processes, and lifecycle tracking. This includes information on compliance with sustainability certifications and industry standards, ensuring that textile products meet established criteria for environmental and social responsibility. This provides assurance to consumers and encourages alignment with global sustainability goals.

2.7 Goal and scope of thesis work

This dissertation serves as an internship report, documenting the collaborative work conducted at CITEVE in conjunction with the University of Padova. The primary objective of this thesis internship is to discern the legal requirements for implementing the Digital Product Passport in the textile sector and assess whether the existing information is sufficient for DPP development.

In the course of investigating implementation, various DPP proposals were analyzed to extract insights into their perspectives on requirements and their approaches to furnishing information on circularity, sustainability, and related aspects for consumer decision-making. This thesis also delves into the potential of the DPP as an educational tool, empowering consumers with the knowledge to evaluate textile article performance and industry best practices, including post-consumer activities.

Exploration of different DPP elements, such as the DPP-system, data protocols, and user interest, is conducted. Furthermore, a real case involving SONAE and CITEVE is presented, highlighting the challenges faced by the industry in the initial stages of DPP application in the textile sector. The intention is to underscore the sector's, particularly the supply chain's, readiness to adopt digital tools and a sustainable mindset in their products and processes.

The thesis focuses on assessing early DPP proposals without real-world implementation experience, specifically concentrating on the initial steps, up to the data gathering phase. It aims to stimulate further discussion on legal definitions, DPP proposal expansion, and ongoing dialogues about circularity and sustainability.

3 Materials and Methods

3.1 Critical Review and Existing Digital Product Passport Methods

The review was conducted using a three-methodology approach, encompassing the examination of scientific papers, grey literature, and participation in workshops/seminars. The objective of this approach was to amass a comprehensive body of information and reinforce the literature review by addressing existing gaps in the available data.

3.1.1 Literature

The methodology employed in this study involves identifying relevant discussions by examining scientific papers, reports, existing regulations, policies, and European Union's plans related to the development of the DPP and the DPP system. The primary influences shaping DPP regulations are the ESPR and CIRPASS, both integral components of the European Commission. Consequently, a substantial portion of the research papers consulted originates from these organizations.

Within this methodological approach, readers will gain insights into the fundamental rationale behind the DPP proposal, its significance, and the elements already defined by the respective regulatory bodies. Unlike the other two methodology options, literature reviews may take some time to become publicly accessible. While new information continually emerges, the support from grey literature and workshops is crucial, as web publications and meetings typically

expedite information dissemination.

In addition to the literature review, grey literature and workshops were explored to provide a comprehensive perspective on the development of the Digital Product Passport.

3.1.2 Grey literature

Numerous companies share information about their approaches to DPP development through CIRPASS, while others share insights on their websites. This category of information complements the literature review, shedding light on the strategies adopted by companies and their diverse proposed solutions to common challenges. It's important to note that grey literature should not be regarded as absolute truth, as it has not undergone expert or peer review. Instead, it should be considered a collection of viewpoints from various companies, providing illustrative examples.

3.1.3 Workshops and Seminars

Workshops and seminars should be considered with the same discernment as grey literature, as they help pinpoint challenges faced by developers. These events aim to identify gaps that require legislative attention to devise standardized solutions. In this report, their incorporation primarily serves to address challenges and concerns within the DPP development landscape.

3.2 Case Study: Collaboration with CITEVE

In this subsection, the collaborative effort with CITEVE is outlined, where the primary goal was to gain a comprehensive understanding of the challenges associated with DPP deployment in SONAE. This collaboration provided valuable insights into the intricacies of the industry and allowed for in-depth discussions with subject matter experts within the organization

3.2.1 Understanding Industry Challenges

During the internship at CITEVE, close interactions and discussions with industry experts played a pivotal role in comprehending the nuances of the challenges encountered within the textile sector. These conversations offered

invaluable insights into the real-world complexities that are often not evident solely through academic research.

3.2.2 Project Implementation Insights

Furthermore, the internship provided an opportunity to actively engage in the implementation of the DPP. This hands-on experience allowed for the practical application of theoretical knowledge and provided firsthand exposure to the challenges faced during project execution. The collaboration with the company highlighted the importance of bridging the gap between academic theory and real-world implementation.

This subsection aims to underscore the significance of the internship at CITEVE in gaining a deeper understanding of industry challenges and the practical aspects of project implementation.

4 Results and Steps of Literature Analysis

By considering the DPP as a tool for both decision-making and policy formulation, it becomes clear that various stakeholders assume distinct roles in its development and utilization. In the upcoming chapter, the functions of each stakeholder will be made clear, and insights into their respective perspectives regarding the DPP will be provided. Additionally, this chapter will highlight the data requirements and precise legislative definitions established up to October 2023, including the definition of the DPP system. With these insights, the subsequent chapter on future work will address the potential definition of any remaining elements identified during this discussion.

4.1 Actors perspective

The perspective of Actors can be defined as their connection and interaction with the DPP. These Actors play a pivotal role in ensuring the functionality and reliability of the DPP. Within the context of this thesis, Actors are defined as all individuals who interact with and derive benefits from the DPP. This encompasses those engaged in the creation of textile articles, who require access to and sharing of data, as well as purchasers of these articles, participants in regulatory processes, individuals in need of data to prolong an article's lifespan, and those seeking information for proper article disposal. As the DPP continues to unlock new markets and diverse opportunities, additional categories of Actors may be identified to accommodate the expanding pool of participants and beneficiaries.

Data access in the system depends on different groups of stakeholders. In the initial phase, the primary actors encompass industry participants, customers, and regulatory authorities. As the data flows evolve, it involves others like recyclers, circulators, resellers, and repairers who support the circular economy. The roles assumed by these actors are pivotal in determining the visual representation, data accessibility, and control mechanisms.

To cater to different levels of data access, a clear definition of stakeholder categories is essential. This definition is particularly important when facilitating data access for 'post-consumer' activities. Data accessible to consumers should adhere to an open access model[6], allowing each economic entity the flexibility to determine their preferred sharing approach. Moreover, data should always be available to support timely decision-making, even when the economic actor who sold the product is no longer active or exists [17].

The economic entities responsible for providing consumers with access to information also have the option to utilize the DPP as a marketing tool[18]. It is crucial for these economic entities to remain compliant with the Green Claims legislation to ensure ethical transparency. This approach highlights the vital role of Actors in shaping the DPP's functionality and accessibility while stressing the importance of ethical transparency in its use.

4.1.1 Industry Players

Industry players encompass those involved in the creation, distribution, and post-consumer activities of textile articles. Regardless of their location, every entity within the supply chain must collaborate to provide the data pertinent to the processes involved in producing articles intended for sale and use in Europe, as dictated by legislation.

They assume the responsibility of collecting and supplying data to the DPP system[1], which is subsequently controlled by the brand or economic entity responsible for introducing the textile article to the market. This data must conform to open standards and interoperable formats, ensuring it is machine-readable, searchable, and well-structured according to [7]. Furthermore, adherence to data sharing protocols, security measures[17], and related considerations

[1]DPP system:IT/software system that enables the consolidation of the data required for DPPs[6]

is of maximal importance.

At present, there is no precise definition regarding the extent to which data can be estimated or the proportion that should be factual, nor how the data will be validated. This determination depends on the maturity of the business and data availability. Moreover, distinguishing between real and estimated data and implementing a validation process are crucial measures to prevent Greenwashing. Currently, the predominant approach among available options is to support their calculations using well-established LCA methods.

Industry players can be classified into two primary categories: those involved in the creation of textile articles (further categorized as Supply Chain and key partners in the following section), and those operating within the economic sector, focusing on lifecycle extension and end-of-life management (classified as Recyclers and Circulators in the subsequent section).

Supply Chain and key partners

The production of textile articles commences with the extraction and processing of natural and synthetic fibres such as cotton, wool, silk, polyester, and nylon are used to produce fabrics and yarns[29]. Following spinning and dyeing, the weaving process enables the yarn to intersect together to become fabrics[30]. The fabric is then subjected to various processes, including treatments to enhance durability, permeability, or dyeing, before it is used in the actual garment manufacturing.[30]

Some of these processes may take place in different countries, often in regions with lower labor and environmental standards [31]. This can lead to cost savings but may also introduce challenges in terms of budget disparities and varying technological opportunities. The entire sequence of activities mentioned, including transportation, forms the structure of the supply chain.

The successful implementation of the DPP relies on the brand[2]. Close collaboration with partners and suppliers is vital to collect and identify the data necessary to meet DPP requirements. It is imperative for the sector to shift its focus from mere product delivery to a conscientious approach of production.

This sector comprises a diverse range of corporations, some of which have the capability to seamlessly integrate their systems with partners to share es-

[2]Brand or economic entity responsible for introducing textile articles to the market

sential information, while others face challenges, particularly among Small and Medium-sized Enterprises (SMEs) and those in regions where digital transition is not yet fully realized. Collaborative efforts among industry players are essential, whether it involves knowledge sharing or providing financial support when needed.

According to Katina Boutis, Director of Sustainability at Everlane, in an interview about sustainability in fashion, the effective use of DPP can be greatly improved when brands that use the same service providers work together to ask for changes from their suppliers. When brands collaborate among themselves and with shared service providers, it can lead to more significant improvements and make DPP more effective[32].

As indicated in [3], under the LEGAL BASIS, SUBSIDIARITY, AND PROPORTIONALITY, the meaning of sustainability for textile products can differ from one place to another. This means that companies (and subsequently, the supply chain) have to follow different national rules, each with its own view of sustainability.

These economic actors are involved in nearly all of the 15 requirements outlined in the initial section of this thesis. This involvement will require system adjustments by industry players. Until states provide more comprehensive definitions, initial calculations can serve as a baseline for proactively identifying areas for improvement.

The following graphic representation illustrates how different entities within the supply chain will collaborate to obtain and share data.

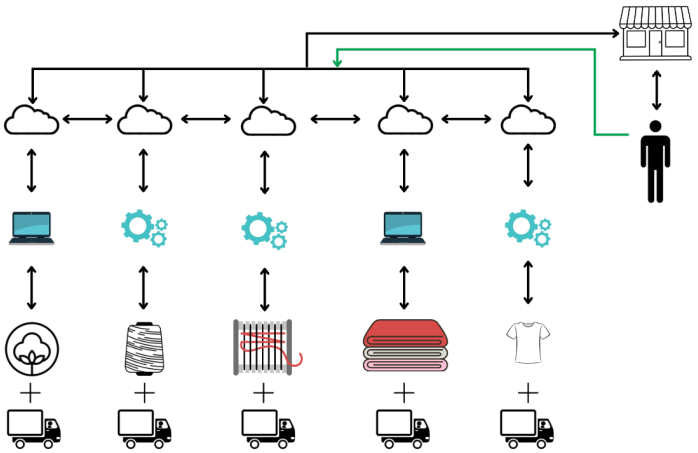

Figure 4.1: Industry perspective, suppliers and third party

The linear model of the textile sector's economy, as per Angelova, the value

to the textile article is added at each step of the production chain, reaching maximum value when it reaches the user, to then lose value after each use due to exploitation or maintenance[33]. The textile article reaches its maximum value when it gets to the user, but it loses value with each use due to wear and tear, promoting excessive consumerism and the view of textile items as fast-disposable.

As for specific product-related information and performance requirements, ESPR plans to describe these in future releases. Currently, researchers and industry players collaborate to determine what should be shared through DPP. According to Plociennik et al., the data provided by these actors includes product or material quantity, quality, composition, energy, water, and raw material demands in the production process. It also covers the physical and chemical properties of materials used and information about their safety for human health and the environment, product and component performance, and details on component removal and replacement. This information helps users extend a product's lifespan and use it optimally [34].

Circulators, Recyclers and Post-Consumer activity enablers

The second category of Industry Players involves post-consumer activities, such as product-as-a-service businesses, resellers, second-hand and vintage shops, repair, recycling, and organizations dedicated to extending the lifecycle and EoL management. These actors require special access to supply chain information [35] to support economic activities, process improvement, research on extending the lifecycle, and fabric recycling. They play multifaceted roles, serving as both customers and service providers, making their contributions to and access from the DPP system essential.

Unlike actors in the supply chain, these industry players strengthen circular economy strategies[36] by providing crucial capabilities and information on processes improvement to the sector. If regulatory entities and authorities can harness data to initiate initiatives, this sector will require regulatory guidance to expand their roles.

According to Plociennik et al., the DPP should encompass documentation for EoL collection, sorting, and treatment, enhanced by user input for better waste management [34]. Brands can include their take-back initiatives and document their steps for handling, recycling, repairing, and EoL activities.

Circularity and sustainability on the textile sector seem to have different meanings and different scopes depending on the actor defining them. When circularity is defined on a waste, it fails to target the industrys more environmentally damaging stages - take and make[37]. Additionally, an exclusive emphasis on waste neglects the interconnected nature of supply chains, where actions at one stage affect the next[38]. Circular business also involves extending the lifecycle of products, enabling repairs, reselling mechanisms, take-back systems, and reverse logistics[36]. The DPP will play a pivotal role on sustainability withing the supply chain and give the tools necessary to scale up the circularity within the sector as this economic actors will gain strength.

To monitor the number of garments in use, [34] suggests comparing the recorded collection fraction with sales volume. This provides insights into the products still in use, those that have left the sales region or been otherwise displaced. To implement this, second-hand shops, resellers, collectors, and informal economic actors need to register their activities in the system. While the idea is intriguing, the extent of information could be extensive during the initial deployment.The DPP and its elements can prepare the system to accommodate more complex follow-up proposals to enable such capabilities.

4.1.2 Customers

Uncertainty arises from whether customers need to provide information to the DPP system. An automated system offers the necessary information to pinpoint the garment's location and its current lifecycle stage.

Data collected from economic actors, as mentioned previously, enables customers to access specific information about how the garment was created, its materials, care instructions, environmental impact, and sometimes even social impact. The available data depends on how much information the brand or economic entity can gather from the supply chain and what they choose to disclose while meeting the DPP requirements. Customers may also find an environmental impact score assigned by the brand, reflecting government-related environmental impact assessments.

This information includes records of any replaced or repaired parts. The responsible individual or organization for these modifications is tasked with updating the DPP, especially for components crucial to health and environmental safety. Proper documentation ensures appropriate handling and optimization

of the product. Users can indicate their intended disposal methods for the product when it reaches the end of its lifecycle. This information aids in better circular economy planning and more efficient waste collection campaigns[34]

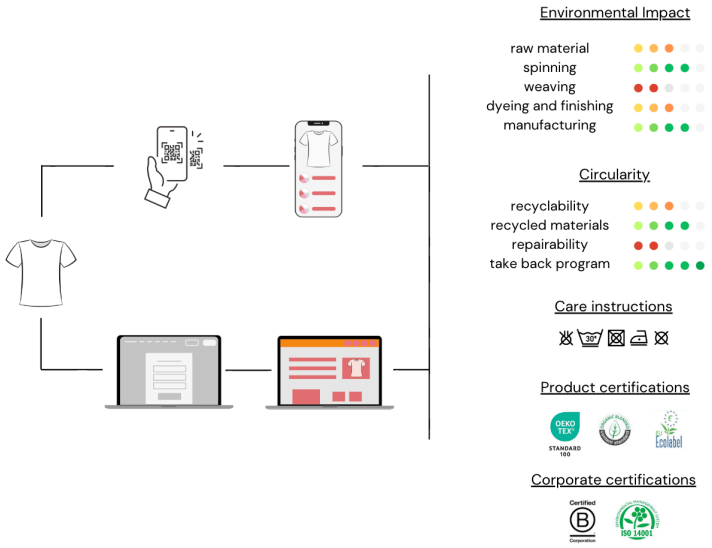

Figure 4.2: Customers' perspective

In the figure 1.2 shows how the customer will be able to access the data. It can be either by accessing information to the data carrier and single information under mobile devices or they can access information through the webpage where the Textile article is being presented. Information here is only descriptive and it's a representation yet it's important to mention that something related to this will be present it to the customer.

4.1.3 Authorities

Regulatory entities and control authorities play a pivotal role in the development and execution of the DPP within the textile sector in Europe. These authorities are instrumental in shaping and overseeing the implementation of the DPP framework.

The DPP serves as a powerful tool, providing a foundation for decision-makers and offering the means to optimize processes. Through the data it collects and centralizes, the DPP enables the precise definition of sustainability targets, the formulation of effective strategies, the initiation of necessary measures, and the calculation of crucial indicators [34]. This data, serving as a baseline, aids in identifying new initiatives within the textile sector. These ini-

tiatives, often guided by legislation and regulations, continually drive progress towards achieving circular economy objectives.

Furthermore, regulatory authorities bear the responsibility of promoting and monitoring accountability among all actors involved in the DPP ecosystem. They ensure that industry players, customers, and other stakeholders adhere to the established standards and regulations. In particular, DPPs empower these regulatory bodies to assess products' compliance with sustainable production and usage regulations, as they provide data for tracking substances of concern throughout a product's entire lifecycle [39].

Clear regulatory incentives, such as producer responsibility, are vital for the successful adoption of circular economy principles by both consumers and businesses [40]. Empowering the creation of sustainable products and circular economy strategies as the norm.

However, concerns about data security and the protection of commercially sensitive information often hinder firms from sharing data. Regulatory policies and measures established by the government can address these concerns, thereby encouraging greater data transparency and collaboration among stakeholders [40].

In essence, regulatory bodies play a crucial role in assessing compliance with regulations on material flows, energy emissions, waste management, and recycling within the textile sector. These regulatory efforts, whether through governmental regulations or industry agreements, aim to uphold minimum standards and foster adherence to the circular economy principles. By doing so, they promote the highest value for components and materials while minimizing the environmental impact of products' manufacture and use [34].

Regulatory entities and control authorities serve as essential guardians of the DPP's effectiveness, ensuring that it aligns with sustainability goals, compliance requirements, and the broader objectives of the circular economy in the textile sector. Their oversight and influence are instrumental in driving progress towards more sustainable and circular practices within the industry.

4.2 Data Structure

The effective implementation of the DPP relies on a robust and well-structured data ecosystem, a foundational element supporting the entire system. Data structure encompasses the requirements for the DPP ecosystem, including the

DPP system, interoperability, data usage, management, control, limitations, DPP protocols, and product identification and data carriers.

The field of information management plays a pivotal role in enabling the DPP landscape, operating within three distinct tiers that collectively provide a comprehensive data framework. These tiers are delineated as follows [40]:

i) Data Collection: Data systematically gathered from various sources, ensuring a comprehensive and accurate representation of product information.

ii) Data Curation, Processing, and Sharing: Involves the thorough curation, processing, and sharing of data. It's crucial for ensuring that the data within the DPP is of high quality, consistent, and readily accessible.

iii) Data Use and Exploitation: Practical application of the data, facilitating its utilization in decision-making, process optimization, and strategic planning.

The complexity of production processes and the growing interconnections across resource-intensive industries necessitate a trans-disciplinary approach to the DPP's data structure. No single industrial ecosystem can manage this alone. Collaboration and interoperability between different actors are essential to create the necessary connections and data flows that underpin the DPP's functionality [5].

A well-structured data ecosystem is the backbone of the DPP, encompassing not only the DPP system itself but also the processes of data collection, curation, processing, sharing, and utilization. Moreover, the interconnections between various industries underscore the need for a collaborative and transdisciplinary approach to data management within the DPP, as it is a shared endeavor that requires coordination and cooperation among multiple stakeholders.

4.2.1 DPP System

The DPP system, an essential IT/software infrastructure, plays a central role in gathering the data needed for the DPPs. It facilitates interaction among the actors across a product's value chain and links physical products to their respective DPPs [6].

The primary goal of upcoming DPPs, created by DPP systems, is to promote transparency in products, components, and materials to support circular economy objectives [6]. DPP systems are designed to enhance supply chain operations by monitoring the entire value chain and sharing information about products, components, and materials [16].

Dr. Guth-Orlowski emphasizes the need for the DPP system to be inclusive, removing cost and technical barriers that could exclude small economic actors from participation [41]. This inclusivity extends to the system's adaptability to add or modify actors, products, or attributes and remove outdated information [41].

The core of the DPP's data structure is the DPP system itself, serving as a central repository for a wealth of product-specific information. Real-time data about component and material status, maintenance, damage, and composition are crucial for making informed decisions regarding reusing components and materials [42].

During a seminar by the European Commission, the DPP system's definition encompassed various standards and protocols related to IT architecture, including data carriers, unique identifiers, access rights management, interoperability (technical, semantic, and organizational), data exchange protocols and formats, data storage, data processing (introduction, modification, and updates), data authentication, reliability, and integrity, and data security and privacy. The DPP registry is also part of this comprehensive definition [43].

The DPP system is foundational, enabling collaboration, transparency, and adaptability to fulfill DPPs' circular economy goals and provide valuable insights into product-related data. Standardization and inclusivity are essential for the DPP system's widespread adoption and its effectiveness in transforming the textile industry's sustainability and circularity practices.

4.2.2 Interoperability

Interoperability within the DPP can be likened to the compatibility of different software applications. Just as various software programs need to communicate and exchange data effectively to provide a seamless user experience, different elements of the supply chain must interact smoothly to create a comprehensive DPP.

The Cambridge dictionary defines interoperability as the degree to which two products, programs, etc. can be used together, or the quality of being able to be used together[44]. The importance of this term on the DPP is because each component of the supply chain will have to provide information to the system related to their process of creating the garment they are involved. This information needs to be shared between actors and authorities can also have

access to manage and control.

Imagine the DPP as a complex puzzle. The brand or economic actor requests specific information from each part of the supply chain to piece together the DPP, which represents the finished picture. Each actor is responsible for creating their unique puzzle piece and delivering it to the brand. However, for all these puzzle pieces to fit together seamlessly, there needs to be effective communication and data exchange between different elements of the supply chain.

Let's say the brand requires information on color, size, weight, manufacturer's name, and water usage. The manufacturing site gathers all the requested data and prepares their puzzle piece. To ensure that these puzzle pieces align perfectly, communication among supply chain elements is crucial. They use of APIs[45] to structure and standardize the data, making it easy to share between the puzzle pieces.

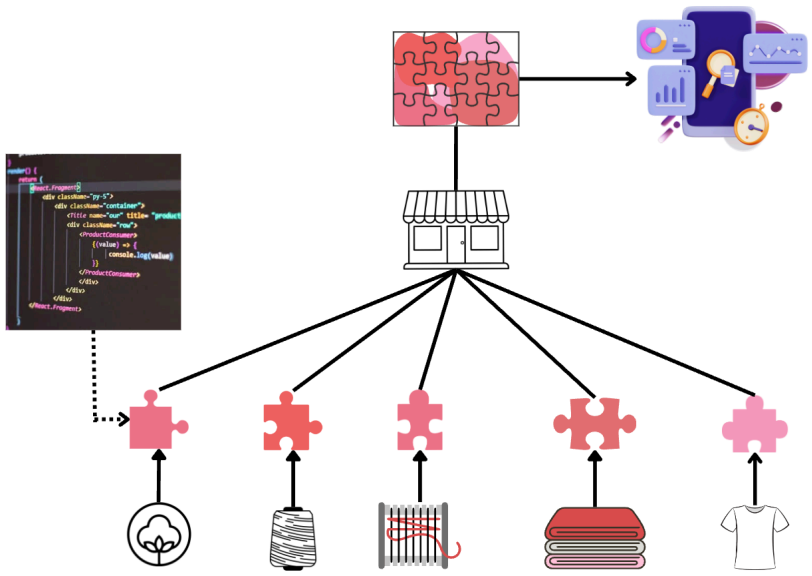

Figure 4.3: Interoperability with API

Because this system has to be secure, the use of Blockchain serves as a protective way to send the information. This API and Blockchain combination seems to be the best option and the most researched proposal to the moment.

In practical terms, interoperability empowers the supply chain with the ability to seamlessly exchange information and enables authorities to manage and control data efficiently. It enhances transparency, data sharing, and collaborative efforts within the textile industry, bringing us closer to achieving the goals of the DPP.

Dr. Guth-Orlowski states that there are seven interoperability levels for the DPP [46], as shown on Figure 4.4.

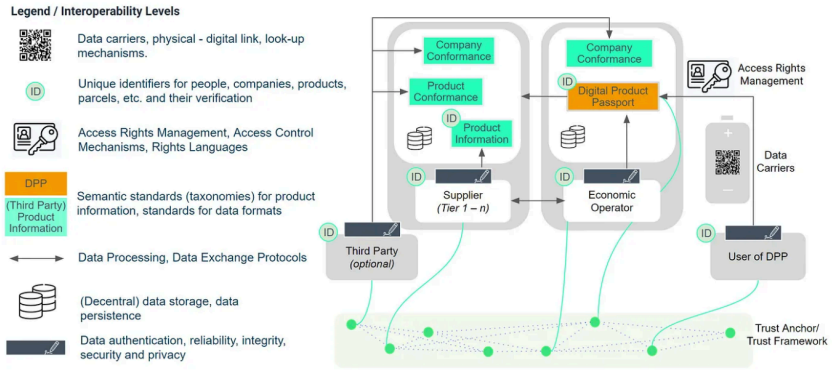

Figure 4.4: Architectural overview and areas of standardization for the DPP (Source: Dr. S. Guth-Orlowski)[46]

4.2.3 Data Usage, Management, Control and Limitations

Data usage and management in the DPP is the cornerstone of an efficient and organized product information system. It encompasses the collection, storage, and utilization of data throughout a product's lifecycle. Whether it's capturing product specifications, compliance data, or maintenance records, comprehensive data management is vital.[34]

For instance, a clothing brand utilizes the DPP to track the origins and characteristics of the fabrics used in its products. Effective data management ensures that comprehensive information about each textile is readily available. This data includes details such as fiber composition, colorfastness, and compliance with safety standards. Such precise data enhances product traceability, quality assurance, and sustainability efforts in the textile industry.

Data control in the textile DPP is vital for safeguarding sensitive information. This entails regulating who can access specific data and under what circumstances. Strict data control mechanisms protect proprietary details and maintain data security. [47]

In the textile DPP, data limitations can impact data quality and reliability. Such limitations may include incomplete records, outdated information, or data that's challenging to verify. Recognizing these limitations is essential for informed decision-making.

For example, a textile supplier uses the DPP to provide product data to clothing manufacturers. Data limitations might include gaps in information about the sustainability of certain dyeing processes. Acknowledging these limitations, the supplier can work on improving data accuracy by updating records and addressing data gaps.

Trade Secrets

In the textile industry, the protection of trade secrets and proprietary information is of paramount importance. Within the DPP framework, concerns arise regarding the safeguarding of critical details, such as unique textile blends, patented finishes, and exclusive manufacturing techniques. These concerns align with the broader context presented in the cited source:

"The increased accessibility and availability of data through DPP could lead to concerns over intellectual property protection and potential competition risks, as firms might worry that their proprietary information and trade secrets could be more easily accessed and utilized by competitors or unauthorized parties, compromising their market advantage and potentially undermining their business interests." [40].

Suppose a textile company employs the DPP to manage data for a fabric renowned for its exceptional stain resistance technology. In this scenario, the data, encompassing the proprietary chemical formula and production methods, is deemed as trade secrets. The concerns outlined in the cited source emphasize the significance of robust data protection measures. To address these concerns, textile companies must implement stringent access controls, encryption protocols, and monitoring systems within their DPP. These measures ensure that only authorized personnel within the organization can access the sensitive trade secret information, protecting the company's competitive edge and preserving its market advantage.

In this way, textile companies balance the advantages of leveraging the DPP for data management with the need to protect their proprietary information and trade secrets, addressing the challenges posed by the open nature of data accessibility in the DPP ecosystem. This approach is critical to maintaining their market position and business interests in the highly competitive textile industry.

4.2.4 Product ID and Data Carrier

A crucial element of the DPP system is the unique product identification, which plays a pivotal role in connecting physical products to their specific information[34]. These product identifiers serve as the digital backbone of the DPP, offering a distinct and unchanging label for each textile article. They stay with the product throughout its entire lifecycle, enabling the collection of comprehensive information that spans various sectors. This is particularly vital for traceability, effective management, and the involvement of circular businesses[3] in the article's lifecycle.

The Product Identifiers, along with other identifiers like Facility and Operator IDs, consist of alphanumeric strings that provide each item with a global and unique identity [6]. These Product Identifiers establish the connection between physical items and their digital information. To access this wealth of information, a data carrier is required. A data carrier typically takes the form of a scannable label on the product, such as a QR barcode, which links to the data stored in the DPP, including pre-sales information for potential buyers [48].

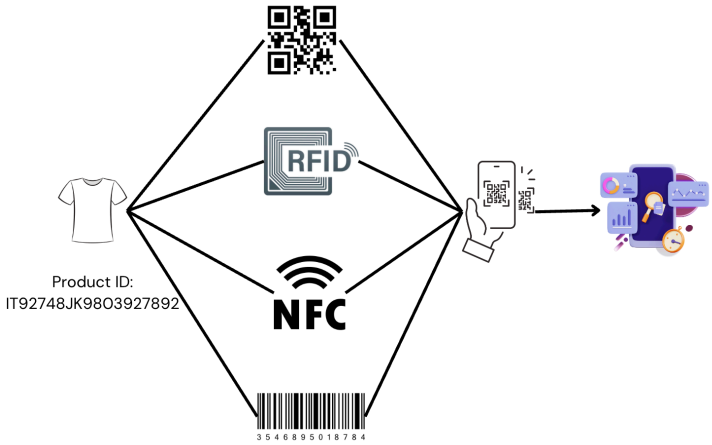

Figure 4.5: Example of Data Carrier and Product ID

The description of how to structure these identifiers is still under development by the European Commission. However, it's worth noting that StandICT.eu has shared a list of standards that specify globally unique identifiers. These standards cover various aspects, including methods to achieve global uniqueness,

[3]These include entities engaged in extending the lifecycle of textile articles, such as second-hand shops, repair services, and recycling facilities.

syntax, and semantics, providing valuable guidance in this regard[17].

Data carriers must remain accessible and readable throughout the entire product lifecycle[7]. This is critical to maintaining the integrity of the DPP and ensuring that circulators and recyclers can continue to add value to the textile article. Data carriers should be designed to withstand various conditions, including wear and tear, washing, and exposure to environmental factors.

4.3 Traceability

Consumer demand for transparency has become a driving force in the fashion industry, prompting a significant shift towards greater openness and traceability [49]. The DPP plays a pivotal role in fulfilling this demand, serving as a tool for enhancing traceability and enabling transparent communication between various actors in the fashion supply chain.

While the fashion industry has made strides in transparency, the focus is shifting towards product-specific transparency, building on the general brand transparency declarations [49]. This evolution recognizes that consumers not only want to know about a brand's overall transparency but also desire detailed information about the specific products they are considering.

Transparency is the initial step in reshaping the fashion industry [50]. To achieve this, material and traceability data become paramount for textile companies adopting circular business models. This category of data encompasses a wealth of information about a product's composition, production processes, origin, and the various companies involved in the supply chain [51].

Traceability presents challenges, including not only concerns about protecting trade secrets but also the need to connect the brand with the entire ecosystem. The tiers of the supply chain may have limited interaction with each other, and typically, only the first tier has direct contact with the brand. Overcoming these challenges and establishing seamless connections throughout the supply chain will be a key strategy that brands must address.

Furthermore, the infrastructure to support the data requirements of the DPP are currently not fully defined and not fully prepared for the demands of such a system. In many cases, various processes, including manufacturing, may be located in countries outside of Europe where the pace of digitisation is slower. This poses a challenge for brands aiming to implement the DPP effectively. To address this, collaboration between brands and their partners becomes essen-

tial. The industry must work together to overcome the limitations of digital infrastructure and ensure that traceability and transparency are maintained throughout the entire product lifecycle.

Effective traceability and transparency must extend throughout the product's entire lifecycle and all the processes in between. The DPP serves as a comprehensive repository for all transparency elements, including certifications, standards, and support of claims. In the end, the DPP could even function as a significant certification for a product, encompassing its entire history and confirming its adherence to sustainability and circularity standards.

4.4 Product based Data

Now that the elements of the DPP system have been defined and discussed, it's time to delve into the information that customers could access through the DPP. One of the objectives of the DPP is to provide customers with product-related information that enables them to make informed decisions about the environmental impact of each product[25]. This section will delineate the information that the DPP can provide, enabling customers to make informed decisions about the environmental impact of products.

The DPP serves as a comprehensive source of information, offering insights into a product's origin, composition, repair and disassembly options, and end-of-life considerations [15]. It provides a holistic view of how various components can be recycled or disposed of at the end of a product's lifecycle, promoting circularity by facilitating maintenance, repair, resale, rental, dismantling, and recycling [49].

While the specific information to be included in the DPP is not yet fully defined, experts anticipate it will be in line with the requirements set by countries like France. This might encompass details regarding the countries of manufacture for tiers 1 and 2, the presence of plastic microfibers, hazardous substances, the use of recycled materials, and the product's recyclability [49]. It's worth noting that true circularity extends beyond the end-of-life stage, and efforts should focus on promoting circular practices throughout a product's lifecycle.

Product performance data plays an equally crucial role, providing valuable insights into a product's market performance and durability [51]. This data category includes information related to consumer behavior, offering data on customer preferences, willingness to pay for products, and the typical rental or

usage duration. It also encompasses details about the product's condition, any damages incurred, the location of common damages, and the overall state of the product.

While textile manufacturers primarily use product performance data to enhance product quality and meet customer demands, it also benefits enabler companies within the DPP ecosystem. This data aids textile manufacturers in adapting their circular business models by improving product durability and market performance. The collection of this data is a crucial aspect that requires further exploration.

To illustrate this, consider the Circularise proposal for data inclusion in the DPP. Ideally, the DPP encompasses the elements listed below, along with any additional "voluntary data" that can be digitized and seamlessly integrated into the system. These components play a pivotal role in elevating the circularity of products [52]

- Product Identification: Information on the product's name, model, serial number, and any other identifying characteristics. A unique product identification is necessary for linking the physical product with its related information.
- Materials: Comprehensive data on all materials used in the product's life cycle, including their origins, availability of critical materials, and material flows.
- Product Design: Details of the processes that transform materials into the technical specification for the product and material flows.
- Technical Specifications: Specifics of the product's performance and technical capabilities, such as power ratings, dimensions, weight, and other relevant specifications.
- Product Lifecycle: Refers to the consecutive, interlinked stages of a product, from raw material use to final disposal.
- Product Maintenance: Records of product service, repairs, upgrades, and relevant maintenance schedules.
- User Manuals: Detailed instructions on how to use and maintain the product safely and effectively.
- Warranty Information: Details of the product's warranty coverage, including applicable terms and conditions.
- Reuse and Recycling Information: Processes by which a product or its components can be reused, refurbished, or returned at the end of its first use, including advice on responsible reprocessing of waste material.

- Energy Recovery: The generation of energy through direct incineration with heat recovery.
- Waste: Any substance, material, or object listed in the categories defined by Directive 2006/12/EC.
- Hazardous Waste: Categories or types of waste in liquid, sludge, or solid form listed in Council Directive 91/689/EEC.
- Environmental Information: Elements or functions of the product that interact with and/or change the environment, expressed in measurable, physical quantities.

4.4.1 Data Availability

One of the primary challenges in data availability stems from the supply chain. Brands often face limitations in obtaining detailed information from various stakeholders along the value chain. Manufacturers, suppliers, and intermediaries may not always have the infrastructure or systems in place to collect and share the necessary data. This limitation can result in information gaps, making it difficult for brands to create comprehensive DPPs. To address this challenge, collaboration and data-sharing initiatives among supply chain partners are crucial. Brands must work closely with their partners to improve data collection and sharing capabilities. Additionally, the development of standardized data formats and protocols can facilitate the exchange of information.

Data availability doesn't end with the product's sale. Post-consumer activities, such as product usage, maintenance, and disposal, generate valuable information that can further enrich DPPs. However, accessing this data presents its own set of challenges. Consumers may not always provide feedback or data on product usage, making it difficult to track a product's condition and performance. Additionally, data on the end-of-life phase, including recycling and disposal, can be scattered and challenging to collect. Brands need to establish mechanisms for encouraging consumers to share relevant data and participate in the DPP ecosystem. This may involve the development of user-friendly interfaces and incentives for data contribution.

Brands, manufacturers, consumers, and other stakeholders must work together to increase the amount of data accessible for DPPs. This collaboration could involve the development of industry-wide standards and guidelines for

data collection and sharing. It also requires a shift in mindset, with a collective commitment to transparency and sustainability. Moreover, public-private partnerships and government incentives may play a role in incentivizing data availability within the textile industry.

Overcoming challenges related to limited data from the supply chain and harnessing post-consumer data will require collaborative efforts, standardization, and a commitment to transparency. Addressing these challenges is crucial for the successful adoption of DPPs, promoting sustainability, and meeting the demands of consumers seeking greater transparency in their purchasing decisions.

4.4.2 Potential uncertainty of Data

Uncertainty in DPP data can stem from several factors, including the source of data, the methods used to collect it, and the balance between real data and calculated data. Brands must navigate these uncertainties to provide transparent and credible information to consumers.

One of the foundational steps in addressing data uncertainty is distinguishing between real data, representing a product's actual characteristics, and calculated data, which is derived from various sources and modeling. Striking the right balance between these two types of data is essential for data accuracy and reliability. To obtain real data, insights from experts like Katina Boutis, Director of Sustainability at Everlane and Dr Subramanian Senthilkannan Muthu, Chief Sustainability Officer at Green Story[32], provide valuable guidance. Her recommendations include:

- Traceability and Transparency: Establishing traceability within the supply chain is crucial. This involves understanding the origins of materials and the various processes involved. It starts with mapping the value chain to identify upstream suppliers.
- Partnerships: Collaboration with suppliers and stakeholders is key. Establishing deep, meaningful partnerships that encourage shared learning and the transition to best practices is essential. The fashion industry should embrace cooperation as the first step towards change.
- Internal Systems: Developing internal systems for data collection and management that break down information into smaller, manageable categories.
- Leveraging Digital Techniques: Utilizing digital technologies to streamline data collection, management, and sharing.

While obtaining all real data may be challenging or even impossible in some cases, best practices for calculated data include:

- Stakeholder Engagement: Involving customers and other sectors in the LCA process to extend the assessment from a product's creation to its end-of-life journey.
- Skill Development: Investing in the development of textile and Life Cycle Assessment (LCA) skills to ensure data accuracy.
- Standardization and Verification: The implementation of standardized data formats and verification procedures is crucial for enhancing data reliability. By creating industry-wide standards for data collection and sharing, uncertainties and inconsistencies can be mitigated.
- Leveraging Digital Techniques: Utilizing digital technologies to streamline data collection, management, and sharing.
- High-Quality Questionnaires: Employing well-designed questionnaires is a critical step in collecting accurate data. These questionnaires should be developed with the input of relevant stakeholders and experts to ensure data quality.
- Leveraging Partnerships: Collaboration with all tiers in the supply chain is invaluable. Building partnerships with upstream suppliers and mapping the value chain provide access to reliable data sources. Understanding the roles and responsibilities of each tier can lead to more accurate calculated data.

Addressing data uncertainty is pivotal to delivering trustworthy and transparent DPPs that empower consumers to make well-informed, sustainable choices.

5 Results of Case Study Application

5.1 Critical Analysis of DPP initiatives

This chapter conducts a critical evaluation of various DPPs initiatives within the textile sector. The focus is on five primary DPP proposals: atma.io, Digital ID, STVgoDigital, ProductDNA, and Circularity.ID. Additionally, an exploration of two alternative solutions, BCome and Green Story, is included. These solutions, while not explicitly labeled as DPPs, closely align with the prerequisites set by the European Commission's ESPR for such passports.

The assessment closely examines these seven approaches for their compliance with 6 out of the 15 ESPR requirements. Achieving uniformity among these proposals is a challenging task due to the multifaceted nature of the ESPR requirements.

This chapter also introduces DPP data protocols, the foundational infrastructure for data management and access to post-consumer activities. An analysis of their goals, scope, and their role in promoting circular practices is provided.

Sustainability data considered by each proposal and their presentation methods are discussed. Using a questionnaire-based approach, the chapter explores the link between consumer understanding and existing knowledge gaps in sustainable textile products.

This chapter offers a comprehensive examination of DPP initiatives in the textile sector, their compliance with regulatory requirements, the significance of DPP data protocols, and the connection between consumer understanding and knowledge gaps in sustainability.

Furthermore, this chapter explores treatment facility information, a topic

elaborated in subsequent sections. Protocols emerge as a more fitting solution for addressing this specific requirement.

5.1.1 Evaluating Recent DPP Proposal Trends

In order to comprehensively evaluate various DPPs initiatives within the textile sector, a meticulous selection of five DPPs and two closely aligned solutions was conducted. The selection was based on the availability of information accessible online, considering that the richness of available proposals varied.

The following initiatives were chosen for examination as they explicitly self-identify as DPPs and have indicated their primary focus on the textile sector, as listed in the proposals gathered by[53].

- atma.io by Avery Dennison [1]

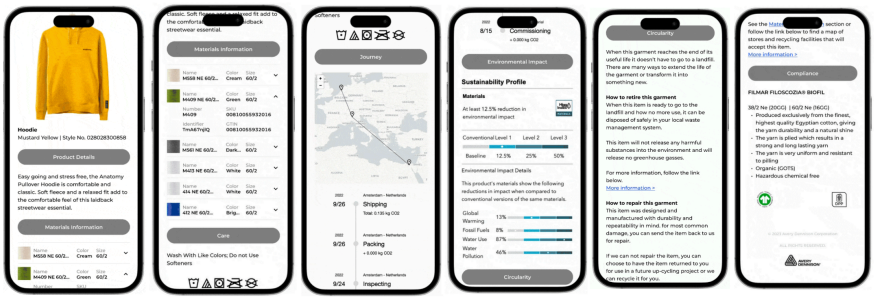

Figure 5.1: atma.io

- Digital ID by EON [2]

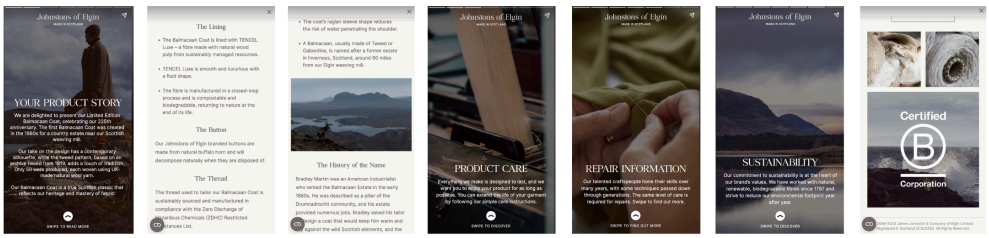

Figure 5.2: digital id

- STVgoDigital by CITEVE [3]

[1] https://www.atma.io/solutions
[2] https://www.eon.xyz/
[3] https://texjourney.com/

Figure 5.3: STVgoDigital

- ProductDNA®by Trimco Group [4]

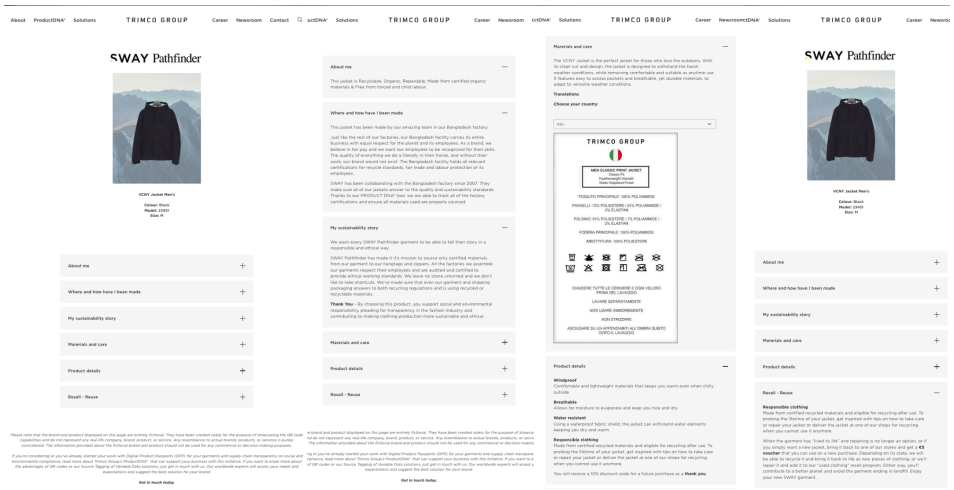

Figure 5.4: ProductDNA®

- Circularity.ID by Circular.Fashion[5]

The selection also includes two alternatives, BCome and Green Story. While they do not explicitly categorize themselves as DPPs, these solutions closely align with the prerequisites outlined by the European Commission's ESPR. This inclusion highlights the possibility of other solutions in the textile sector that may already meet or partially meet ESPR's requirements without explicitly adopting the DPP label.

- BCome by BCome[6]

[4] https://www.trimco-group.com/
[5] https://circularity.id/
[6] https://bcome.biz/view-demo/

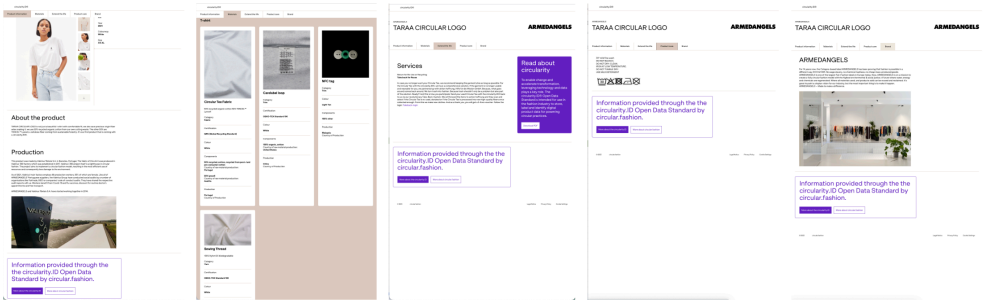

Figure 5.5: Circularity.id

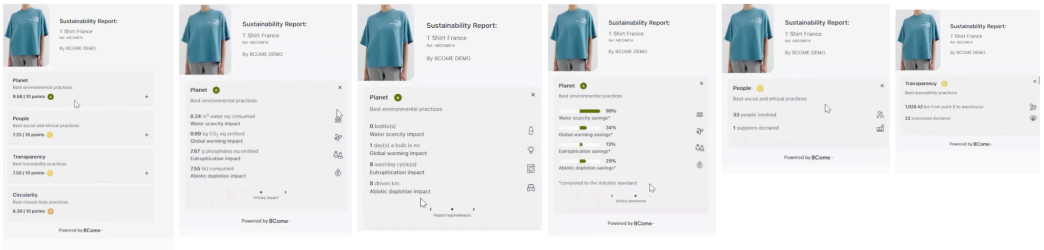

Figure 5.6: BCome

- Green Story by greenstory [7]

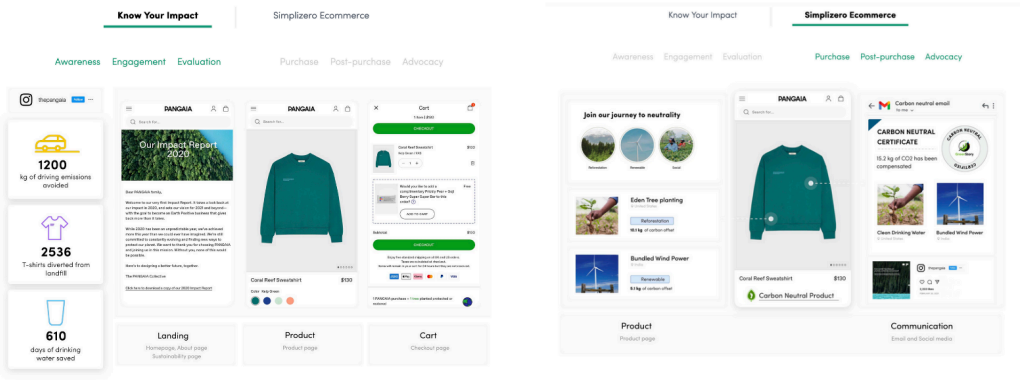

Figure 5.7: Green Story

5.1.2 Comparative elements definition

The assessment of the initial set of 15 requirements, initially introduced in this thesis, reveals their varying applicability to the unique demands of the textile

[7] https://greenstory.io/

sector. Notably, specific prerequisites, such as a unique product identifier, a global trade ID, relevant commodity codes, compliance documentation, unique operator and facility identifiers, and importers, seamlessly integrate into the textile supply chain. As a result, they are designated as System Elements in Table 5.1.

On the contrary, certain requirements pose challenges when it comes to their integration into the DPP, mainly because they do not align well with the nuances of the textile industry. These unincorporated elements encompass aspects like the provision of product performance information, detailed user manuals, comprehensive instructions, safety warnings, and related data. Consequently, they are omitted from Table 5.1.

To evaluate compliance with these criteria in DPPs, we've observed the following:

- Substance of Concern: This requirement is either explicitly mentioned chemicals calculated or certification in the description or assumed based on LCA data.
- Importer: Identifying the responsible party is straightforward.
- Information Related to Manufacturers: This involves traceability information, which should be described and accessible on the platform.
- Voluntary EU Ecolabel: This includes any sustainability-related certifications.
- Information for Consumers: This relates to care labels and washing instructions.
- System Elements: Specific system requirements

In evaluating each proposal for the Environmental information, several comparative elements were considered. These elements include:

- Environmental Assessment Frameworks (E.A. Frameworks): This refers to the specific framework and the elements it encompasses, as each DPP has its unique approach to environmental impact analysis.
- Benchmark Comparison: This aspect focuses on what each DPP compares its metrics to, helping to assess their performance relative to established benchmarks.
- Scoring and Typology: This explores whether the proposal provides a clear and easily understandable scoring system, which aids in quickly comprehending the information.
- Information Digestibility: This element delves into whether the DPP supports its scores or claims with additional information or graphical representations to enhance comprehension.

- Traceability Type: This examines how the traceability of the product is presented within the DPP.
- Data Type Comparison: This part evaluates how the data is obtained, whether it relies on LCA or other reporting frameworks, real data calculations, or a combination of these methods.

The inclusion of these comparative elements is driven by the need to highlight the diverse approaches taken by each platform in presenting environmental information. While the mere presentation of environmental data can be straightforward, the crucial aspect is ensuring that consumers can readily comprehend the significance of this information. Therefore, the definition of these elements serves as a strategic tool in this analysis to determine the most effective approach for conveying information. The ultimate goal is to empower customers to make informed decisions based on the environmental impact of each textile article and allow for education on this sector.

DPP Proposals in ESPR Context

The Table 5.1 provides a comparison of requirement completeness based on the available options found online. It's worth highlighting that this information may not represent the most up-to-date versions of the proposals but rather what is being presented as a marketing tool or in seminars. To interpret the table, the symbol "•" indicates that the requirement is fully completed or presented in the DPP, "o" signifies that it is partially presented or broadly mentioned, and "x" denotes that the requirement is not shown in the proposal.

The Table 5.1 illustrates that only two proposals fully meet 100% of the requirements: atma.io and STVgoDigital. Circularity.ID follows closely, with almost full compliance. The "substance of concerns" category is marked as partially fulfilled because it is not shown on the DPP itself, but their website mentions the ability to integrate chemical information into their DPP[54].

Digital ID meets 50% of the requirements and partially fulfills the remaining 50%. The "substance of concern" category is not displayed on the DPP, but their website describes the capability to calculate chemicals and compliance certification[36]. Information related to the manufacturer is partially present, although the style of presentation makes it somewhat unclear. The traceability aspect only covers a single producer, leaving it open to interpretation whether this will be the case for the entire supply chain or if further explanations about the component/material-manufacturer relationship will be provided in other

sections. In the Voluntary EU eco-labels category, they present the company's B-Corps certification, but no other certifications like oeko-tex or REACH for the product.

Table 5.1: Evaluation DPPs vs ESPR current requirements

Feature	atma.io	Digital ID	STVgoDigital	ProductDNA®	Circularity.ID
Substances of Concern	•	o	•	o	o
Importer	•	•	•	•	•
Information Related to Manufacturer	•	o	•	o	•
Voluntary EU Ecolabel	•	o	•	x	•
Information for Consumers	•	•	•	•	•
System Elements	•	•	•	•	•

ProductDNA®partially meets 50% of the requirements, partially meets 33.3%, and does not meet 16.6% of them (at least based on what was available online). Similar to the previous description, the "substance of concern" category is neither shown on the DPP nor mentioned explicitly, but their website discusses the ability to gather data on chemical compliance, leading to a partial fulfillment assessment. Information related to the manufacturer is presented as a description of the facility in Bangladesh, but only one tier is shown. There is no clarification about how much of the supply chain will be covered, whereas the French regulation requires proposals to show information about Tiers 1 and 2[49]. Thus, this proposal only mentions Tier 1. Lastly, the Voluntary Ecolabel is not displayed at all, despite mentioning that their manufacturing in Bangladesh has various certifications, which are not presented, either for the product or on a company level.

Table 5.2: Evaluation non-DPPs vs ESPR current requirements

Feature	BCome	GreenStory
Substances of Concern	o	o
Importer	•	•
Information Related to Manufacturer	•	•
Voluntary EU Ecolabel	x	•
Information for Consumers	•	•
System Elements	•	•

Among the alternative options, GreenStory comes close to achieving 100% compliance. The only aspect missing is the visual presentation of "substance of concern." However, since GreenStory is a proposal based on LCA calculations, the inclusion of chemicals is necessary to meet the LCA requirements fully. Thus, to fulfill all ESPR's requirements, they would only need to display or discuss chemicals in their proposal.

BCome, like other proposals, does not show "substance of concern." However, they mention that they consider chemicals in their calculations, so it's only a matter of presenting this information on their proposal. Additionally, there is no mention or display of Voluntary Ecolabels, with no certifications shown for the company or the product in their proposal. BCome met 66.66%, partially met 16.66% and missed 16.66%.

Evaluating Environmental Reporting in DPPs

This section, titled "Evaluation for Environmental Reporting," visually assesses how the proposals present environmental information from their unique perspectives.

To start, it's crucial to grasp what factors influence individuals when purchasing textile articles, as this lays the foundation for their perceptions of environmental information. A questionnaire, with responses from 85 individuals, was conducted. While the participant number may not be substantial, the primary goal of this thesis is not to decipher human behavior but to explore the challenges of implementing the DPP in the textile sector and the potential advancements in circularity and sustainability that the DPP may offer.

To comprehend the responses, a few questions related to their persona were included, aiming to understand the composition of the sample, including their age, gender, and location. The results reveal that the majority of respondent are located in Europe, predominantly women, and fall within the 26 to 35 age range.

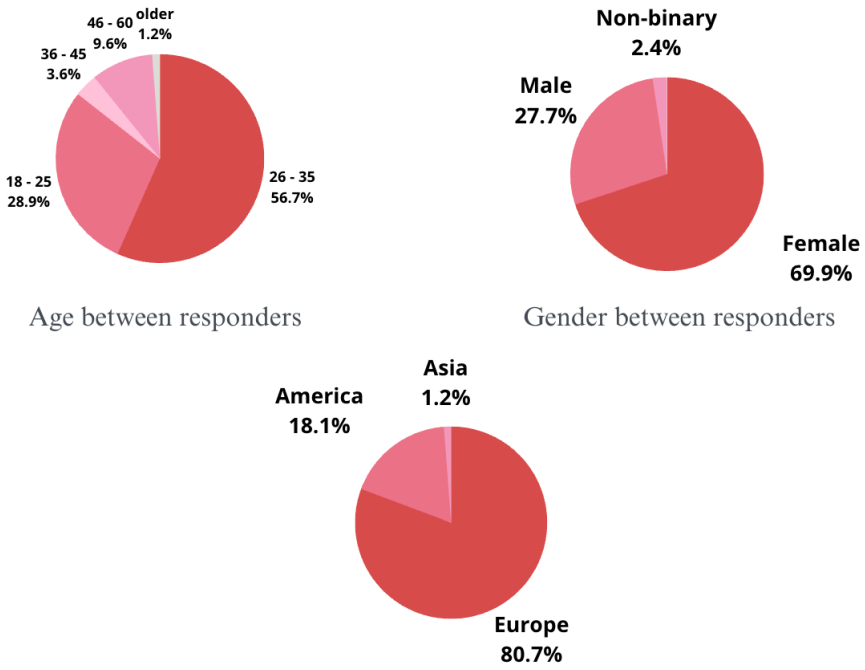

Figure 5.8: Results questionnaire: Characterization of respondents

Having established the categorization of the sample, participants were asked about their priorities when purchasing textile articles. This with the goal to identify the factors they consider crucial when deciding whether to buy a garment or not.

Figure 5.9 highlights that people prioritize qualities such as quality and functionality, price, comfort, style, and durability when purchasing garments. Environmental impact factors fall in the middle, with less than 25% of the 85 respondents selecting this option. Sustainable production and distribution, sustainable materials, and social responsibility rank even lower in their considerations. The current findings suggest that shoppers do not prioritize any form of environmental information when buying textile articles and for the majority, is not even considered.

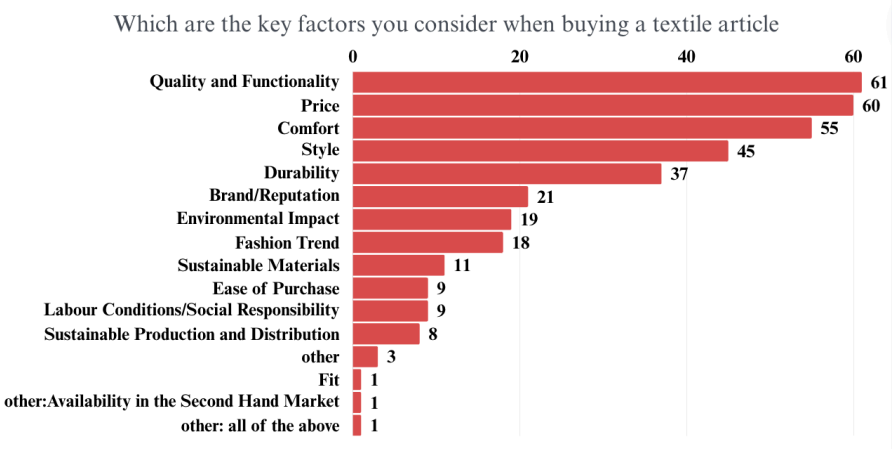

Figure 5.9: Results questionnaire: Key factors customers consider when buying textile article

To understand if this is true, a hypothesis was developed. Despite the current key factors indicating that people may not prioritize green elements, the hypothesis proposes that individuals indeed care about environmental and social aspects. However, they might not have sufficient access to information or possess the necessary skills to understand the limited information currently available. Therefore, improving access to comprehensive and understandable information could lead to greater consideration of environmental and social aspects in their purchasing decisions. Supporting this hypothesis, the questionnaire included the questions shown on Figure 5.10:

The data presented in Figure 5.10 demonstrates that shoppers perceive the current availability of environmental and sustainable information during shopping is far from sufficient. Additionally, when aasked whether the knowledge they possess on these topics is adequate to make informed decisions, only 26.8% of respondents felt they had enough knowledge, while the rest admitted to having some knowledge but not enough or require further education. This highlights the potential for DPPs to function as educational tools, cultivating awareness and behavioral change by providing relevant environmental and sustainable information. DPPs can provide the necessary infrastructure for shoppers to distinguish the positive, negative, and improved impact of their choices.

To ensure DPPs effectively enhance knowledge and support decision-making, a standardized framework for the information presented by brands is necessary. Currently, each proposal independently decides what environmental information to disclose and how to present it.

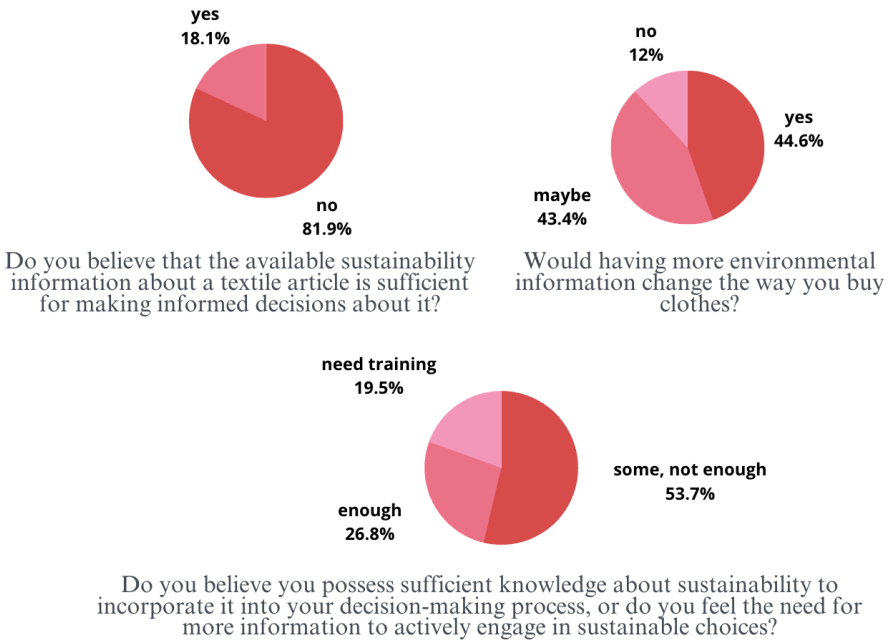

Figure 5.10: Results questionnaire: Environmental Information sufficiency

To highlight the diverse perspectives of various proposals regarding environmental information, an evaluation of their viewpoints has been established. Table 5.3 outlines the elements included in the Environmental Assessment Frameworks of different DPPs.

As shown in Table 5.3, there are some common elements shared among these frameworks. However, each DPP presents them in a unique way. In this analysis of the different environmental assessments, ProductDNA®was established as undefined in this context (more details will be discussed in the upcoming tables). Currently, there is no established definition for what qualifies as environmental or sustainable information. The question of whether regulatory authorities will provide further definitions remains open. It is known that each geopolitical region can define these requirements themselves [40]. Therefore, the DPP will need to comply with each region's definition.

Considering the survey results, which revealed that people may lack advanced skills in comprehending this type of information, the presentation of diverse elements related to sustainability and environmental information by various proposals may lead to confusion. If different brands opt for different DPPs to convey their information, less-knowledgeable customers may struggle to recognize the distinctions, potentially causing frustration and impeding the

DPPs from achieving their intended goals. Similar to what is presented on Table 5.3.

Table 5.3: Environmental Assessment Frameworks description

E. A. Frameworks Name	what encompasses	DPP
Envir. Impact Index	global warming, Fossil Fuels, Water Use, Water Pollution, carbon footprint, waste, energy usage	atma.io
Impact Areas	Climate Change, Ozone Depletion, Ecotoxicity for aquatic freshwater, Human Toxicity - cancer effects, Human Toxicity - non-cancer effects, Particulate Matter/Respiratory Inorganics, Ionising Radiation - human health effects, Photochemical Ozone Formation, Acidification, Eutrophication - terrestrial, Eutrophication - aquatic, Resource Depletion - water, Resource Depletion - mineral, fossil, Land Transformation [55]	Digital.ID
Envir. Index	water consumption, carbon footprint, chemical products consumption, recovered waste	STVgoDigital
Composition	Story based composition	Circularity.ID
Major environmental indicators	water scarcity, global warming potential, eutrophication, abiotic depletion	BCome
Environmental impact mapping	Emissions, Energy, Water	GreenStory

A more uniform Environmental Assessment Framework can improve the educational aspect of DPPs, helping customers develop a shared understanding of this topic. The use of LCA terminology is a common trend in the proposals, which is positive as LCA provides know standardization criteria. Nevertheless, it might be too technical for those less familiar with this subject. Some proposals, like GreenStory, aim for simpler presentations by categorizing environmental information into three areas: Emissions, Energy, and Water. This approach is encouraging as it is easy to understand.

For better decision-making support, additional aspects were examined. This includes comparing the environmental data calculated within the Environmental Assessment Framework with other databases or similar products, providing consumers with indicators of a product's environmental performance and its position in the market. Additionally, it was evaluated whether the DPP assigns

a score to the garment, what this score represents, and the format used to explain the information. Collectively, these factors streamline the decision-making process, as detailed in Table 5.4.

Table 5.4: Evaluation Environmental Reporting DPPs

Feature	atma.io	Digital ID	STVgoDigital	ProductDNA®	Circularity.ID
E. A. Frameworks	Envir. Impact Index	Impact Areas shown as story	Envir. Index	Undefined	Composition
Benchmark Comparison	Against Global Industry Average (Higgs)	None	None	None	None
Scoring and Typology	Levels from 0 to 3 (best)	none	Letters A (best) to F	Letters (undefined)	None
Information Digestibility	Descriptive	Visual and further information	Visual and further information	Descriptive	Descriptive
Traceability Type	Country and Process	Country and Material	Country and Process	Undefined	Country and Component
Data Type Comparison	Undefined	LCA and real data	LCA, real data and database	Undefined	database (Circular Material Check) and real data

Atma.io is the only proposal that presents a comparison between the environmental impact of the textile article against a global industry average and they clearly define that they use Higgs information. STVgoDigital has mentioned that they also want to provide this option but it is not yet implemented, perhaps in future developments. The rest of the proposals could benefit from adding this to their DPPs as it is a good and easy-to-understand mechanism to inform consumers if the textile article production is performing better or if there are areas for improvement.

Next is the Eco-score and how it is represented. Atma.io, STVgoDigital, and ProductDNA®offer this option, with varying presentation styles, all of which are easily understandable, even though they differ. This option is seen as eye-

catching and aids in quick decision-making. While there may be differences in how each proposal defines what is good or bad, this option is generally viewed very positively, similar to other consumer apps.

Information digestibility pertains to how the proposals convey information. The most common approach is to present information in a narrative or textual format. However, Digital ID and STVgoDigital have chosen to provide visual representations in combination with text. These visual representations can include icons, graphs, and images. While adding more information is essential, it's crucial to handle this aspect carefully, as it's where potential greenwashing can occur. Therefore, not only should the information be accurate, but any claims made in this area should also be verified.

Traceability is one of the most critical and discussed sections. As mentioned in previous chapters, brands are hesitant to share too much of their supply chain, as it may contain trade secrets or sensitive information they don't wish to disclose, such as sharing suppliers with other high-end or lower-end brands. However, this is a requirement of the DPP, and how it is presented was part of the assessment. All proposals except ProductDNA®chose to disclose the country of origin. Differences arise when providing information about the process, materials, or components (e.g., labels, buttons, etc.).

Lastly, the Data Type Comparison is particularly important, as it illustrates how the proposals plan to obtain information. While Atma.io and ProductDNA®are undefined in this regard due to the lack of available online information at the time of this thesis, they likely follow one of two trends that are common in the industry. This involves either adhering to established LCA standards (or something similar) or creating their own database and calculation methods.

STVgoDigital is a unique proposal as it combines elements of LCA, real data, and their proprietary calculations and database. This comprehensive approach places a strong emphasis on acquiring real data, making it a valuable choice for traceability within the textile industry.

The decision to label these elements as "undefined" in Table 5.4 serves to highlight the challenges and the scarcity of information currently available regarding the definitions and details of these DPP proposals. These proposals are often presented on websites or in seminars, and their implementation with brands is at various stages some are in testing, while others are still in the development process. Therefore, it's important to emphasize that the lack of

information is not a deficiency on their part but rather a reflection of the limited details provided, making it difficult to ascertain whether they incorporate these characteristics or not.

Table 5.5: Evaluation Environmental Reporting non-DPPs

Feature	BCome	GreenStory
E. A. Frameworks	Major environmental indicators	Environmental impact mapping
Benchmark Comparison	Against Global Industry Average and Relative Savings	Relative Savings (car rides, off the road cars)
Scoring and Typology	Letters A (best) to E	none
Information Digestibility	Visual and further information	Visual and further information
Traceability Type	None	None
Data Type Comparison	LCA and real data	LCA and real data

Table 5.6 presents the evaluation of additional proposals. Similar to the ones categorized as DPP in the previous table, these proposals were assessed based on how they present environmental information. BCome and GreenStory both offer relative savings, making environmental information easily understandable by comparing it to everyday items like car rides, lightbulbs, or glasses of water. BCome goes a step further by providing a comparison against global industry averages based on best practices and eco-labels for each of their four categories (People, Planet, Transparency, and Circularity), making it the most comprehensive option in this category.

Both options use a combination of visual aids and further information, along with a mix of LCA and real data for their comparisons. In terms of traceability, since both proposals are LCA-based, they can easily incorporate traceability, even though they don't currently display it on their platforms. This indicates that these options have the potential to align with DPP characteristics with some adjustments.

5.1.3 Key Findings from the Analysis of Recent DPP Proposals

Atma.io and STVgoDigital emerge as the most congruent proposals in this assessment, as they both fulfill all the requirements outlined by the ESPR. The most frequently missing elements among both DPP and non-DPP proposals are Substance of Concern, Information Related to Manufacturer, and Voluntary Eco-label.

When it comes to presenting environmental information, brands must be aware of consumers' limited knowledge and the textile and fashion sector's history of greenwashing. To build consumer trust, brands should provide real, standardized, easily understandable, and verifiable information.

Brands that support LCA-based information can be considered best practices because it is a well-recognized, standardized approach that's easy to control. Establishing a common environmental framework among brands and authorities would facilitate standardization and define the minimum elements required for displaying environmental information. This is essential as the current diversity of approaches makes it challenging to compare and comprehend the different options available.

5.1.4 Evaluating Recent DPP Protocol Proposal Trends

It's essential to establish a clear distinction between DPP and DPP-protocol. DPP represents the platform that interacts directly with the customer, while the DPP-protocol serves as the backbone, supporting the data collection and management system. This differentiation is crucial as these are two distinct components within the DPP ecosystem.

Incorporating DPP-protocols into this thesis is significant because they play a pivotal role in supporting the Circular Economy. They provide the necessary information to post-consumer activities and extended life-cycle activities, making them a vital part of the sustainability cycle.The DPP-protocols are:

- Circular Product Data Protocol™V1.0 by EON [8]
- Trace4Value by TrusTrace [9]
- circularity.ID®Open Data Standard by circular.fashion [10]

[8] https://www.eon.xyz/initiatives/circular-product-data-protocol
[9] https://trace4value.se/
[10] https://circularity.id/open-data-standard.html

This comparative analysis will provide insights into the capabilities and focus of these DPP-protocols, contributing to a better understanding of their roles in advancing the Circular Economy.

5.1.5 Comparative elements definition

The assessment of DPP-protocols is indeed different from the previous analysis, given that these protocols are not the final product but rather support systems. To evaluate them, the following considerations were taken into account:

- Goal: As outlined in the sources.
- Scope: The defined scope as per the sources.
- Target user groups: The intended audience for these protocols.
- Enables circularity: Whether the elements included in the protocol support circularity.
- Circularity: Information related to circularity from the sources.

These components collectively provide a comprehensive perspective on how each protocol facilitates circularity and its potential impact. The combination of evaluating both the extent to which circularity is supported and how it is defined, based on available information, enables a more thorough assessment. Additionally, the inclusion of a notes section allows for the recognition of protocols that offer more than just data collection, potentially supporting best practices. This aspect is vital for understanding their potential impact on circularity in the future.

It's worth noting that these protocols were not chosen randomly. The Circular Product Data Protocol™V1.0 and the circularity.ID®Open Data Standard are related to the DPPs previously analyzed. Trace4Value is a proposal coordinated by RISE[11] and was introduced at the iTechStyle Summit [12]. These three proposals have distinct scopes, which were determined based on their respective descriptions.

[11] https://www.ri.se/en

[12] iTechStyle Summit by CITEVE in Porto, Portugal, in May 2023 - https://mkt2.citeve.pt/2eve4CDq/summit23

Table 5.6: Evaluation Circularity enabling of DPP-protocols

Feature	Circular Product Data Protocol™V1.0	Trace4Value	circularity.ID®Open Data Standard
Goal	Define essential product data necessary for the re-circulation and regeneration of apparel products within the circular economy. This involves the transmission of product identity data to collaborate with value chain partners and enhance circular business models. [36]	Aims to create a digital product passport for textile products from production to sales.[56]	Standardizes information and data exchange formats to support recyclers and sorting facilities by the identification of challenges and needs from the material production phase to design, use, and finally sorting and recycling. [54]
Scope	Cradle to cradle	Cradle to crate	Cradle to grave
Target user groups	Circulators (Collectors, Sorters, Resellers, Renters, Repairers, etc.) and Regenerators (Recyclers)	Supply Chain	Recyclers and sorting facilities
Enables circularity	Yes; enables product and material identification for resale, repair, reuse, and recycling. Supports reverse logistics and circular business models. Measures circular economy efforts. [36]	Focuses on supply chain information[56]. Needs to expand its focus on enhancing the garment's lifecycle.	Yes; incorporates circularity from design[54].
Circularity	Reduced resource consumption, resale, collection, sorting, repair, recycling, regeneration, rental, and sharing	Performance, recyclability, take-back and recycling instructions, disassembly instructions, circular design strategies, social brand statements, and environmental footprint	For fashion industry use in labeling, identifying, and optimizing digital product data for a circular economy.

Furthermore, it's important to emphasize that these protocols do not store product data. Instead, they function as systems that aggregate and structure the data for seamless transfer between systems.

Each of these protocols has a distinct scope that aligns with its respective goal. Circular Product Data Protocol™V1.0 aims to fully close the loops, making products recyclable, repairable, and available as a service, thereby encompassing the entire lifecycle. Its cradle-to-cradle approach is reflected in its target audience, which includes Circulators and Regenerators. This means the protocol gathers information from both the supply chain and users to support post-consumer activities, enabling seamless integration into the circular economy. The definition of circularity adopted by this protocol goes beyond recycling, emphasizing other integrated loops like renting, sharing, regeneration, repair, and, most notably, reducing consumption.

The circularity.ID®Open Data Standard is another valuable option, categorized as cradle to grave. It focuses on providing information to recyclers and sorting facilities while also emphasizing design techniques, aiming to ensure that products are designed with circularity in mind from their inception. Although its goal and scope may appear somewhat limited, as they don't explicitly mention other extended lifecycle options, the data they collect can potentially be applied to a broader range of activities. Their circularity definition centers on effective recycling, which is commendable, but there's room for expansion beyond waste-centric circular thinking.

Lastly, Trace4Value's goal is distinctly focused on providing supply chain information up to the point of sale, leading to its categorization as cradle to crate. It primarily serves the DPP without extending or enabling the system for the circular economy. While it effectively delivers information for customer decision-making, there is potential for broader application in supporting circular business practices. The protocol's perspective on circularity revolves around manufacturing concepts, such as performance, take-back, and disassembly, along with circular design strategies, social brand statements, and environmental footprints. To enhance its adaptability to the circular framework, Trace4Value could broaden its understanding of circularity and incorporate additional elements into its system.

5.1.6 Key Findings from the Analysis of Recent DPP Protocol Proposals

There are no definitive right or wrong perspectives on these protocols. Moreover, the potential development of additional protocols is beneficial, as it can introduce diverse ideas and expand the concept of circularity. Collaboration among protocol systems and creators is crucial to enhance interoperability and foster innovation. In the context of achieving circularity in the textile sector, a combination of Circular Product Data Protocol™V1.0 with the design thinking and methodology from circularity.ID®Open Data Standard appears to be the most promising approach at this early stage.

The prevailing trend among these protocols predominantly centers on providing information related to recycling. However, it's vital to acknowledge that this approach offers a limited interpretation of circularity. While the textile sector's current emphasis is commendably directed toward reducing the substantial annual waste it generates, circularity encompasses a broader spectrum. It involves not only recycling but also efforts to reduce consumption rates, extend the lifespan of garments, and ensure appropriate end-of-life treatment for products, whether through recycling or other sustainable practices.

In this context, regulatory authorities could play a pivotal role by offering guidance on the comprehensive definition of circularity, along with establishing minimum requirements that a garment or brand should meet to be considered circular. With such clarity and in alignment with one of the ESPR's requirements to demonstrate an article's performance, the incorporation of a well-defined concept of circularity within this category could provide a foundational framework for the textile industry. This framework has the potential to enhance circularity, sustainability, and even contribute to advancing social justice within the sector.

5.2 Strategic Foundations for DPP Adoption

DPP adoption presents its own set of challenges. Consumers will need time to become familiar with the information and brand claims. However, this process can be an opportunity to rebuild trust between brands and end-customers. It's crucial that the data provided in the DPP is accurate and verifiable, as any misleading information could damage the textile sector's reputation.

The information presented in the DPP should be easily understandable,

and brands should refrain from using it as a tool to push more clothing sales. Instead, they should always keep the DPP's primary objective in mind. Brands can leverage the DPP as a means of verifying and presenting their sustainable initiatives, allowing end-customers to track these efforts.

As mentioned earlier, the DPP should serve not only as a compliance tool for regulations but also as an educational resource. This will empower shoppers to consider sustainability when making their purchasing decisions. It's a way to encourage and enable consumers to make more environmentally responsible choices.

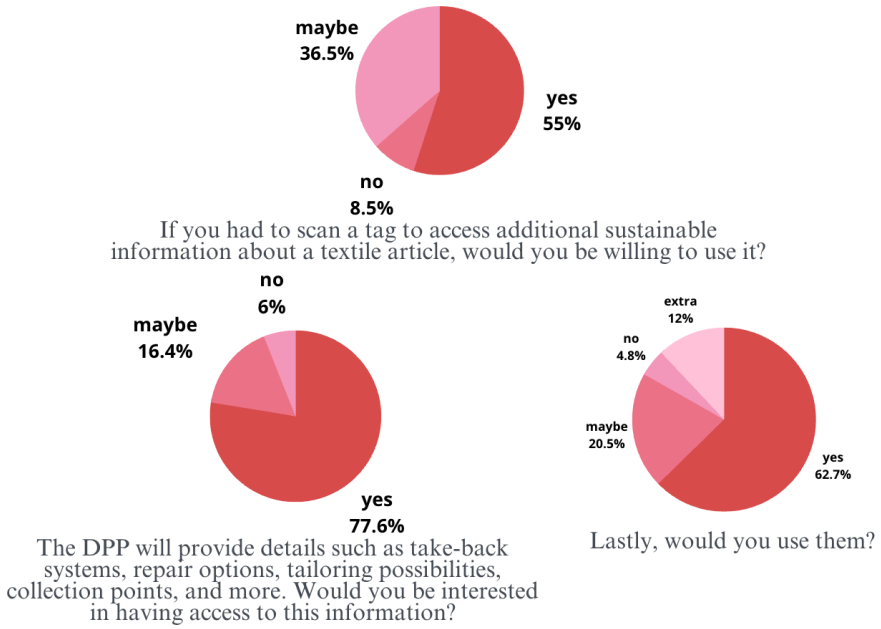

Figure 5.11: Results questionnaire: Use of DPP

The questionnaire results indicate a significant level of interest and potential for DPP adoption among end-customers. Only a small percentage, 7.4%, expressed that they would not use the DPP, while the majority expressed interest, with 30% in the "maybe" category. This supports the hypothesis that people are interested in environmental and sustainability topics but currently lack sufficient information to make informed decisions.

The high level of interest and potential adoption of DPPs, , as indicated by the survey results, suggests that consumers are open to using these platforms to make more sustainable choices. When asked about the potential for enabling future circularity businesses with the DPP, an overwhelming 82.4% expressed interest in this possibility, and 72.1% stated they would use these options with-

out hesitation. While there is a small "no" section, the fact that it's less than 10% indicates a high level of potential adoption. The real challenge may lie in influencing the "maybe" category to have higher implementation, as this group represents a significant portion of respondents. It's important to note that even the "no" category may change their minds over time, making the overall outlook for DPP adoption quite positive.

Regarding the presentation of DPP information, the current proposal involves scanning information via a phone and accessing an extra tab on websites to find the relevant details[57]. However, in future updates, the information should be readily available to the customer, particularly on web platforms. This would make it more convenient for consumers to access important data, such as sustainability scores and other decision-making tools, directly and at a glance.

This user-friendly approach can further enhance the usability and effectiveness of DPPs in helping consumers make informed choices while shopping for textile products.

5.2.1 Examining SONAE's Experience with Early DPP Adoption

SONAE, a multinational corporation known for its diverse business ventures, operates globally with a focus on innovation and effective execution to bring progress benefits to a broad audience, including overseeing textile brands like Zeitreel[**SONAE**]. The collaboration between CITEVE and SONAE in adopting STVgoDigital as their DPP stems from a joint effort by these Portuguese enterprises to contribute to sustainable development.

In this collaborative effort, CITEVE, functioning as a technological center, contributes its expertise with the established DPP proposal, STVgoDigital. CITEVE's role primarily revolves around providing technical knowledge, while SONAE plays a key role by contributing crucial data and infrastructure necessary for the successful implementation of STVgoDigital into their systems. However, challenges have emerged during this implementation phase.

The DPP demands comprehensive information about various processes across different tiers of the supply chain. A significant challenge faced by CITEVE is the relatively low digital maturity level of the textile sector, coupled with a lack of clear connectivity between its various actors. Traditionally, brands maintain direct contact with the first tier of the supply chain. Nevertheless, for the DPP to function optimally, a comprehensive mapping of the entire supply chain is

required, and this mapping is currently not very clear. Bridging the information gap for necessities like traceability and manufacturer details becomes a critical task in this context.

The development of the DPP comprises three key components: the data visualization layer (representing the DPP itself), the data processing layer, and the data-gathering layer. STVgoDigital serves as the DPP but relies on high-quality data for optimal results. Importantly, STVgoDigital is integrated into all three layers, presenting unique challenges spanning across these layers.

DATA GATHERING LAYER

The data gathering layer plays a pivotal role in collecting crucial information. In CITEVE's proposal, this process involves the capability to request data from SONAE's supply chain system through an API system or collect it via a web questionnaire or other sources, depending on the maturity of the data owner system. This stage faced initial challenges related to data availability.

STVgoDigital relies on real data for its calculations, meaning that it requires information preferably from sensors or smart systems, which economic actors within the supply chain often lack. The textile sector demonstrates a low level of maturity in terms of data collection systems. While STVgoDigital accepts estimated data for transportation-related aspects, all other data must be real. Economic actors find it challenging to provide this real data, adding complexity to the implementation process.

Another significant challenge arises from the overall digital maturity of the textile sector. The existing systems are not robust enough to meet STVgoDigital's requirements, exposing the sector's technological immaturity. Additionally, communication within SONAE's supply chain network falls short of the robustness needed for STVgoDigital. The DPP demands data from multiple tiers, and identifying these tiers proved to be a complex task for SONAE's team.

This information is valuable for CITEVE, as systems of this nature must be easy to implement and mature alongside the sector while acting as drivers for technological evolution. CITEVE tackles this challenge by offering diverse techniques for data collection, enabling less mature actors to contribute their information. They also work alongside different supply chain layers to map the entire supply chain in detail.

DATA PROCESSING LAYER

CITEVE's proposal, STVgoDigital, features two main scores and four subcategory scores, calculated by their experts. While the detailed calculations are proprietary, the fundamental elements for the DPP are depicted in Figure 5.12, taked directly from [50].

Table 2
Environmental and Circular Indicators considered, for computing the Environmental and Circular Score (ECS).

Data	Description
Water consumption	Water consumption for the product under evaluation, per batch
Quantity of Recycled Water	Quantity of recycled water, per batch
Electricity consumption, total	Electricity consumption for the product under evaluation, per batch
Renewable electricity bill	Annual average of the amount indicated in the monthly electricity bills and/or established in the contract
Self-consumption of renewable energy	Total consumption of own renewable electricity, for the product under evaluation, per batch, in percentage
Natural gas consumption	Consumption of natural gas for the product under evaluation, per batch
Steam consumption	Steam consumption for the product under evaluation, per batch
Steam pressure	Vapor pressure (gauge) of the acquired vapor
Hot water consumption	Hot water consumption for the product under evaluation, per batch
Hot water consumption	Average temperature of hot water acquired
Consumption of thick fuel oil	Consumption of thick fuel oil for the product under evaluation, per batch
Biomass consumption	Biomass consumption for the product under evaluation, per batch
Coal consumption	Coal consumption for the product under evaluation, per batch
Consumption of other types of energy	Consumption of another type of energy for the product under evaluation, per batch
Diesel consumption	Diesel consumption for the product under evaluation
Gasoline consumption	Gasoline consumption for the product under evaluation
Liquid petroleum gas (LPG) consumption	Consumption of propane gas for the product under evaluation, per batch
Consumption of chemicals	Consumption of chemicals for the product under evaluation, per batch
Quantity of Recovered Chemicals	Consumption of recovered chemicals, for the product under evaluation, per batch
Quantity of Non-Hazardous Chemicals	Consumption of non-hazardous chemicals for the product under evaluation, per batch
SVHC quantity in products	SVHC consumption for the product under evaluation, per batch
Wastewater volume	Wastewater volume for the product under evaluation, per batch
COD concentration	Annual average of Chemichal oxygen demand (COD) concentration based on liquid effluent characterization reports
BOD5 concentration	Annual average of Biochemichal oxygen demand (BOD5) concentration based on liquid effluent characterization reports
TSS concentration	Annual average of Total suspended solids (TSS) concentration based on liquid effluent characterization reports
Quantity of solid waste	Total amount of solid waste generated for the product under evaluation, per batch
Quantity of textile waste	Quantity of textile waste generated for the product under evaluation, per batch
Quantity of non-hazardous waste	Quantity of non-hazardous waste generated for the product under evaluation, per batch
Quantity of recovered waste	Quantity of total waste valued for the product under evaluation, per batch
Quantity of valued textiles	Quantity of textiles valued for the product under evaluation, per batch
Quality control to colour changing	Colour fastness to washing – colour changing (ISO 105 C06)
Quality control to staining	Colour fastness to washing – staining (ISO 105 C06)
Quality control to artificial light	Colour fastness to artificial light (EN ISO 105 B02)
Quality control to pilling resistance	Pilling resistance of the woven fabrics (EN ISO 12945-2)
Quality control to abrasion resistance	Abrasion resistance of the woven fabrics (EN ISO 12947-2)

Figure 5.12: STVgoDigital Data Environmental and Circular Score (ECS) [50]

The elements mentioned, along with those related to the social aspect (which won't be covered due to the scope of the thesis), form a significant part of CITEVE's thorough analysis and expertise. However, acquiring this information has proven challenging for CITEVE and SONAE, as reaching the right individuals has been difficult. Working closely with SONAE to map the supply chain, CITEVE has dedicated efforts to identify the appropriate contacts and request the necessary information.

It's essential to highlight that these calculations heavily depend on accurate and real data, requiring a robust verification process. Collaboration with the industry introduces a challenge in this aspect, as the usual methods of information validation may not be applied consistently. While the responsibility for verification is beyond CITEVE's scope, they emphasize the importance of comprehensive validation. External authorities may need to intervene to ensure the accuracy and methodology of the calculations are appropriately verified.

DATA VISUALIZATION LAYER

The current stage of the DPP, STVgoDigital, involves data gathering, and the identification of challenges for this layer is pending completion as CITEVE and SONAE are still in the process of gathering data. The DPP layout has been established and shared with SONAE, making the proposal well-understood and ready for implementation.

For future deployments of STVgoDigital, a comprehensive analysis of challenges will be conducted, and corresponding plans will be developed to effectively mitigate these challenges.

CULTURE

In addition to the previously mentioned system and DPP challenges, insights from discussions with SONAE's team, CITEVE, and the author of this thesis provide clarity on the significant resistance faced by this proposal within the industry.

Primarily, a substantial part of the resistance stems from financial constraints. Establishing the system for data collection and storage, obtaining data gathering tools, and acquiring necessary skills require a significant investment in both system requirements and personnel development. This financial aspect poses a considerable challenge, especially as it necessitates an initial investment for a "test run" of the system.

Secondly, discussions with SONAE's team uncover the reluctance within the supply chain to embrace more sustainable options or tools, citing a lack of customer demand. This underscores a broader industry issue where brands often resist change unless driven by customer requests or regulatory mandates. Consequently, the involvement of legal authorities and regulations in sustainable and circular initiatives becomes crucial, alongside a proactive push from customers.

The third aspect is the prevailing absence of a sustainability and circular culture within the sector, encompassing both companies (brands and supply chain actors) and individuals. Despite growing environmental concerns, a comprehensive shift requires more than good intentions from a few stakeholders. The DPP, with its potential to identify gaps in sustainable practices, serves as a strategic tool for developing solutions and new business models. However, it also highlights the potential misuse of information in the textile sector. Empha-

sizing the educational role of the DPP, it becomes pivotal in underscoring the need for a cultural and mindset shift, requiring careful consideration due to the sensitivity of the matter.

Lastly, the introduction of ambiguity in the requirements, as discussed earlier in this chapter, has posed a notable challenge in the deployment of the DPP with SONAE. Both CITEVE and SONAE express hesitation regarding the extent of information required to be showcased. While CITEVE, grounded in scientific principles, calculates sustainability based on scientific norms, SONAE, functioning as a brand, is cautious about revealing what they consider "extra" information. The absence of clear definitions in this area contributes to ambiguity within the proposals.

5.2.2 Current Challenges for the application of the DPP

The application of DPPs faces substantial challenges, notably arising from diverse sustainability approaches across different geopolitical regions [40]. For DPPs to truly make a global impact on sustainability, they must surpass regional boundaries and be acceptable and interoperable worldwide. Achieving this ambitious goal entails extensive negotiation processes, with the European Union's move towards a regional DPP regulation being a noteworthy stride in this direction [40].

However, the practical implementation of DPPs goes beyond deploying technologies and governance mechanisms; it involves reshaping the business models of firms within the industrial ecosystem. This encompasses redefining their value propositions, cost structures, revenue models, and potentially changing the customer base they serve [40].

The complexities of industrial ecosystems pose a significant hurdle for DPP implementation due to their highly complex, dynamic, and geographically dispersed supply chains. Many firms currently lack complete visibility and transparency over their supply chains, including supplier networks and product origins [40]. Achieving universal acceptance and interoperability for DPPs in such a multifaceted context requires a thorough understanding of these challenges and effective strategies to overcome them.

The Ambiguity in Legal Frameworks for DPP Implementation

The lack of homogeneity among the DPP proposals, as highlighted in the thesis, can be attributed to the current ambiguity in regulations. The early stage of the ESPR's DPP proposal, with its general guidelines meant to cover multiple sectors, has created an environment where specific requirements are not well-defined for each sector. Collaboration between DPP development companies and regulatory bodies is essential to address pending issues and provide clarity on implementation.

In addition, the verification process of DPPs is crucial. It can serve as a compilation of certifications and social and environmental claims, making the DPP a comprehensive end-certification. However, clear guidelines are needed not only for DPP implementation but also for its use and content. Establishing such guidelines will ensure the credibility and reliability of the information provided through DPPs, aiding consumers in making informed decisions.

The definition and requirements for post-consumer activities and additional circularity initiatives should also be clearly outlined. Regulatory authorities should prioritize these requirements and emphasize their completion within the supply chain. This approach will encourage sustainability and circularity in the textile sector and support the broader goals of the DPP ecosystem.

6 Conclusions and Future Work

6.1 Conclusion

The Digital Product Passport presents a promising path for advancing the circular economy, serving as a data repository to identify areas of opportunity and fostering connections between circular and linear options within the textile sector. Acting as a data baseline, it captures the entire lifecycle of a textile article, from raw material extraction to end-of-life, highlighting all the possible options in between. This includes unexplored areas such as new businesses opportunities and has the potential to integrate and explore further known proposals like repair, second-hand options, and product-as-a-service that also contribute to the circular economy.

The adoption of DPP aligns with Industry 4.0, emphasizing the use of high technology and smart systems, a domain not traditionally associated with the textile sector and its supply chain. Implementing such advanced systems might pose financial and technical challenges, especially for small or medium enterprises, but the ESPR proposal said that this should not cause any economic affectation to the sectors.

This thesis considers the ESPR's proposal to be broad for the Textile sector because it doesn't provides detailed definitions or expectations for the requirements. While it's not expected to be too specific, the diversity in information from each DPP proposal, as seen in the assessment, shows the need for standardization in some areas. This thesis recommends standardizing the environmental assessment framework, especially the information about the environmental impact of each garment. The aim is to provide consistent information and

enable the DPP to act as an educational tool. This helps customers make effective decisions and understand and distinguish garments, promoting overall improvement and sustainability.

The DPP works as a tool throughout the supply chain and to the customer. Its potential extends beyond improving the circularity of products to enhancing circular practices within the industry. The assessment of DPP-protocols is crucial as these data gathering tools consider actors beyond the supply chain. In the analysis, the difference in understanding circularity and the target user group significantly influenced the goals and scope of the proposals. A clearer description of what circularity means for the textile sector would contribute to the development of more comprehensive proposals, aligning with the goals outlined in the ESPR's proposal.

Traceability poses a significant challenge in the industry, involving concerns such as trade secrets and the challenge of identifying various tiers within the supply chain. In the implementation of STVgoDigital, these challenges were evident, along with the sector's lack of a sustainable culture and immaturity in their systems. The absence of a sustainable and circular culture underscores the necessity for robust legal regulations to effectively bring about change in the sector, with the expectation that the DPP will offer support in this aspect.

6.2 Future Work

Since the analysed ESPR's proposal in this study was the initial version, future versions of the legislation might address the identified gaps. In subsequent iterations, the legislation should clarify elements that appear challenging for the textile sector, such as understanding the expectations behind product performance and unique identifiers.

The industry must also define potential changes to their systems to support DPP requirements. Although the DPP is not yet mandatory throughout Europe, it will be, and brands should monitor French regulations, as they propose its application in 2024. This provides an opportunity to anticipate future challenges for brands across the rest of Europe.

Enhanced collaboration among brands is crucial to exert a more substantial impact on the supply chain, especially for those brands or economic actors sharing suppliers or providers. This collaboration can lead to a more significant and rapid response within the supply chain.

Finally, there is a need for a clear description of how data will be validated and verified. Given the history of green-washing in the textile sector, authorities should establish a defined solution to prevent this issue in the near future, specially on the DPP as a solution based on data.

References

[1] Marcello Colledani and Abdelrahman Abdalla. *D3.1 Benchmark of existing DPP-oriented reference architectures. January (M4)*. 2023. URL: https://cirpassproject.eu/wp-content/uploads/2023/03/CIRPASS_Benchmark-of-existing-DPP-oriented-reference-architectures.pdf.

[2] Solita and Gaia Consulting. *Digital Product Passport*. Solita, 2022.

[3] Directorate-General for Environment European Commission. "establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC". In: *EUROPEAN COMMISSION* (2022).

[4] European Environmental Agency. *Circular business models and smarter design can reduce environment and climate impacts from textiles*. Accessed on April 22, 2023. 2022. URL: https://www.eea.europa.eu/highlights/circular-business-models-and-smarter.

[5] Joerg Walden, Angelika Steinbrecher, and Maroye Marinkovic. "Digital Product Passports as Enabler of the Circular Economy". In: *Chemie Ingenieur Technik* (2021).

[6] Maike Jansen et al. "Stop Guessing in the Dark: Identified Requirements for DigitalProduct Passport Systems". In: *Systems* (2023).

[7] The Digital Product Passport as defined in the Proposal for Eco-design for Sustainable Product Regulations (ESPR). In: *CIRPASS* (2022).

[8] Guillaume Ragonnaud. "'Green claims' directive. Protecting consumers from greenwashing". In: *EPRS: European Parliamentary Research Service* (2023).

[9] CIRPASS. *About CIRPASS*. Accessed on September 30, 2023. 2022. URL: https://cirpassproject.eu/.

[10] European Parliament. *Circular economy: definition, importance and benefits*. Accessed on April 22, 2023. 2023. URL: https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits.

[11] Ellen MacArthur Foundation. *A new textiles economy: Redesigning fashions future*, Accessed on April 22, 2023. 2017. URL: https://ellenmacarthurfoundation.org/a-new-textiles-economy.

[12] Saurabh Vaidya, Prashant Ambad, and Santosh Bhosle. "Industry 4.0 A Glimpse". In: *Procedia Manufacturing* (2018).

[13] CIRPASS. *What is a Digital Product Passport (DPP), FAQ*. Accessed on May 30, 2023. 2022. URL: https://cirpassproject.eu/faq/.

[14] GS1. *The new EU sustainability textile strategy*. 2023. URL: https://gs1.eu/wp-content/uploads/2023/03/The-DPP-ApparelTextile-Industry-Briefing-Document.pdf.

[15] Thomas Götz et al. *Digital Product Passport: the ticket to achieving a climate neutral and circular European economy?* Report. Cambridge Institute for Sustainability Leadership, 2022. URL: https://circulareconomy.europa.eu/platform/sites/default/files/cisl_digital_products_passport_report_v6.pdf.

[16] Thomas Adisorn, Lena Tholen, and Thomas Götz. "Towards a Digital Product Passport Fit for Contributing to a Circular Economy". In: *energies* (2021).

[17] Jens Gayko and Benjamin Helfritz. "Report of TWG Digital Product Passport: Landscape of Digital Product Passport Standards". In: *StandICT.eu* (2023).

[18] Carsten Stöcker. *Beautifying the Future: Unleashing the Potential of Digital Product Passports in the Cosmetics Industry*. Accessed September 2023. URL: https://medium.com/spherity/beautifying-the-future-unleashing-the-potential-of-digital-product-passports-in-the-cosmetics-569a012b9f69.

[19] European Union. *UN Environment Programme - Environment for Development*. 2012. URL: https://capacity4dev.europa.eu/groups/unep/info/about-united-nations-environment-programme_en.

[20] Rachel Arthur. "Sustainable Fashion, COMMUNICATION STRATEGY 2021 - 2024". In: *UN Enviroment Programme* (2020).

[21] United Nations. *THE 17 GOALS*. 2015. URL: https://sdgs.un.org/goals.

[22] UN Departmenr of Economic and Social Affairs. *Agenda 21: Core Publication*. URL: https://sustainabledevelopment.un.org/content/dsd/agenda21/res_agenda21_04.shtml.

[23] UN Enviroment Programme. *Sustainable consumption and production policies,* 2020. URL: https://www.unep.org/explore-topics/resource-efficiency/what-we-do/sustainable-consumption-and-production-policies.

[24] Peter Glavic. *Evolution and Current Challenges of Sustainable Consumption and Production*. https://doi.org/10.3390/su13169379. 2021.

[25] European Commission. *Questions and Answers on EU Strategy for Sustainable and Circular Textiles*. Accessed September 2023. URL: https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_2015.

[26] European Commission. *Circular economy action plan*. Accessed September 2023. URL: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en.

[27] CITEVE. *About CITEVE*. Accessed on May 30, 2023. URL: https://www.citeve.pt/artigo/sobre_nos.

[28] CITEVE. *bioeconomia na indústria têxtil*. Accessed September 2023.

[29] Bonfiglioli S.P.A. *Textile*. Accessed September 2023. URL: https://www.bonfiglioli.com/international/en/sector/textile.

[30] Albini Group. *Production Process*. Accessed September 2023. URL: https://www.albinigroup.com/en/behind-the-fabric/production-process/.

[31] Nikolina ajn. "Textiles and the environment". In: *EPRS: European Parliamentary Research Service* (2022).

[32] Green Story. *The use and misuse of data and life cycle assessment (LCA) in fashion*. YouTube video. 2022. URL: https://www.youtube.com/watch?v=LYMatOpY2yw&t=1s.

[33] Radostina A. Angelova. "The circular economy: a new paradigm for the textile and clothing industries". In: *ResearchGate* (2020).

[34] Christiane Plociennik et al. “Requirements for a Digital Product Passport to Boost the Circular Economy”. In: *INFORMATIK* (2022).

[35] William Neale. “Progress in Codecision”. Presentation at the European Commission webinar on the Digital Product Passport, 12 June 2023. 2023.

[36] EON. *The Circular Product Data Protocol for Apparel*. Online presentation. 2021. URL: https://www.circulardataprotocol.org/.

[37] Taylor Brydges. “Closing the loop on take, make, waste: Investigating circular economy practices in the Swedish fashion industry”. In: *Journal of Cleaner Production* (2021).

[38] Rachel Bick, Erika Halsey, and Christine C. Ekenga. “The global environmental injustice of fast fashion”. In: *Environmental Health* (2018).

[39] Berger et al. “Digital Battery Passports to Enable Circular and Sustainable Value Chains: Conceptualization and Use Cases”. In: *Journal of Cleaner Production* (2022).

[40] David J. Langley et al. “Orchestrating a smart circular economy: Guiding principles for digital product passports”. In: *Journal of Business Research* (2023).

[41] Dr. Susanne Guth-Orlowski. *The digital product passport and its technical implementation*. 2021. URL: https://medium.com/.

[42] Iker Laskurain-Iturbe et al. “Exploring the influence of industry 4.0 technologies on the circular economy”. In: *Journal of Cleaner Production* (2021).

[43] António DE SOUSA MAIA. “A quick introduction to the Digital Product Passport for textiles”. shared by European Commission.

[44] Cambridge Dictionary. *interoperability*. Accessed on October 20, 2023. URL: https://dictionary.cambridge.org/dictionary/english/interoperability.

[45] Chris Stretton, Pierre Ouannes, and Nabil Ahmed. *Scalable and interoperable digital product passport system*. Accessed on September 30, 2023. 2022. URL: https://www.circularise.com/blogs/scalable-and-interoperable-dpps.

[46] Dr. Susanne Guth-Orlowski. *Implementing Digital Product Passports using decentralized identity standards*. 2023. URL: https://medium.com/.

[47] Chris Stretton. *Digital product passports (DPP): what, how, and why?* Accessed on October 20, 2023. URL: https://www.circularise.com/blogs/digital-product-passports-dpp-what-how-and-why.

[48] Melanie R.N. Kinga, Paul D. Timmsa, and Sara Mountneyb. "A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns". In: *Journal of Cleaner Production* (2023).

[49] Pantxika Ospital et al. "A DIGITAL PRODUCT PASSPORT TO SUPPORT PRODUCT TRANSPARENCY AND CIRCULARITY". In: *Gobal Fashion Conference 2022* (2022).

[50] Luís Alves et al. "A Traceability Platform for Monitoring Environmental and Social Sustainability in the Textile and Clothing Value Chain: Towards a Digital Passport for T&C". In: *Preprints* (2023).

[51] Markus Bjerre and Nikolaj Parbo. *Looping on Data: Best practices and barriers for sharing data in circular business models*. Report. Danish Busines Authority, 2021. URL: https://erhvervsstyrelsen.dk/sites/default/files/2022-01/Looping%20on%20data_0.pdf.

[52] Tian Daphne and Chris Stretton. *What data goes into a digital product passport?* Accessed on October 25, 2023. URL: https://www.circularise.com/blogs/data-in-a-dpp#nestes-digital-product.

[53] CIRPASS. *CIRPASS DPP-related Initiatives Dataset*. Accessed on October 30, 2023. URL: https://cirpassproject.eu/dpp-related-initiatives-dataset/.

[54] circular.fashion. *CIRCULARITY.ID: The transformation to data-driven circularity in fashion*. 2021. URL: https://circularity.id/open-data-standard.html.

[55] EON. *What you should know about Product Environmental Footprint*. Accessed on October 30, 2023. URL: https://www.eon.xyz/insights/what-you-should-know-about-product-environmental-footprint.

[56] Trustrace. *Trace4Value: Digital Product Passport inTextile Data Protocol*. 2022. URL: https://trace4value.se/subproject/digital-product-passport-in-textile/.

[57] Joao Rodrigues Frade and Jose Manuel Panizo. “Considerations on technical design”. Presentation at the European Commission webinar on the Digital Product Passport, 12 June 2023. 2023.

Acknowledgments

I would like to begin by expressing my deepest gratitude to all the individuals who have supported me professionally and morally, whether directly or indirectly, throughout the writing of this thesis.

I express special thanks to Professor Anna Mazzi for her trust and accepting to supervise me, making room for this thesis in her busy schedule. My deepest appreciation goes to my co-supervisor Dott. Carla Joana Silva for her encouragement and support. I would also like to recognize and extend my gratitude to Miguel Sá and Paula Rodrigues from CITEVE and Elena Battiston from the University of Padova. The evolution and development of this thesis would not have been possible without their advice, expertise, and dedication.

Integrated Project be@t Textile Bioeconomy, to strengthen the National Bioeconomy, financed by the Environmental Fund through Component 12 Promotion of Sustainable Bioeconomy (Investment TC-C12-i01 Sustainable Bioeconomy No. 02/C12-i01/202), of European funds allocated to Portugal by the Recovery and Resilience Plan (RRP), within the scope of the European Union (EU) Recovery and Resilience Mechanism, framed in the Next Generation EU, for the period 2021 2026.

Statement of Originality

I, Teresa Dianelly Flores Ramirez, hereby declare that the work presented in this dissertation, titled "Exploring the Feasibility and Limitations of Digital Product Passports in the Textile Industry: A Critical Assessment of Current Models", is entirely my own original work. I affirm that it has not been fully or partially submitted previously in any other Italian or foreign university for assessment purposes.

I further confirm that the content of this dissertation is the result of my own intellectual endeavours, and I have appropriately cited all sources used. This work does not infringe upon the intellectual property rights of any third party, and its contents do not constitute plagiarism.

I understand the consequences of submitting work that is not my own and affirm the honesty and integrity of this academic contribution.

Teresa Dianelly Flores Ramirez