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**The Digital Product Passport in the
Fashion and Textile Industry:
Translating ESPR Requirements into a
Product Data Model**

Supervisor:

Prof. Andrea Tuni

Candidate:

Francesca Miele

Abstract

The fashion and textile industry is characterised by long and fragmented supply chains, where information about materials, processes and treatments is spread across many actors and is not always recorded in a consistent way. Because of this, tracing products, assessing environmental impacts and meeting new sustainability requirements is often difficult.

Recent European regulations, in particular the Ecodesign for Sustainable Products Regulation (ESPR), introduce the Digital Product Passport (DPP) to improve product transparency. However, although the regulatory framework is being defined, there is still little clarity on how the required information should actually be organised and managed in practice within the textile sector.

The aim of this thesis is to understand how DPP-related information can be structured in a practical way. Starting from the information categories emerging from the European regulatory context, a conceptual data model was developed using Unified Modelling Language (UML). The model organises product, material, environmental and supply-chain information and analyses data ownership and information flows among the actors involved.

The work was carried out in collaboration with the company Surge, where the proposed structure was implemented on an existing digital platform and tested using three products (T-shirt, jacket and footwear) to verify its applicability.

The results show that implementing the Digital Product Passport is mainly an information-management challenge rather than a purely technological one. Its adoption requires clear data structures, defined responsibilities for providing information and coordination along the supply chain. The thesis therefore translates regulatory transparency requirements into a structured data model and discusses the organisational implications of product-level traceability in the textile sector.

Keywords: Digital Product Passport; Data Model; Supply Chain Traceability

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1. The Environmental and Structural Challenges of the Fashion and Textile Industry

1.1 The Environmental Profile of the Fashion and Textile Industry

The fashion and textile sector is considered one of the most environmentally impactful industries (Bick et al., 2018). According to the Ellen MacArthur Foundation (2017), greenhouse gas emissions from the fashion and textile sector amount to approximately 1.2 billion tonnes of CO₂-equivalent annually, a level reported to be comparable to the combined emissions of international aviation and maritime shipping.

The sector is also highly water-intensive, consuming around 79 billion cubic meters of water per year worldwide, and relies extensively on raw materials, using nearly 98 million tonnes of non-renewable resources annually, primarily for the production of synthetic fibres (Ellen MacArthur Foundation, 2017).

The scale and projected growth of these environmental impacts are illustrated in **Figure 1**.

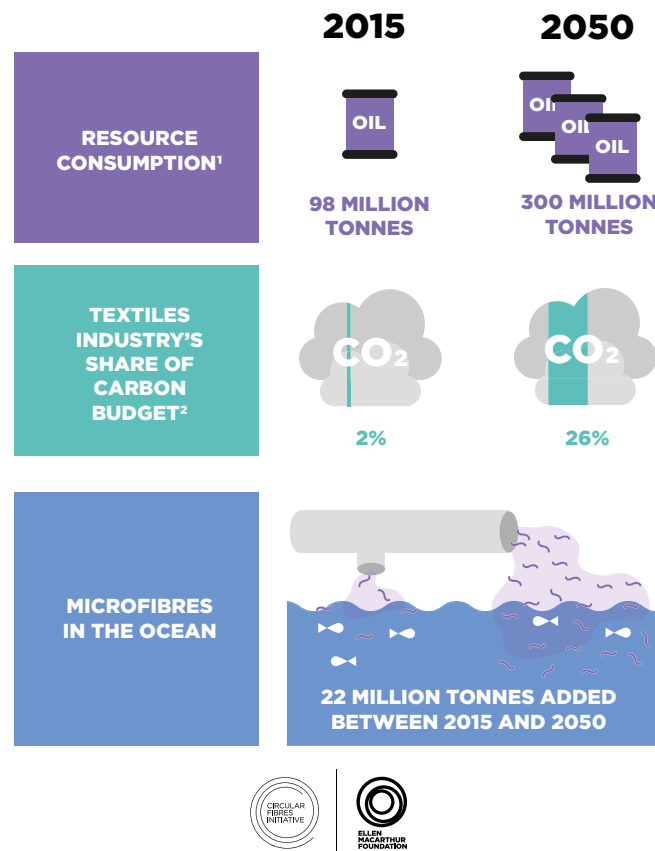


Figure 1. Environmental impacts of the fashion and textile industry and projected growth to 2050. Adapted from Ellen MacArthur Foundation (2017), *A New Textiles Economy: Redesigning fashion's future*.

These impacts are largely driven by rapid production cycles and highly fragmented global supply chains. Ragab et al. (2024) emphasise that key stages such as fabric pretreatment, dyeing and finishing require substantial quantities of water, energy and chemicals, contributing to significant pollution across air, water and soil. Global clothing production has expanded substantially over recent decades. Production volumes have approximately doubled over the past 15 years, reflecting the growing scale of the fashion industry (Ellen MacArthur Foundation, 2017).

Shamsuzzaman et al. (2025) point out that textile waste management remains inefficient, mainly because of limited recycling infrastructure and the technical challenges associated with separating blended fibres. Consequently, a large share of post-consumer textiles still ends up in landfills or incineration, while only a small portion is collected. Most collected garments are either sold in second-hand markets or downcycled into lower-value products rather than used for material recovery (Brooks, 2015; Ellen MacArthur Foundation, 2017). Although reuse can extend the lifetime of garments, it does not prevent the eventual loss of textile materials from the system. Closed-loop recycling is particularly rare: less than 1% of the material used to produce clothing is recycled into new garments (Ellen MacArthur Foundation, 2017). As a result, significant quantities of fibres and raw materials are permanently lost each year.

Taken together, these dynamics demonstrate how difficult it is to monitor environmental pressures within a supply chain that is both global and complex, where information rarely flows seamlessly across all actors involved (Jensen et al., 2023).

1.2 Resource Intensity as a Structural Feature of Textile Production

Textile production is highly dependent on natural resources, with water playing a central role across all production processes. Wet processing is closely linked to high water consumption rates, ranging between 100 and 300 litres per kilogram of fabric (Teixeira et al., 2025).

At the aggregate level, the extent of water use can be even more pronounced. Sustainability analysis of the fast fashion phenomenon has found textile production to be connected to total water use of between 79 billion and 93 billion cubic meters every year, in addition to its contribution to global industrial water pollution (Bailey et al., 2022).

At the regional level, the ecological effects of water-intensive fibre production have also been observed. A frequently cited example is the desiccation of the Aral Sea in Central Asia, where large-scale irrigation for cotton cultivation significantly contributed to the depletion of

water resources and severe ecological degradation (Bailey et al., 2022). This case illustrates how textile raw material production can generate environmental impacts far beyond the production location.

Similar dynamics have been observed in other cotton-producing regions, contributing to lower water availability due to irrigation-intensive agriculture (Bailey et al., 2022).

These patterns indicate that water overdraft in the fashion and textile industry is not a random or isolated occurrence, but rather reflects a structural reliance on water-intensive production models.

1.3 Chemical Dependency and the Challenge of Hidden Inputs

Chemical use is central to textile production. Thousands of substances are employed to give fabrics their colour, texture and functional properties. However, as Maity et al. (2020) point out, information on the risks associated with many chemicals is incomplete, especially for substances used early in the supply chain where regulatory control is often weaker.

Some chemicals may remain in finished textiles, while others enter wastewater streams during dyeing and finishing. (Panhwar et al., 2024) note that several dyes and auxiliaries are persistent in the environment and difficult to treat, increasing the risk of contamination when wastewater is not adequately managed.

This lack of clarity regarding which chemicals are used, and in what quantities, contributes to a broader transparency challenge. Many brands have limited visibility over upstream chemical use, which makes it difficult to assess risks or verify compliance with environmental and safety standards.

1.4 Greenhouse Gas Emissions in the Textile Sector

According to Niinimäki et al. (2020), greenhouse gas emissions associated with textile products arise across multiple stages of the product lifecycle rather than from a single production activity. A substantial share of emissions originates in the early phases of production. Fibre production, textile manufacturing and garment construction together account for roughly two-thirds of the sector's climate impact, reflecting the high energy requirements of these processes. Synthetic fibres such as polyester are particularly carbon-intensive because

they are derived from fossil resources, while natural fibres also generate emissions through agricultural inputs, including fertilisers and irrigation.

However, emissions are not limited to manufacturing activities. Downstream lifecycle stages also contribute to the overall climate impact of clothing. The use phase — including washing, drying and ironing — can account for approximately 14% of the total climate impact of clothing consumption (Niinimäki et al., 2020). Additional emissions arise from transportation across geographically dispersed supply chains and from end-of-life treatments such as landfill and incineration (Niinimäki et al., 2020).

Overall, the climate impact of clothing is not linked to a single actor or production site, but to a chain of interconnected processes involving suppliers, manufacturers, logistics systems and consumers. For this reason, assessing environmental performance in the textile sector requires considering the entire lifecycle of the product. Consequently, Life Cycle Assessment (LCA) is commonly used to evaluate environmental impacts across all stages of a garment's life (Niinimäki et al., 2020).

1.5 Life Cycle Assessment (LCA) as a Framework for Environmental Evaluation

The need to systematically assess resource use and environmental impacts associated with industrial production has led to the development of Life Cycle Assessment (LCA) as a methodological framework for environmental evaluation. LCA is a widely recognised approach used to analyse potential environmental impacts related to products, processes, or services across their life cycle and is commonly applied within sustainability assessments (International Organization for Standardization, 2006a).

The methodological foundations of LCA are defined by internationally recognised standards. In particular, ISO 14040 establishes the principles and framework of LCA, while ISO 14044 specifies the requirements and guidelines for conducting LCA studies (International Organization for Standardization, 2006a, 2006b). According to these standards, an LCA study is structured into four main phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation (International Organization for Standardization, 2006a). This structured approach aims to ensure transparency, consistency, and comparability across different studies.

The primary objective of LCA is to provide a holistic perspective on environmental impacts by accounting for inputs, outputs, and emissions across the various stages of a product's life cycle (International Organization for Standardization, 2006a). A key methodological aspect

concerns the definition of system boundaries, which determines which life cycle stages are included in the assessment (International Organization for Standardization, 2006a). Depending on this choice, LCA studies may differ significantly in scope and results (Muthu, 2014).

Common system boundary approaches include cradle-to-gate and cradle-to-grave assessments (International Organization for Standardization, 2006a). Cradle-to-gate LCA considers environmental impacts from raw material extraction up to the manufacturing stage, ending when the product leaves the production facility, while excluding the use and end-of-life phases (International Organization for Standardization, 2006a). This approach is often adopted when downstream stages are highly variable or difficult to quantify (Muthu, 2014). In contrast, cradle-to-grave LCA encompasses the entire life cycle of a product, including raw material extraction, manufacturing, use, and end-of-life processes such as disposal or recycling (International Organization for Standardization, 2006a). The selection of system boundaries is therefore a critical methodological decision, as it directly influences the interpretation of LCA results (Muthu, 2014).

Within the fashion and textile industry, LCA has been increasingly applied in response to concerns related to high resource consumption, extensive chemical use, and growing volumes of textile waste (Shamsuzzaman et al., 2025). Textile products are characterised by complex and globalised supply chains, involving multiple processing stages across different geographical contexts (Jensen et al., 2023). In this setting, LCA is commonly used to compare alternative fibres, materials, or production processes and to support sustainability assessments and reporting activities (Muthu, 2014).

Despite its relevance, the application of LCA in the textile industry presents several challenges. One of the main limitations relates to data availability and quality, as supply chains are often fragmented and characterised by limited transparency (Koszewska, 2018). As a result, LCA studies frequently rely on secondary data and generalised assumptions, which may not fully reflect specific production conditions, particularly in upstream stages of the supply chain (Muthu, 2014).

Moreover, the inherent complexity of textile products, including fibre blends, diverse processing techniques, and finishing treatments, introduces additional uncertainty into life cycle assessments. The evaluation of end-of-life stages remains particularly challenging, as pathways such as reuse, recycling, and disposal are often simplified or insufficiently represented, despite their increasing relevance in discussions on textile waste management and circular economy strategies (Muthu, 2014; Nayak et al., 2021). Overall, these limitations

suggest that while LCA represents a valuable framework for environmental evaluation in the fashion and textile industry, its effectiveness is closely linked to the availability of reliable data, traceability, and robust information flows across the supply chain. Without structured lifecycle information, environmental impacts cannot be consistently monitored or compared, particularly in globally distributed value chains (Jensen et al., 2023).

1.6 Structural Challenges: Fragmented Supply Chains and the Limits of Traceability

According to (Haseli et al., 2026), fashion supply chains are highly fragmented and involve multiple actors across different countries. This fragmentation makes it difficult to collect and share information consistently, and many companies still rely on separate digital systems or even manual data entry, which prevents the smooth flow of information along the supply chain.

Moreover, some digital traceability tools do not withstand the chemically intensive steps of textile production. Technologies such as RFID tags or printed labels can be damaged or removed during processes like dyeing or washing, interrupting the link between the physical product and its digital record (Teixeira et al., 2025).

These limitations make it challenging for brands to verify claims, monitor environmental and social risks, or provide recyclers with accurate information on materials and treatments. In practice, the lack of a coherent and integrated information system widens the sector's transparency gap (Haseli et al., 2026; Teixeira et al., 2025).

1.7 From a Linear to a Circular Economy in the Textile Sector

1.7.1 From a Linear to a Circular Economic Model

The fashion and textile industry has historically developed within a linear economic model, commonly described as “take–make–dispose”. In this model, raw materials are extracted, transformed into products, consumed, and eventually discarded at the end of their useful life. While this approach has enabled large-scale production and rapid consumption cycles, it has also resulted in significant environmental pressures, including resource depletion, waste generation and pollution. As highlighted in the literature, the linear model is characterised by a systematic loss of material value, as products are rarely designed to be reused, repaired or recycled once they reach the end of their first use phase (Ellen MacArthur Foundation, 2015) (Korhonen et al., 2018)

The concept of circular economy has emerged as an alternative economic paradigm in which resource flows are organised to maintain material and product value within the system for as long as possible (Korhonen et al., 2018). Rather than focusing exclusively on end-of-life waste management, circular economy describes a systemic approach in which products, components and materials are kept in use for as long as possible and at their highest value. This shift implies a rethinking of product design, production processes and lifecycle management, moving away from disposal-oriented practices towards strategies that preserve material and functional value over time.

In this context, value refers not only to the raw material contained in a product, but also to the labour, energy, manufacturing processes and organisational inputs embedded in it (Korhonen et al., 2018). When a product is discarded and recycled, only the material fraction is recovered, while most of the economic and functional value created during production is lost (Korhonen et al., 2018).

Within this perspective, circular economy encompasses a broad range of strategies that go beyond recycling alone. Strategies operating close to the use phase—such as reuse, repair and refurbishment—retain a larger share of the value embedded in the product, whereas recycling preserves only the material content (Ellen MacArthur Foundation, 2015).

Within circular economy frameworks, strategies that maintain products in use are generally considered more effective than those based solely on material recovery (Korhonen et al., 2018).

1.7.2 Core Principles of the Circular Economy

The circular economy is commonly defined through a set of core principles that distinguish it from traditional linear models of production and consumption. A key principle is value retention, which refers to the ability to preserve functional and economic value of products and resources over time. Instead of allowing value to be lost through early disposal, circular economy is characterised by maintaining products, components and materials in use for as long as possible, thereby reducing the need for virgin resource extraction and mitigating environmental impacts.

In order to clarify how this principle can be applied in practice, the literature often refers to a hierarchy of circular strategies. (Potting et al., 2017) propose a framework of ten strategies, commonly known as the “10R framework”, which range from refuse and rethink to recycling and recovery. This hierarchy highlights that not all circular strategies are equally effective.

Actions that remain closer to the use phase of a product—such as reuse, repair and refurbishment—are generally associated with higher levels of value retention than strategies focused on material recovery the end of the product’s life (**Figure 2**).

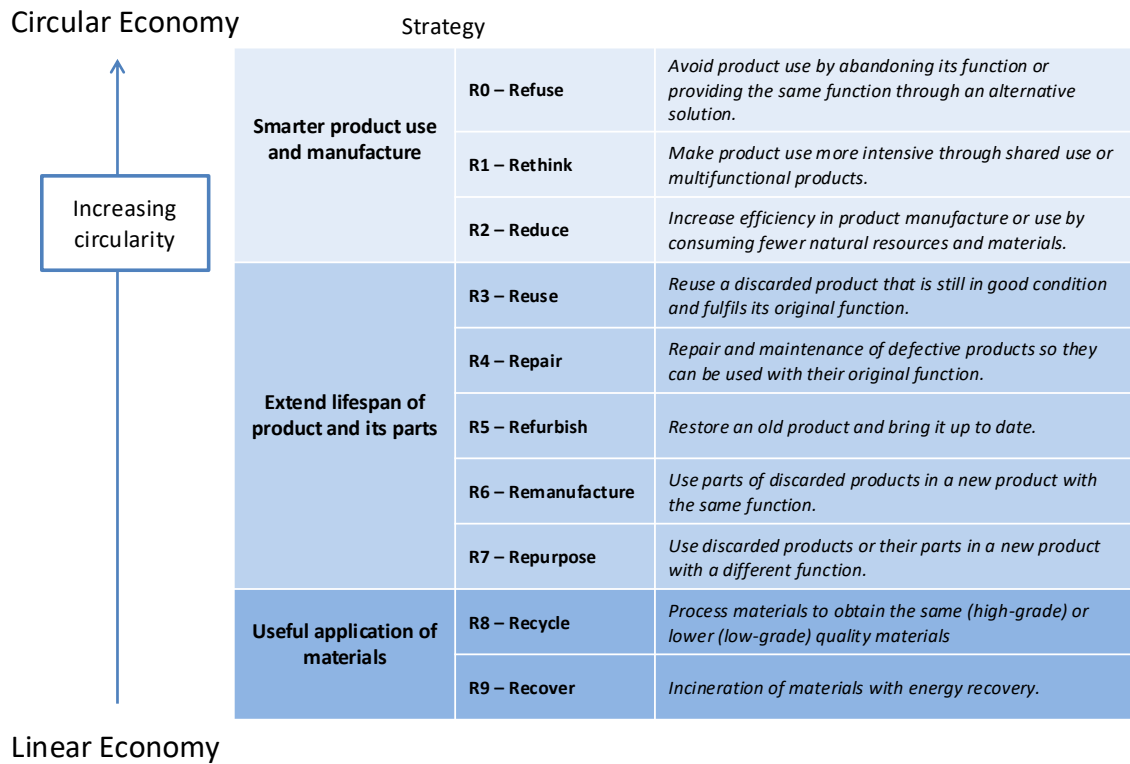


Figure 2. Hierarchy of circular economy strategies within the production chain, ordered according to their capacity to retain material and functional value.
Source: adapted from Potting et al. (2017).

Building on this approach, (Morseletto, 2020) argues that circular economy should not be interpreted as a loose collection of practices, but rather as a goal-oriented system in which strategies are prioritised according to their contribution to clearly defined sustainability objectives. From this perspective, recycling represents only one possible option within a broader set of circular strategies and should not be automatically considered the preferred solution. Greater emphasis is instead placed on strategies that extend product lifespans and limit the need for energy- and resource-intensive reprocessing.

A further principle underlying the circular economy is lifecycle thinking, which requires environmental impacts and resource use to be considered across all stages of a product’s life. This perspective draws attention to the importance of early design decisions, as they strongly influence durability, reparability and the potential for reuse or recycling. Taken together, the

principles of value retention and lifecycle thinking provide the conceptual foundation of circular economy and emphasise the need for systemic approaches rather than isolated interventions limited to specific lifecycle stages.

1.7.3 Challenges of Implementing Circular Economy in the Textile Sector

Sections 1.2–1.5 illustrated the environmental and structural pressures affecting the textile industry; these same characteristics also complicate the practical implementation of circular economy principles. In practice, keeping materials in use over time requires the ability to identify and recover products and their components; however, this proves particularly challenging in the textile sector. These difficulties stem from barriers operating at multiple stages of the product lifecycle.

A first set of constraints arises at the level of the product itself. In the textile sector, one of the main barriers to circularity relates to material complexity (Koszevska, 2018). The wide variety of fibres used—natural, synthetic and regenerated—already complicates environmental assessment processes, but material blends introduce an additional level of difficulty for end-of-life management.

Cotton–polyester blends are particularly common and, as Kahoush & Kadi (2022) highlight, their fibre composition and structural characteristics vary considerably due to limited standardisation in fibre ratios, yarn structures and finishing treatments. Recycling technologies require reliable information on material composition and previous processing in order to function effectively; when blended textiles cannot be clearly identified, recyclers face uncertainty in selecting appropriate processes. As a result, current technologies struggle to separate fibres efficiently and many products are downcycled or discarded. From a circular economy perspective, this lack of material clarity directly limits strategies aimed at maintaining value close to the use phase, such as reuse and fibre-to-fibre recycling, and many garments are not designed to support such strategies at end-of-life (Koszevska, 2018).

A second group of barriers concerns the organisation of the production system. Textile supply chains are global and highly fragmented, involving numerous actors operating across different geographical contexts (Korhonen et al., 2018). The dispersion of production stages reduces visibility over materials, chemical inputs and processing conditions, limiting the availability of reliable information for circular decision-making.

Based on interviews with companies in the Dutch technical and interior textiles industries, Hartley et al. (2022) show that circular economy implementation is not constrained by a single technical issue but by multiple interconnected obstacles arising across production and product-management stages. Their findings indicate that, rather than purely technological limitations, companies face coordination problems, inconsistent information and organisational misalignment among supply-chain actors.

Similarly, Chen et al. (2024), analysing the reprocessing of pre-consumer textile waste in China, identify ten barriers to circular supply-chain implementation and find that, in the short term, social and managerial factors—particularly coordination and organisational practices—are more influential than technical limitations. Even where recycling technologies are available, firms may therefore struggle to implement circular solutions because supply-chain organisation and information exchange do not support circular objectives.

A third set of barriers relates to economic incentives. Circular strategies such as repair, refurbishment and product take-back require additional labour, coordination and reverse-logistics activities, altering firms' cost structures and often demanding new business models (Bocken et al., 2016). In many cases, producing new products remains economically more attractive than extending the life of existing ones, particularly where virgin materials and manufacturing processes are inexpensive (Kirchherr et al., 2018). This dynamic is especially visible in the fashion sector, where the fast-fashion model—based on high volumes, low prices and short product lifetimes—reduces the value retained in individual garments and makes reuse or repair difficult to implement at scale (Niinimäki et al., 2020).

Taken together, material complexity at the product level, fragmented supply chains at the system level and misaligned incentives at the market level limit the practical implementation of circular economy principles in the textile industry. A common element across these barriers is the lack of reliable knowledge about products and material flows throughout the lifecycle. While circular economy principles provide a valuable conceptual framework, their implementation depends on the availability of consistent information and visibility across actors and stages. This explains the growing attention to transparency-oriented approaches, as circular strategies require reliable information on products, materials and processing conditions across the lifecycle. Consequently, enabling circularity in practice requires structured and accessible product information that can accompany a product throughout its lifecycle and be shared among supply-chain actors and information systems.

These challenges highlight the central role of information in enabling circularity in complex supply chains. Adisorn et al. (2021) emphasise that maintaining materials in productive use

through reuse, repair and high-quality recycling requires access to reliable information on product composition and chemical treatments. However, Jensen et al. (2023) and van Capelleveen et al. (2023) show that fragmented supply chains and inconsistent data flows make such transparency difficult to achieve. While digital technologies such as IoT systems, blockchain and digital identifiers are often proposed as solutions, Psarommatis & May (2024) argue that technological tools alone are insufficient without appropriate governance and data-management frameworks.

1.8 The Need for Transparency as a Foundation for Regulatory Innovation

Across the challenges described in Sections 1.2–1.5—resource intensity, chemical dependency, material complexity and supply-chain fragmentation—a common issue emerges: the lack of reliable, consistent and accessible information along the textile supply chain. More broadly, this limitation is closely related to the insufficient standardisation of how information is generated and exchanged. Variations in production processes, as well as in the recording and transfer of data along the supply chain, further hinder material traceability. Information on fibres and treatments is often documented using heterogeneous formats or is not consistently shared among actors, reducing transparency and limiting the usefulness of available data for downstream stages.

In the absence of traceable and verifiable data on materials, processes and inputs, neither companies nor regulators are able to fully assess environmental impacts or effectively support the transition toward circularity. Improving material traceability therefore becomes essential not only for more accurate environmental assessments, but also for enabling recycling systems and circular strategies that depend on consistent and reliable information regarding material composition and processing history.

The growing need for transparency has consequently attracted increasing regulatory attention and encouraged the development of digital tools aimed at improving information flows across the industry. These evolving policy frameworks provide the basis for the Digital Product Passport, which will be discussed in Chapter 3. Within this context, the availability of tools capable of systematically assessing environmental impacts across complex and fragmented supply chains becomes particularly relevant.

1.9 Conclusions: From Environmental Challenges to Transparency Needs

The analysis presented in this chapter shows that environmental challenges in the textile sector are closely linked to information-related limitations, particularly the lack of reliable and shared product data across the supply chain. These issues are associated with fragmented supply chains, limited data availability and uneven information flows across the product lifecycle.

In response to these challenges, new regulatory initiatives have emerged in recent years with the aim of improving transparency, strengthening information requirements and supporting more sustainable and circular practices. Against this background, Chapter 2 examines the European Union regulatory framework developed to address these issues and its implications for the fashion and textile industry.

2. The EU Policy Framework for Sustainable and Transparent Products

The analysis presented in Chapter 1 highlights that many environmental challenges in the fashion and textile sector are closely linked to limited product information and fragmented supply chains. The absence of reliable and shared data on materials, processes and actors makes it difficult to assess environmental impacts, implement circular strategies and verify sustainability claims. These limitations are not easily addressed through voluntary initiatives alone. Instead, they require a coordinated policy framework capable of improving product design, strengthening information flows and promoting more responsible production and consumption models (European Commission, 2020; European Commission, 2022b).

In the past few years, the European Union has introduced an ambitious set of initiatives to support this transition. The European Green Deal offers the strategic foundation for transforming the EU economy, while the Circular Economy Action Plan (CEAP), the Sustainable Product Initiative (SPI) and the Ecodesign for Sustainable Products Regulation (ESPR) translate this vision into concrete regulatory measures. Together, these initiatives mark a shift from voluntary sustainability practices towards a more structured, data-driven model in which products must meet specific environmental and transparency requirements (European Commission, 2022c).

A cross-cutting theme within these policies is the need for reliable information. Circularity, due diligence and market enforcement all depend on accurate and accessible data on materials, chemicals, production processes and the actors involved along the supply chain. This logic has led to the development of the Digital Product Passport (DPP), which aims to provide structured and interoperable product information throughout the lifecycle (European Commission, 2022c).

This chapter examines how the EU policy landscape has evolved to support this shift. It starts by analysing the European Green Deal and the CEAP, integrates academic perspectives on the circular transition, and then explores the SPI and the ESPR as the regulatory core of the new product governance model. It also considers how due diligence requirements complement these frameworks and how the Battery Passport offers the first real example of digital traceability in practice.

2.1 The European Green Deal: A New Framework for Sustainable Transformation

Launched in 2019, the European Green Deal sets out the EU's vision of becoming the first climate-neutral continent by 2050 (European Commission, 2019). It does not function as a single legislative act; rather, it provides a broad roadmap that redefines climate policy, industrial strategy, biodiversity protection, and resource (European Commission, 2019).

A key idea of the Green Deal is that Europe must shift from a linear economic model based on extraction and disposal towards a circular approach that keeps materials in use for as long as possible (European Commission, 2019). Policymakers emphasise that many environmental impacts originate in the design phase of products. Improving durability, reparability and recyclability therefore becomes essential for reducing impacts upstream, rather than relying solely on waste-management solutions at the end of a product's life (European Commission, 2020).

Digitalisation also plays a central role. The Green Deal recognises that limited visibility across supply chains—especially in high-impact sectors such as textiles—prevents regulators, businesses and consumers from assessing sustainability claims and making informed choices (European Commission, 2019; European Commission, 2020). Greater traceability and access to reliable information are seen as prerequisites for effective environmental governance (European Commission, 2019; European Commission, 2020).

The Green Deal provides the political basis for subsequent initiatives, including the Circular Economy Action Plan, the Sustainable Product Initiative and the ESPR. For textiles, it sets clear expectations: products should last longer, contain fewer hazardous substances, shed fewer microplastics, and be supported by traceability systems that enable circularity (European Commission, 2022a). These principles directly anticipate the development of the Digital Product Passport.

2.2 The Circular Economy Action Plan (CEAP): Shifting Product and Consumption Models

Adopted in 2020, the CEAP operationalises the vision of the Green Deal by placing sustainability and circularity at the core of EU product policy. The CEAP identifies product design as a determining factor of environmental impact and shifts attention from end-of-life solutions to upstream interventions (European Commission, 2020).

Instead of focusing solely on improving recycling rates, the CEAP emphasises the importance of designing products that are durable, repairable, upgradable and recyclable from

the start (European Commission, 2020). Its objective is to prevent waste generation and maximise material value throughout the entire lifecycle (European Commission, 2020).

The textile sector is identified as a priority for the CEAP due to its rapid growth, the prevalence of mixed fibres, low recycling rates and high environmental footprint (European Commission, 2020). The CEAP therefore paved the way for the EU Strategy for Sustainable and Circular Textiles, which calls for longer-lasting products, reduced reliance on fossil-based fibres, better recycling technologies and clearer information for consumers and producers (European Commission, 2020).

The CEAP also recognises that the lack of reliable product information undermines circularity (European Commission, 2020). If actors across the supply chain do not have access to accurate data on material composition, chemical treatments and environmental performance, it becomes very difficult to verify claims or ensure efficient reuse and recycling (European Commission, 2020). To address this, the CEAP explicitly highlights the need for digital solutions—laying the foundation for the Digital Product Passport (European Commission, 2022c).

2.3 The EU Strategy for Sustainable and Circular Textiles

Following the Circular Economy Action Plan, the European Commission addressed the textile sector more directly through the adoption of the EU Strategy for Sustainable and Circular Textiles in 2022 (European Commission, 2022b). While the previous initiatives introduced general principles for sustainable products, this strategy focuses specifically on fashion and textile value chains.

The document recognises that the sector presents structural challenges that make the transition to circular models particularly complex. These include global and fragmented supply chains, the widespread use of blended materials and limited visibility over production processes (European Commission, 2022b). For this reason, the strategy does not concentrate only on waste reduction, but considers the entire lifecycle of textile products, from design to end-of-life management (European Commission, 2022b).

The strategy does not rely on a single regulatory measure, but proposes a combination of coordinated actions addressing different aspects of the sector. These include requirements on product design and durability, measures against the destruction of unsold textiles, initiatives to reduce microplastic release, extended producer responsibility schemes and actions aimed at

improving consumer information and transparency (European Commission, 2022b). Within this broader policy framework, information availability is identified as a key enabling condition for circularity across the value chain.

The strategy identifies a set of key intervention areas for the textile sector, covering product design, consumption patterns, waste management and information transparency. Within this framework, digital information tools are presented as necessary to enable circular practices and market surveillance. In particular, the strategy explicitly foresees the introduction of a Digital Product Passport for textile products as a mechanism to improve traceability, provide reliable product information and support reuse, repair and recycling activities across the value chain (European Commission, 2022b).

A key aspect of the strategy therefore concerns the role of information within the textile value chain. The European Commission highlights that several circular practices, including reuse, repair and fibre-to-fibre recycling, are currently difficult to implement because relevant product information is often missing or fragmented across the supply chain (European Commission, 2022b). In many cases, actors do not have reliable knowledge of material composition, chemical treatments or processing history, which limits both the verification of sustainability claims and the management of products at the end of their life (European Commission, 2022b).

For this reason, the strategy anticipates the introduction of the Digital Product Passport for textile products, which is later formally established in the Ecodesign for Sustainable Products Regulation (European Commission, 2022b). The passport is conceived as a digital set of information accompanying the product and containing structured data on materials, environmental characteristics, care instructions and end-of-life handling (European Commission, 2022c). Within this perspective, the Digital Product Passport is intended not only as a regulatory requirement, but as a tool to support circular practices, improve transparency and enable more informed decisions by both companies and consumers (European Commission, 2022b).

The measures outlined in the strategy are later translated into product policy through the Sustainable Product Initiative and subsequently implemented through the Ecodesign for Sustainable Products Regulation, which provides the legal basis for introducing Digital Product Passports in specific product groups, including textiles (European Commission, 2022c).

2.4 The Sustainable Product Initiative (SPI): Rethinking Product Policy

The Sustainable Product Initiative was introduced to redefine the EU’s approach to product sustainability. Building on the CEAP, the SPI acknowledges that the previous Ecodesign Directive—focused mainly on energy-related products—was no longer adequate for addressing broader environmental challenges (European Commission, 2022d).

The SPI proposes a flexible and comprehensive framework aimed at making sustainable products the default option in the EU market. It introduces potential requirements related to durability, reparability, recyclability, recycled content and the restriction of harmful substances (European Commission, 2022d).

A central element of the SPI is its focus on information governance. Policymakers identify the lack of reliable data on materials, chemicals and manufacturing processes as a major barrier to circularity and regulatory enforcement (European Commission, 2022d). The SPI therefore calls for harmonised data structures and interoperable systems capable of sharing product information across the entire supply chain (European Commission, 2022d).

This initiative directly paves the way for the Ecodesign for Sustainable Products Regulation, which transforms these principles into binding requirements and formally introduces the Digital Product Passport (European Commission, 2022d).

2.5 The Ecodesign for Sustainable Products Regulation (ESPR): The Core Legal Architecture

Adopted in 2024, the ESPR establishes the legal framework for setting sustainability requirements for almost all physical goods placed on the EU market, including textiles. It expands the scope of the previous Ecodesign Directive and extends regulatory attention across the entire product lifecycle.

2.5.1 Scope and Structure

The ESPR empowers the European Commission to adopt delegated acts specifying detailed requirements for specific product groups. Textiles are expected to be among the first groups regulated due to their environmental significance (European Commission, 2022c). The regulation applies to manufacturers, importers, distributors and online platforms, ensuring that sustainability and information requirements are respected throughout the market.

2.5.2 Sustainability Requirements

The ESPR includes potential requirements covering:

- product durability and reliability,
- reparability and upgradability,
- recyclability and remanufacturability,
- minimum levels of recycled content,
- restrictions on hazardous substances,
- improved resource and energy performance.

For textiles, these obligations address many of the structural challenges described in Chapter 1, including fibre blends, chemical treatments and short product lifespans.

2.5.3 Information Requirements and the Digital Product Passport

One of the most innovative elements of the ESPR is the introduction of the Digital Product Passport. The DPP is expected to provide structured, digital information on (European Commission, 2022c):

- material composition,
- chemical substances,
- environmental performance,
- repair and disassembly instructions,
- recycled content,
- supply-chain traceability.

The DPP must be interoperable, updatable and linked to a unique product identifier (European Commission, 2022c). Its purpose is to support circularity, market enforcement and the verification of sustainability claims (European Commission, 2022c).

2.5.4 Governance and Enforcement

The ESPR also introduces a governance and enforcement framework designed to ensure that sustainability and information requirements are effectively implemented. This framework involves several actors (European Commission, 2022c): European standardisation bodies, which are responsible for developing the technical specifications needed to operationalise the regulation; national market-surveillance authorities, which oversee compliance through

inspections and digital checks; and the digital infrastructure that supports the management, exchange and verification of DPP data.

Enforcement mechanisms include both physical and digital controls, allowing authorities to verify whether products placed on the market meet the requirements set out in the delegated acts. In cases of non-compliance, the regulation foresees corrective measures and penalties. This governance structure is essential for ensuring that the DPP becomes a reliable and trustworthy instrument rather than a voluntary or loosely monitored tool.

2.5.5 Importance for the Textile Sector

For the textile sector, the ESPR represents a significant shift in how products must be designed, documented and placed on the EU market. The regulation directly addresses long-standing challenges such as limited material transparency, complex fibre blends and the lack of reliable information on chemical treatments.

Most importantly, it creates the legal and technical foundation for the introduction of a Digital Product Passport for textiles. The DPP has the potential to fill critical information gaps and support circularity across the value chain. These implications will be explored in detail in Chapter 3.

2.6 Due Diligence and Corporate Accountability in EU Supply Chains

The EU's sustainability transition also depends on responsible supply-chain management. The Corporate Sustainability Due Diligence Directive (CSDDD), adopted in 2024, requires companies to identify, prevent and mitigate environmental and human-rights risks across their value chains (European Parliament and Council of the European Union, 2024).

For the textile sector—characterised by long, global and opaque supply chains—due diligence plays a crucial role. Companies must map suppliers, assess risks linked to working conditions and chemical management, and implement corrective measures when necessary.

Due diligence and the ESPR are complementary:

- the ESPR provides structured product information through the DPP.
- the CSDDD ensures that companies take responsibility for actual conditions within their supply chains.

Together, they promote a more transparent and accountable textile industry.

2.7 The Battery Passport as a Precedent for Product-Level Digitalisation

The Battery Passport, introduced under the EU Battery Regulation (2023), represents the first concrete implementation of a digital product passport within the European legislative framework (European Parliament and Council of the European Union, 2023). Batteries placed on the EU market must now be accompanied by a digital record containing information on composition, carbon footprint, supply-chain due diligence, recycled content and repairability (European Parliament and Council of the European Union, 2023). This provides a practical demonstration of how digital tools can be used to support transparency, ensure regulatory compliance and enable circularity across the product lifecycle.

This experience is extremely valuable for understanding the potential of Digital Product Passports in other sectors, including textiles. The battery passport reveals both the opportunities, and the challenges associated with product-level data governance: successful implementation requires robust data standardisation, interoperable technological infrastructures, and clear access-control mechanisms to guarantee the reliability and security of information shared across complex supply chains (European Parliament and Council of the European Union, 2023).

To illustrate how the Battery Passport organises these heterogeneous data points into a structured framework, **Figure 3** presents the data categories defined by the Battery Pass Consortium.

The visual layout highlights seven content clusters—ranging from general product information to materials, carbon footprint, durability, circularity and due diligence—demonstrating how a single digital passport can accommodate regulatory, environmental and technical requirements.

This example is particularly relevant for the textile sector, as many of these categories map directly onto the information gaps identified in earlier chapters. The Battery Passport therefore provides an important reference point for envisioning how a future Textile Digital Product Passport could be designed and implemented.

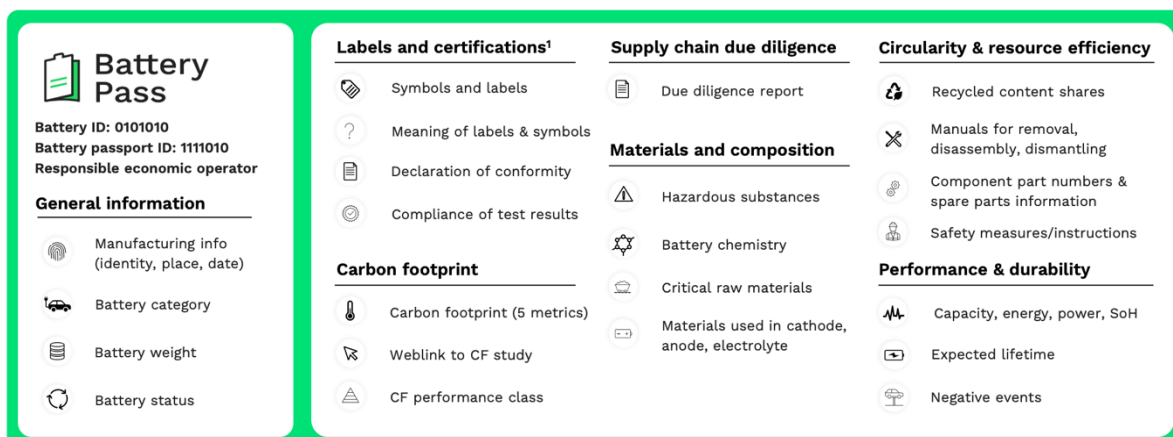


Figure 3. Data categories of the Battery Passport, adapted from Battery Pass Content Guidance – Executive Summary (2025).

2.8 Conclusions: Towards Product Transparency and Digital Traceability

The evolution of EU policy—spanning the Green Deal, the CEAP, the SPI and the ESPR—shows a clear transition toward more transparent, circular and information-driven product governance. These initiatives collectively move the EU away from fragmented policy approaches and toward a lifecycle-based regulatory model.

The Digital Product Passport emerges as a central instrument in this framework. While the ESPR entered into force in 2024, the delegated acts specifying the Digital Product Passport requirements for specific product groups are still under development, with implementation expected to progress in the coming years.

By providing reliable data on materials, chemicals, environmental impacts and supply-chain processes, it enables circularity, strengthens market enforcement and supports more informed decision-making by consumers and businesses.

This regulatory landscape sets the stage for Chapter 3, which will analyse the Digital Product Passport in detail and explore its implications for the textile and fashion industry.

3. The Digital Product Passport in the Fashion and Textile Sector

The fashion and textile sector has entered a period in which transparency and access to reliable information have become increasingly important. As discussed in Chapters 1 and 2, many sustainability issues in the industry are linked to the lack of clear and consistent data about supply chains, production processes and material choices. Because textile value chains are long, fragmented and often global, companies frequently struggle to trace the origin of fibres, understand the environmental impact of production stages or verify the claims made by suppliers. These gaps make it difficult not only to assess the real footprint of a product but also to comply with the growing number of regulations that require detailed, product-level information.

The Digital Product Passport (DPP) has been introduced as a possible response to these challenges. Rather than being a simple collection of product information, it is defined as a system that enables product-related data to be generated, shared and accessed by different stakeholders throughout the product lifecycle (King et al., 2023). In this context, the passport does not correspond to a single database or label, but to a structured information framework connecting actors across the value chain and supporting circular economy practices.

Building on this definition, the DPP can be described as the creation of a digital space that gathers key information about a product and makes it available during its entire lifecycle. The passport remains persistently linked to the product through a unique product identifier, allowing stakeholders to retrieve relevant information whenever needed.

Instead of treating sustainability information as something separate or optional, the DPP ensures continuous access to product-related data throughout the lifecycle, including information on materials, processes, use and end-of-life options (Jensen et al., 2023).

For the fashion sector, this approach is particularly relevant. Many environmental and social impacts occur in the upstream supply chain, yet the related information is often unavailable to brands or downstream actors (CIRPASS-2 Consortium, 2025). Therefore, a structured and verifiable digital passport could help close these gaps and support more informed decision-making. It may also enable circular practices—such as repair, reuse or recycling—which rely on accurate and reliable information about the product’s characteristics (CIRPASS-2 Consortium, 2025). In this sense, the DPP has the potential to become an important tool for improving accountability and supporting the sector’s transition towards more sustainable models.

3.1 Understanding the Digital Product Passport

Even though the DPP is closely associated with EU regulations, many authors describe it as broader than a mere compliance tool. It is often presented as a digital file that accompanies the product and gathers information from different actors over time, rather than a static document that remains unchanged (Zhang & Seuring, 2024). This dynamic nature is one of the key elements that distinguish the DPP from traditional labels or certificates.

Most definitions found in the literature highlight a few essential components. The first is a unique digital identity, which allows a specific item to be recognised and linked to its own information set (Psarommatis & May, 2024). This identity is crucial because it enables item-level traceability, something particularly valuable in fashion, where products differ widely among collections in materials and finishing processes.

A second component is the data structure. Authors generally agree that the passport should include information on materials, production steps, chemical treatments, environmental performance, durability, maintenance and potential end-of-life options (Jensen et al., 2023). Although the exact content will vary by product category, the idea is to create a consistent, comparable set of information that can be used by manufacturers, authorities, consumers, and recyclers (CIRPASS-2 Consortium, 2025).

Several studies also point out that the DPP should be understood as part of a larger information ecosystem involving digital platforms, shared standards and organisational processes that support data exchange (King et al., 2023). In this perspective, the passport is only one element of a broader socio-technical system, and its effectiveness depends on how well the different actors involved can collaborate and share information.

Another key aspect is interoperability. Fashion supply chains span multiple countries and involve suppliers with very different digital capabilities. For this reason, the DPP needs to rely on common taxonomies, data models and communication rules that allow information generated in one part of the chain to be accessed and interpreted by others (Koppelaar et al., 2023). Without this shared framework, the passport would risk becoming fragmented or difficult to use.

Overall, the DPP can be described as a technical and organisational framework designed to improve transparency, traceability and circularity in product value chains. For the fashion sector, where information is often scattered or unavailable, this represents a significant opportunity to address long-standing challenges and support the transition to more sustainable practices.

3.2 Information Requirements for Fashion and Textile Products

The usefulness of the Digital Product Passport depends largely on the type and quality of information it contains. For the textile sector, this aspect is particularly important because many sustainability impacts are linked to early production stages that are usually less visible to brands and consumers. (Stridsland et al., 2023)int out that inconsistent or incomplete data are among the main barriers to sustainability assessments in fashion (Stridsland et al., 2023). The DPP aims to provide a more structured and comprehensive approach.

A first group of information relates to material composition. This includes the types of fibres used, their proportion in the final fabric, any blends, additives or finishes, and relevant certifications. Material information is essential to evaluate environmental impacts and to determine whether a product can be reused or recycled effectively (Carvalho et al., 2025).

A second group concerns manufacturing processes. Textile production involves multiple steps—such as spinning, weaving, dyeing, finishing and garment assembly—that often take place in different countries. The DPP can help document energy and water use, chemical treatments and emissions across these stages (Alves et al., 2023). Having access to this information is valuable for both internal decision-making and meeting external reporting requirements.

Third is product performance, especially durability and repairability. These aspects are increasingly relevant as circular business models grow and documenting them within the passport can support consumers and service providers who want to extend the product’s lifespan (Walden et al., 2021).

Environmental indicators represent a fourth component. Although Life Cycle Assessment (LCA) is commonly used to estimate impacts, the results are not always linked to specific products. Integrating LCA-based information into the passport can help improve the credibility and comparability of sustainability claims (Riedelsheimer et al., 2020).

Finally, the DPP includes information related to end-of-life options, such as recyclability, disassembly instructions or material recovery pathways. For textiles—where blended fibres and chemical finishes often create barriers to recycling—this information is crucial (Zhang & Seuring, 2024).

Taken together, these information categories reflect a lifecycle approach. The goal is to provide a complete and accessible picture of the product that supports transparency and circularity across the value chain.

3.3 Physical Carriers of the Digital Product Passport

In the textile and fashion sector, the choice of the physical data carrier plays a central role in determining how the Digital Product Passport can be accessed and used throughout the product's life. Although the idea of linking a garment to a digital identity may seem straightforward, the literature shows that different technologies behave very differently when applied to textiles, especially because garments are washed, stretched, folded, ironed and handled much more intensively than products in other industries.

In addition, generating product-level information across textile supply chains can be challenging. Different stages of production often use different units of measurement (e.g. fibres in kilograms, fabrics in meters, garments in pieces), and technological coefficients such as material losses during cutting processes may complicate the attribution of upstream material quantities to individual garments.

According to recent studies, the three most discussed carriers for garments are QR codes, RFID tags, and NFC tags, each offering specific advantages and limitations depending on how they interact with textile materials.

QR codes are generally considered the most accessible solution. They can be printed directly on care labels or attached as small tags, and they are easy for consumers to scan using a smartphone. As shown in the study by (Domskienė & Gaidule, 2024), interviews with garment producers in the Baltic Sea region highlight that many manufacturers already use QR codes for internal documentation or customer communication, mainly because they are inexpensive and quick to implement (2024). However, their durability may be limited. As also observed by (Domskienė & Gaidule, 2024), printed codes can fade with washing or friction, and scanning requires line-of-sight and appropriate lighting. For this reason, several interviewees noted that QR codes may be a practical starting point for the first implementation stage of the DPP but may not be sufficient for long-term traceability.

RFID tags are already widely used in the fashion industry for inventory management and logistics. As noted by (Nayak et al., 2015), RFID technology allows faster and more accurate identification than barcodes and does not require direct line-of-sight, which makes it suitable for bulk reading during distribution or sorting processes. The same study also points out that RFID has been successfully adopted by several brands and retailers, showing its practical viability. At the same time, RFID integration into garments presents technical challenges: tags must resist heat, detergents and mechanical stress, and their performance can be affected by certain fibres or garment structures (Nayak et al., 2015). In addition, RFID systems are

generally not easily accessible to final consumers via smartphones, as reading RFID tags typically requires dedicated readers rather than standard mobile devices (Nayak et al., 2015). These aspects make RFID effective but more demanding in terms of design and production, particularly for products that undergo frequent washing.

NFC tags share some characteristics with RFID but offer additional functions, such as two-way communication and the possibility of storing small amounts of data that can be updated when needed (Domskienė & Gaidule, 2024). The interview study by (Domskienė & Gaidule, 2024) shows that NFC is particularly appreciated for its ease of use, especially on the consumer side, since most smartphones can read NFC tags intuitively without requiring alignment or scanning conditions. NFC can also be integrated as sew-in or heat-resistant components, although at a higher cost. For this reason, it can be inferred that NFC may be more suitable for higher-value items or for brands interested in offering interactive services, such as authentication or repair information.

Beyond the technical behaviour of each carrier, (CIRPASS-2 Consortium, 2025) emphasises that the choice also depends on the required granularity of the DPP. If the passport needs to operate at item level, which is considered essential for enabling circularity and lifecycle tracking, technologies like RFID or NFC may offer more reliable long-term performance than printed solutions, especially in industrial sorting and recycling environments. However, many companies interviewed in the study by (Domskienė & Gaidule, 2024) expressed concerns about costs and integration complexity, suggesting that a mixed approach could emerge in the early stages of implementation.

Overall, the literature suggests that there is no single “best” data carrier for all fashion products. QR codes offer an easy and low-cost entry point, while RFID and NFC provide better durability and support more advanced applications, such as item-level traceability and interaction across multiple lifecycle stages. In practice, the choice will depend on factors such as the product category, expected lifespan, price point, and the specific circular strategies the company intends to support. What is clear, however, is that the data carrier is not just a technical detail: it fundamentally shapes how the Digital Product Passport can function in real conditions within the fashion value chain.

3.4 Technical Architecture and Functional Logic of the DPP

Beyond its content, the Digital Product Passport relies on a technical architecture that defines how information is created, stored and shared. Several authors agree that the passport

should not be based on a single centralised database but should instead rely on a distributed model where different actors keep control over their own data while contributing to a shared system (Koppelaar et al., 2023).

This approach requires:

- Distributed data storage, where information remains close to its source and can be updated when needed.
- Shared data models and formats, to ensure that information generated by different organisations can be interpreted consistently (Jensen et al., 2023).
- Clear governance rules, which define who can upload, modify or access each type of data (King et al., 2023).
- Interoperable infrastructures, which allow data to be transferred across platforms and systems.

The DPP is also characterised by a lifecycle-oriented logic. Information can be added not only during production but also during use, repair and end-of-life processes (Zhang & Seuring, 2024). This dynamic structure differentiates the DPP from traditional product documentation, which tends to be static and disconnected from later stages of the product's life.

For the fashion sector, adopting this architecture may require significant changes in how companies collect and manage data. However, it also offers an opportunity to build a more reliable information system capable of supporting sustainability goals and circular innovation.

3.4.1 Granularity Options for Textile Product Passports

A key aspect in understanding the functioning of the Digital Product Passport is how the product is identified within the system. In this regard, the CIRPASS-2 Consortium (2025) proposes a structured distinction between granularity levels within the Digital Product Passport framework. Granularity refers to the level at which digital information is associated with a physical product across its lifecycle and directly influences how effectively the passport can support traceability and circular practices (CIRPASS-2 Consortium, 2025).

Based on this framework, three levels of product identification can be distinguished:

- **Model-level:** one passport for all items of the same model.
- **Batch-level:** one passport for items produced in the same batch.

- **Item-level:** one passport for each individual product.

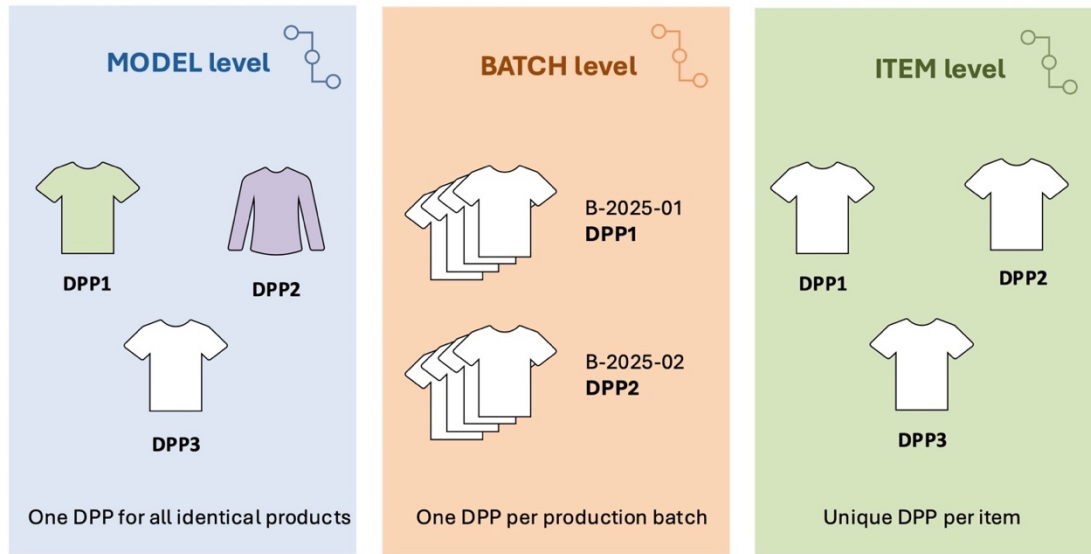


Figure 4. Levels of granularity for Digital Product Passports: model-level, batch-level and item-level.

Model-level identification is easier to implement because it links information primarily to product design specifications rather than to individual objects in circulation. In the textile sector, however, garments that originate from the same model may diverge considerably after sale due to wear, washing cycles, repairs, alterations, or contamination. Circular activities such as sorting, reuse, and recycling operate on the specific returned item, not on the product category. Consequently, aggregated information provides only general characteristics, as it remains linked to the original product specifications rather than to the condition of the individual item once it is in use, and therefore cannot reliably support operational decisions such as assessing suitability for reuse or selecting an appropriate recycling process (CIRPASS-2 Consortium, 2025).

Batch-level identification can improve traceability in logistics and manufacturing control, but its effectiveness for downstream circular practices remains limited. The definition of a “batch” varies across suppliers and production stages, which makes the information difficult to interpret consistently along the supply chain and does not fully resolve the problem of identifying individual returned products (CIRPASS-2 Consortium, 2025).

For these reasons, item-level granularity is identified as providing the highest value for lifecycle management and circularity, particularly in sectors such as fashion where variations between garments can be significant (CIRPASS-2 Consortium, 2025). By linking data to the

individual product, the Digital Product Passport can accompany the item across ownership changes and use phases, enabling services such as repair, resale, authentication and more accurate sorting and recycling processes.

However, the transition to item-level identification may require new processes for serialisation, inventory management and data capture. These challenges are relevant for brands, but particularly for small and medium-sized enterprises in the upstream supply chain (CIRPASS-2 Consortium, 2025).

4. Methodology

4.1 Overview of the methodological framework

This chapter describes the approach adopted to explore the development of a potential Digital Product Passport (DPP) for the fashion and textile sector. The work was carried out in collaboration with Surge and is based on the European regulatory framework available. Since the Digital Product Passport has not yet become mandatory and many of its technical and operational requirements are still under definition, as discussed in Chapter 2, as the delegated acts specifying the DPP framework are still under development following the entry into force of the ESPR in 2024, the process follows an exploratory approach that accounts for regulatory uncertainty and practical constraints related to data availability in the sector.

The main objective is to understand how the information associated with a Digital Product Passport can be structured into a coherent data model. Starting from the information categories identified in existing European policy documents and reference studies, the work focuses on organising the available information and defining how different information domains can be connected within a single structure. The aim is not to propose a definitive or standardised version of a Digital Product Passport, but to develop a framework that supports the structured organisation of product-related information at a conceptual level, given the early state of the regulatory framework.

The process is structured as a sequence of interconnected phases, each associated with a specific intermediate output that supports the subsequent step. An initial phase is dedicated to the definition of DPP information requirements, which provides a structured overview of the main categories of information relevant for product transparency and traceability. These information requirements form the basis for the design of a conceptual data model, developed using (Object Management Group, 2017). UML is used as a modelling tool to organise entities and relationships and to translate high-level information requirements into a structured representation (Object Management Group, 2017). At this stage, UML is used to organise the available information without defining a final technical specification.

Based on the conceptual data model, further steps address the identification of data validation principles and the analysis of data ownership and data flows along the textile supply chain. These activities intend to reflect the distributed nature of data availability in the sector and to clarify how responsibilities for different types of information may be allocated across supply chain actors.

As part of this workflow, the proposed approach is tested by applying it to three selected product types: a T-shirt, a jacket, and a pair of shoes.

These products were selected because they represent increasing levels of production and supply chain complexity, characterised by a growing number of components, materials, and manufacturing steps. Their selection supports the methodological objective of observing how information requirements and data ownership considerations may vary across different product configurations, rather than of presenting exhaustive case studies.

As part of this process, a visual representation of the supply chain was developed to illustrate production stages, material flows, and the distribution of data ownership across supply chain actors. This visual tool was created within the scope of this work to support the analysis of data responsibilities and is used to facilitate the interpretation of the data model during the testing phase.

Following the conceptual design phase, the data model was implemented on the Surge platform as part of the collaboration. This implementation phase involved entering potential DPP-related data and testing the proposed data structure using the three selected product examples, with the aim of supporting a subsequent assessment of applicability and internal consistency. As part of this phase, a QR code and a dedicated landing page were created to enable digital access to the Digital Product Passport information and to support the testing of the model in a digital environment.

Figure 5 provides an overview of the methodological workflow and illustrates the logical sequence of the different phases, together with their associated intermediate outputs. The figure serves as a reference framework for the structure of this chapter, while the specific outputs produced at each stage are addressed separately in the results section.

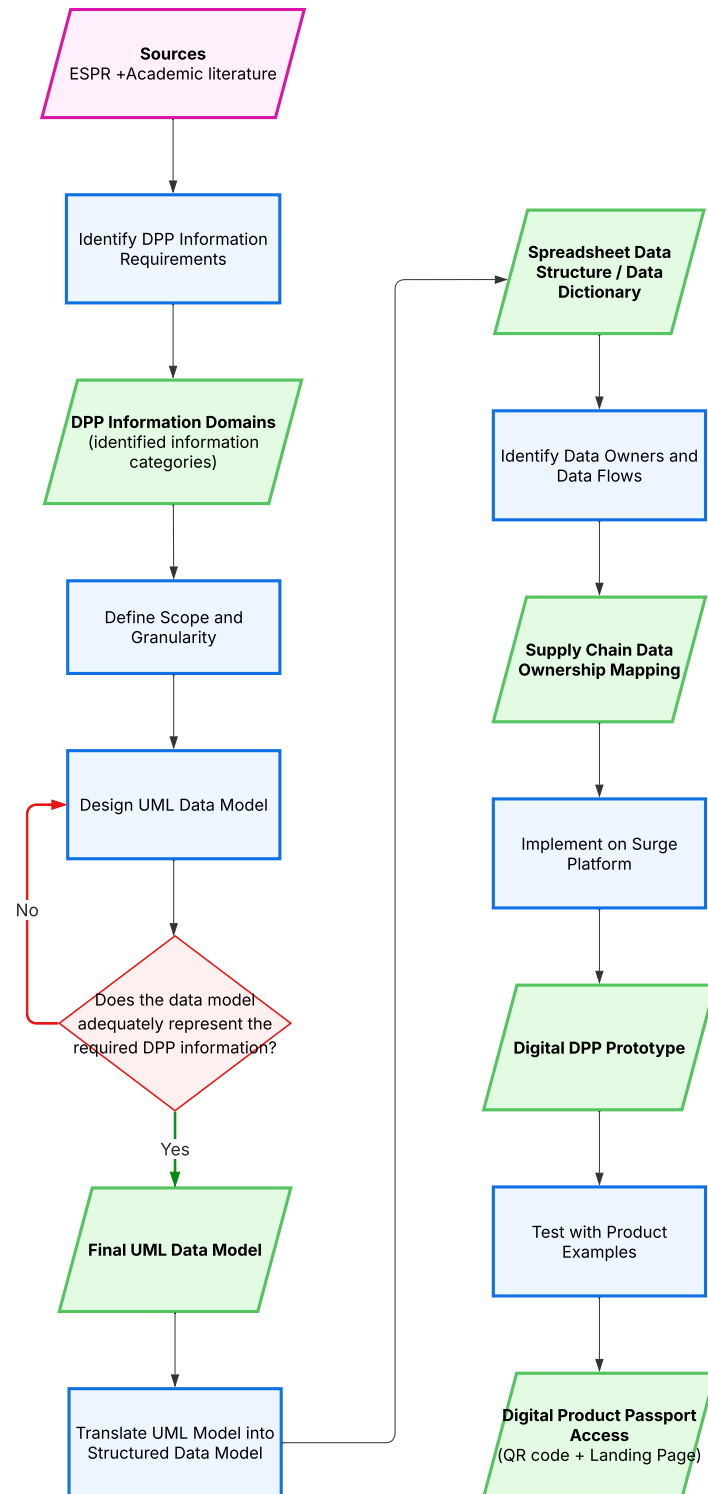


Figure 5. Overview of the methodological workflow adopted in this study.

4.2 Definition of DPP information requirements

The definition of information requirements represents the first step preceding the design of the conceptual data model. Before developing the UML structure, it was necessary to identify which types of information could be considered relevant for a Digital Product Passport (DPP), taking into account the current regulatory context and the objectives related to transparency and traceability.

This step was informed by the study “Digital Product Passport for the Textile Sector” published by the European Parliamentary Research Service (EPRS) in 2024. The document was used as a reference to understand the range of information categories discussed at the European policy level, rather than as a fixed or prescriptive specification. Given the evolving nature of the regulatory framework, the study supported an exploratory identification of information relevant to the development of a Digital Product Passport for textile products.

Based on this reference, different types of product-related information were analysed in relation to the main stages of the product lifecycle. The identified information was then organised into broader groups in order to reduce fragmentation and to support a clearer structuring of the data to be modelled.

As a result, the information requirements were grouped into a set of macro-level domains that define the scope of the information considered in this study. The identified domains are the following:

- product identification and general product information.
- material composition and components.
- manufacturing and transformation processes.
- supply chain and logistics information.
- environmental and sustainability-related aspects.
- end-of-life and disposal-related information.

The selection of these domains reflects the directions emerging from the European regulatory framework, while maintaining flexibility in light of its ongoing development. Attention was also paid to how information is distributed among different actors along the textile value chain, in order to reflect the fragmented nature of data availability in the sector.

This step resulted in the definition of the information domains that guide the subsequent design of the conceptual data model.

4.3 Design of the Digital Product Passport Data Model

4.3.1 Data modelling procedure

Once the information requirements were defined, the next phase of the methodological workflow focused on translating them into a UML data model. This phase involved identifying the main classes corresponding to the previously defined information domains and progressively refining them by defining their associated attributes.

The modelling process followed an incremental approach. Initial macro-level classes were defined to represent the core elements of the Digital Product Passport. These classes were subsequently detailed by specifying the required fields for each class, based on the information requirements identified in the previous phase.

UML diagrams were used as a working tool to structure classes, attributes, and relationships, and to support internal consistency during model development.

4.3.2 Criteria for structuring the conceptual data model

The structuring of the conceptual data model started from the information requirements emerging from the European regulatory context. In particular, the macro-level information categories suggested within the ESPR framework were used as a reference to identify the main types of data that a Digital Product Passport for textile products is expected to include. These categories provided an initial basis for the modelling activity and helped define the scope of information considered in this study.

The organisation of the data model was developed around the product as the central reference element of the Digital Product Passport. In this context, the product represents the entity to which all information domains are linked, allowing different types of information—such as materials, manufacturing processes, and supply chain-related data—to be organised within a single coherent structure. This product-centred approach reflects the conceptual idea of the Digital Product Passport as an information system associated with a specific product placed on the market.

Starting from the identified macro-level information categories, the model was progressively structured by linking each category to the product entity. This made it possible to organise heterogeneous information within the same framework, while maintaining a clear and consistent reference point for the Digital Product Passport.

During the modelling process, the product was structured into product elements. The model therefore treats the product not as a single unit but as a set of elements to which specific information can be associated. This choice, developed in collaboration with Surge, allowed material- and transformation-related information to be organised at a finer level of detail. In textile products, different parts of the same item may involve distinct materials and processing steps, and therefore require separate data associations. Organising information at this level made it possible to associate relevant data with the appropriate element of the product, while keeping the finished product as the main reference entity of the Digital Product Passport.

Overall, these structuring choices supported the development of a conceptual data model that allows different types of product-related information to be organised in a clear and consistent way, in line with the objectives of the study and the scope of the Digital Product Passport.

In addition, the definition and refinement of specific attributes were supported by practitioner-oriented reference materials used as a non-normative aid to support the interpretation of emerging Digital Product Passport data requirements and to assess the practical completeness of the proposed data structure.¹

4.3.3 Granularity and scope of the data model

The level of granularity adopted in this study corresponds to the product model and is based on the use of a Global Trade Item Number (GTIN). This choice emerged during the early stages of the work as a way to keep the scope of the analysis manageable in a first approach to the Digital Product Passport.

Working at batch level, and even more at item level, would have required a much higher level of detail and a broader set of information to be consistently collected and managed. As discussed in the (CIRPASS-2 Consortium, 2025) work on DPP granularity for textiles and apparel, finer levels of granularity increase the potential of the Digital Product Passport, but also significantly expand the amount of data involved and the complexity of the system. For the purpose of this study, adopting a GTIN-based approach made it possible to focus on the

¹ An example of practitioner-oriented material is the “DPP Data Requirements Matrix” shared by Gianluca Managò on LinkedIn (2024), used as a non-normative reference to support the interpretation of Digital Product Passport data requirements.

structure of the data model without extending the scope beyond what could be realistically handled at an early stage.

During the modelling process, the implications of this choice became clearer. As the UML structure was developed, it emerged that some categories of data needed to be separated and organised more carefully in order for the model to work in a coherent way. This led to a progressive refinement of the data structure, aimed at improving clarity and making the model applicable to different types of products.

For this reason, the definition of granularity and scope was not treated as a fixed decision taken at the beginning of the work, but as an iterative process. While developing the data model, it was necessary to continuously assess the usefulness of different types of information and to reflect on how essential certain data elements were for the overall functioning of the model.

Overall, the adoption of model-level granularity represents a pragmatic choice that supported the development of a coherent and structured conceptual data model, while leaving open the possibility for future extensions towards more detailed levels of granularity.

4.3.4 Environmental impact data assumptions

In line with institutional literature on the Digital Product Passport, environmental impact information was included within the scope of the proposed data model, as environmental performance is identified as a key information category for future product transparency requirements (European Parliamentary Research Service, 2024).

As discussed in Chapter 1, Section 1.7, life cycle assessment (LCA) provides the methodological framework for the evaluation of product-related environmental impacts.

Building on this background, the present study assumes that environmental impact information is available in the form of aggregated LCA results generated by external and specialised third parties.

Accordingly, the proposed data model does not aim to perform, replicate or validate LCA calculations. Its role is instead limited to receiving, structuring and storing aggregated environmental impact indicators and related methodological information, without requiring access to underlying inventory data or calculation models.

4.4 Data Structuring and UML Model Translation

After the development of the conceptual UML data model, a further step was carried out to better organise the information identified for the Digital Product Passport. In particular, the UML model was translated into a spreadsheet-based structure, which was used as a working tool to list, organise, and review the data associated with the proposed data model.

Each class defined in the UML diagram was represented separately, with all related attributes explicitly listed. For each attribute, the type of information expected was specified (for example textual, numerical, Boolean, or based on a predefined set of values). This step was introduced to clarify how different kinds of information are represented within the model and to support a more consistent interpretation of the data.

When attributes were associated with a limited number of possible values, these were documented separately as reference lists. This choice was made to reduce ambiguity, avoid the use of free-text entries, and keep the overall structure of the data clear and manageable within the scope of the study.

In addition, attributes were classified according to their relevance for the Digital Product Passport. A distinction was made between attributes considered necessary to describe the product at model level and attributes that were treated as optional, depending on data availability and product characteristics. This distinction reflects the fact that not all types of information have the same importance, are equally available for all products and actors within the textile supply chain.

Overall, this step did not aim to define strict or automated validation mechanisms, but rather to support a clearer organisation of the data model and to assess which information could realistically be associated with a product-level Digital Product Passport under current conditions.

4.5 Identification of data owners and data flows

After the organisation of the conceptual data model and the definition of data attributes, the next step of the methodology focused on analysing data ownership and data flows along the textile supply chain. This step aims to address the question of who provides each type of data included in the Digital Product Passport.

As a first step, the spreadsheet structure previously developed was populated with example data for the three selected products (T-shirt, jacket, and shoes). This activity was carried out to

work with concrete examples and to better understand how the defined attributes could be populated in practice.

Based on this exercise, data owners were identified for each macro-level information category and for the attributes included within them. This step aimed to understand which actors along the supply chain are typically associated with the availability of different types of information.

Once data owners had been identified, the analysis was further developed through a visual representation of data flows along the supply chain. Using the T-shirt as an example, two alternative production scenarios were considered: outsourced manufacturing and in-house manufacturing. These selected scenarios were used to explore how data availability and responsibilities may vary depending on the organisation of production.

The visual representation illustrates the main production stages, material transformations, and logistics steps, together with the actors involved at each stage. It was developed as a support tool for the analysis, with the aim of facilitating the interpretation of data ownership and information flows within the proposed data model.

Overall, this step helped clarify how the information included in the Digital Product Passport could be associated with different actors along the supply chain under selected manufacturing arrangements.

4.6 Implementation of the data model

The implementation phase consisted of applying the conceptual data model within the existing Surge platform. The platform already included a predefined structure and several information fields; however, it was updated and reorganised according to the classes and attributes defined in the UML data model developed in this study. This work was carried out in collaboration with the development team at Surge, and the data prepared during the modelling phase were entered into the platform following the proposed structure.

This phase allowed verification of whether the information could be organised consistently according to the designed model and whether the structure could accommodate product-related data in practice. The objective was therefore to assess the coherence of the proposed data model when applied in a real digital environment.

The three selected products (T-shirt, jacket and shoes) were used as reference examples. They were employed to populate the different information categories and to evaluate the applicability of the model across products characterised by different levels of complexity.

4.7 Testing of the data model using product examples

For the three selected products (T-shirt, jacket and shoes), example product data were developed to apply the proposed data model to concrete cases. The data were created using an Excel-based structure, aligned with the conceptual data model and the tables defined in the previous phases, and were subsequently uploaded to the platform.

The use of example data made it possible to populate the different information categories included in the model and to observe how the data structure behaves when applied to products characterised by different levels of complexity.

Once uploaded, the data were used to generate a digital representation of each product, including a dedicated landing page associated with the corresponding Digital Product Passport. Access to the product information is provided through a QR code linked to each landing page, allowing the content of the passport to be viewed in a digital environment.

This phase focuses on demonstrating how the Digital Product Passport can be accessed and used in practice. It also aims to support the evaluation of whether the proposed data model is coherent and applicable, rather than assessing the accuracy of the data.

5. Results

5.1 Conceptual Data Model of the Digital Product Passport

This section presents the results of the data modelling activity carried out within this study. The main output of this phase is the conceptual data model of the Digital Product Passport, developed using Unified Modelling Language (UML) and illustrated in **Figure 6**.

The UML diagram provides an overall representation of the structure of the proposed Digital Product Passport, highlighting the main entities, their attributes and the relationships that connect different information domains. The model adopts a product-centred approach, in which the product represents the central reference element to which all other information is linked. All the classes discussed in the following sections are included in this overall UML diagram and can be visually identified in **Figure 6**, which serves as a comprehensive overview of the proposed data model. This choice is consistent with the definition of the Digital Product Passport proposed for the textile sector by the European Parliamentary Research Service, which conceptualises the DPP as a system associating a product identifier with data characterising the product, its processes and the stakeholders involved throughout the product lifecycle (Legardeur & Ospital, 2024).

In line with the methodology described in Chapter 4, the conceptual UML structure was further translated into a spreadsheet-based representation to support a clearer organisation and interpretation of the information identified within the model. This additional step was used as a working tool to explicitly list attributes, data types and reference values associated with each class. The detailed spreadsheet structure, including attribute definitions, data types, validation logic and reference lists, is reported in Appendix A.1.

To support clarity and readability, the following sections describe the UML model in a structured and progressive manner. Each class included in the model is analysed individually, with particular attention to its role within the overall structure, the attributes it contains and its relationships with other entities. The description starts from the product and from the information required to identify and characterise it, which constitute the foundation of the overall data structure.

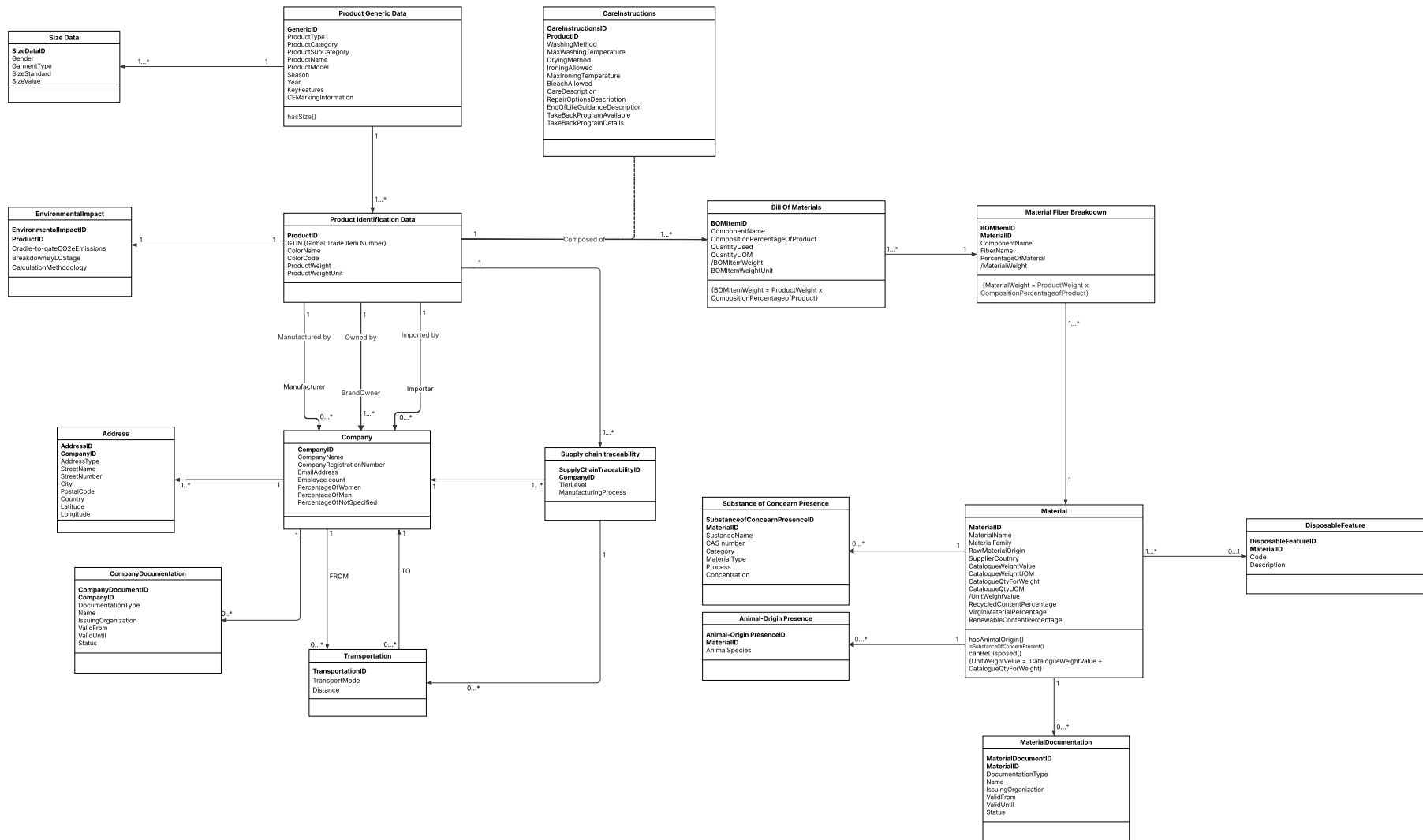


Figure 6. Conceptual UML data model developed for the Digital Product Passport in the textile sector.

5.1.1 Product Identification Data

Within the proposed UML data model, the initial and central information block is represented by the Product Identification Data entity. This entity includes the core attributes required to uniquely identify the product and to provide a basic descriptive and physical characterisation. It therefore represents the reference point upon which the other information domains of the Digital Product Passport are built.

This modelling choice reflects the product-centred perspective adopted in the European Parliamentary Research Service study on the Digital Product Passport for the textile sector, where the product is considered the central element around which information related to materials, processes and stakeholders is structured (Legardeur & Ospital, 2024).

Within this entity, a key attribute is the Global Trade Item Number (GTIN), which is used to identify the product as a trade item placed on the market. The GTIN is a standardised numeric identifier defined and managed by GS1 and is widely used to uniquely identify trade items at global level (GS1, n.d.). Depending on the application context, the GTIN may be expressed in different formats, including 8-, 12-, 13- and 14-digit codes (GS1, n.d.). In the present model, the GTIN is treated as a mandatory field and is validated as digits only, with a length constraint consistent with the GS1 format (8–14 digits).

In addition to the GTIN, the Product Identification Data entity includes a system-generated identifier (ProductID) that supports internal data management and ensures the uniqueness of each product record within the model. The entity also captures a limited set of basic descriptive and physical attributes, namely product colour and product weight. Product colour is represented through two mandatory attributes, ColorName and ColorCode, both constrained as enumerated values and validated against a controlled “Colors” reference table to avoid inconsistencies; the corresponding reference table is reported in Appendix A.2. Product weight is expressed as a numeric value (ProductWeight) and complemented by an associated unit of measurement (ProductWeightUnit), selected from a predefined list of units (g / kg / lb).

Overall, these attributes provide the minimum level of information required to consistently represent the product and to enable the linkage of additional information domains within the Digital Product Passport.

5.1.2 Product Generic Data

Following the definition of the Product Identification information, the UML model introduces the Product Generic Data entity, which provides a general descriptive characterisation of the product at model level.

The Product Generic Data entity is linked to the Product Identification Data through a one-to-many relationship, meaning that a single generic product description can be associated with multiple identified products. This structure reflects the fact that several product variants may share the same general descriptive characteristics while being identified through different GTINs.

As explained in Section 5.1.1, the Product Identification Data entity refers to individual trade items uniquely identified through a GTIN. However, several variants of the same product may share common descriptive attributes, such as product type, category, season or year. These shared attributes are therefore stored in the Product Generic Data entity, which represents information defined at model level and can be linked to multiple product variants identified through different GTINs.

The attributes associated with the Product Generic Data entity describe the product in terms of type, category and subcategory, as well as product name and model. Product type is defined through a limited set of predefined values - namely Apparel, Footwear, Accessories and Sport - which provide a high-level classification of the product. Product category and subcategory further refine this classification by assigning the product to more detailed predefined classification schemes. Given the potentially large number of categories and subcategories, these values are managed through dedicated reference tables, which are reported in Appendix A.3.

Additional attributes capture temporal and contextual information commonly used in the fashion sector. In particular, the Season attribute is constrained to a limited set of values (Spring/Summer, Fall/Winter and Carryover), while the Year attribute specifies the reference year of the collection. Together, these attributes allow the product to be contextualised within a specific collection cycle.

The entity also includes a KeyFeatures attribute, defined as free text, which allows the inclusion of additional descriptive elements that are not explicitly covered by the predefined classification fields.

Furthermore, the Product Generic Data entity includes information related to CE marking. In the context of apparel, footwear and accessories, CE marking is not generally required and applies only to specific product categories subject to European Union harmonisation

legislation. Typical examples within the textile sector include personal protective equipment such as protective gloves, high-visibility garments and other safety-related apparel, for which CE marking indicates compliance with applicable EU requirements concerning safety, health and environmental protection (European Commission, n.d.). For this reason, CE marking information is included in the model as a conditional attribute, applicable only to product types for which it is required under the relevant regulatory framework.

Finally, the entity includes a Boolean attribute indicating whether size-related information is associated with the product. This attribute supports the linkage between the Product Generic Data entity and size-specific data, allowing the model to distinguish between products for which sizing information is relevant and those for which it is not.

5.1.3 Size Data

The UML model also includes a Size Data entity, which stores size-related attributes of a product. These attributes may vary across different versions of the same product model, while the general descriptive characteristics remain unchanged.

The Size Data entity is connected to the Product Generic Data entity through a one-to-many relationship: a single product model can be associated with multiple size entries. This structure allows the same product to be offered in different sizes without duplicating general product information.

The attributes included in the Size Data entity capture the key dimensions required to define product size in a consistent manner. In particular, Gender is constrained to a limited set of predefined values (Male, Female and Kids), while GarmentType specifies the product category to which sizing rules apply (Top, Bottom, General and Footwear). Together, these attributes provide the contextual basis for the interpretation of size information.

In addition, the entity includes a SizeStandard attribute, which identifies the sizing system adopted. This attribute is constrained to a predefined list of commonly used standards (IT, INT, EU, FR, US and UK), reflecting the coexistence of multiple sizing conventions in the fashion sector. The actual size assigned to the product is captured through the SizeValue attribute. To ensure consistency and avoid ambiguity, the value of this attribute is validated against a dedicated size reference table, based on the combination of Gender, GarmentType and SizeStandard. Given the potentially large number of valid size combinations, the corresponding reference tables are reported Appendix A.4.

5.1.4 Environmental Impact

The data model includes an Environmental Impact entity aimed at representing climate-related environmental performance information associated with a specific product.

In the proposed model, environmental impact information is associated with the Product Identification Data through a one-to-one relationship, reflecting the fact that impact values refer to a specific identified product placed on the market. Each record is uniquely identified by an EnvironmentalImpactID.

The entity includes a quantitative attribute for cradle-to-gate CO₂e emissions, expressed in kilograms of CO₂ equivalent. This attribute is included only when life cycle assessment data are available, in accordance with the methodological assumptions defined in Section 4.3.4.

To support transparency and interpretation of aggregated emission values, the model includes a BreakdownByLCStage attribute, which allows emissions to be allocated across the main life cycle stages. Finally, the CalculationMethodology attribute is defined as an enumerated field constrained to a predefined list of recognised standards and data sources, including PEF, ISO 14067, the GHG Protocol, Ecoinvent and an open “Other” category.

5.1.5 Bill of Material

The UML model further includes a Bill of Material (BOM) entity, which represents the composition of the product in terms of its constituent components. At this level, the BOM describes the elements that physically make up the product, such as fabrics, linings, accessories or trims, without yet addressing the detailed material or fibre composition of each component.

The Bill of Material entity is linked to the Product Identification Data entity through a one-to-many relationship, indicating that a single identified product can be composed of multiple components. This structure reflects the modular nature of textile products, which are typically assembled from several distinct components, each contributing to the overall structure of the product.

Each component included in the BOM is uniquely identified through a system-generated BOMItemID, which ensures traceability at the level of individual components. The ComponentName attribute specifies the type of component (e.g. outer fabric, lining, zipper), while the CompositionPercentageOfProduct attribute indicates the proportion of the overall product that the component represents in terms of weight.. This value is expressed as a

percentage and is constrained so that the sum of all component percentages for a given product equals 100%.

In addition to compositional information, the Bill of Material entity includes attributes related to the quantity of each component used. The QuantityUsed attribute captures how much of a given component is required, while the corresponding unit of measurement is specified through the QuantityUOM attribute, constrained to a limited set of predefined values (piece, m and m²). These units describe the physical quantity of material needed to manufacture the component (e.g., area of fabric, length of webbing, or number of items). This approach allows components with different physical characteristics to be represented in a consistent manner.

The BOM also includes weight-related information for each component. The BOMItemWeight attribute represents the weight contribution of a specific component to the overall product and is automatically calculated based on the product weight and the component's percentage contribution. The associated unit of measurement is specified through the BOMItemWeightUnit attribute, constrained to g or kg. This calculation ensures alignment between product-level and component-level weight information while avoiding redundant data entry.

By modelling components within the Bill of Material entity, the data model introduces an intermediate level between the product and the detailed material and fibre information. Material composition is instead addressed in a dedicated entity, enabling a clear distinction between product structure and material-related information.

5.1.6 Material Fiber Breakdown

Building on the component-level representation introduced through the Bill of Material, the UML model includes the Material Fiber Breakdown entity, which describes the fibre composition of each component.

The Material Fiber Breakdown entity is linked to the Bill of Material through a one-to-many relationship. Each record represents a single fibre component within a specific BOM item, allowing a component to be described through multiple fibre entries representing the different fibres and their respective shares.

The association between the two entities is implemented through the BOMItemID attribute, which acts as a foreign key referencing the corresponding BOM item and linking each fibre breakdown entry to a specific component of a given product.

Each record within the entity also includes a `MaterialID`, which references an existing identifier defined in the Material data category and enables the linkage between fibre-level composition and additional material-related information within the model. The `ComponentName` attribute is included to support readability and facilitate interpretation when analysing fibre composition at component level.

The fibre composition is represented through the `FiberName` attribute, which identifies the fibre used in the component. This attribute is constrained to a predefined set of values defined in a controlled reference table, reported in Appendix A.5.

The `PercentageOfMaterial` attribute specifies the proportion of the component attributed to each fibre and is expressed as a percentage (0–100). Finally, the `MaterialWeight` attribute represents the weight contribution of each fibre and is automatically calculated based on the weight of the corresponding component (`BOMItemWeight`) and the associated fibre percentage (`PercentageOfMaterial`).

5.1.7 Material

After defining the product composition at component and fibre level, the UML model introduces the Material entity, which collects standardised information about the materials used across products and components. This entity provides the material-level attributes associated with each `MaterialID` referenced in the Material Fiber Breakdown entity, enabling fibre composition data to be consistently linked to additional material-related information.

The entity includes descriptive attributes such as `MaterialName` and `MaterialFamily`, which support consistent naming and classification of materials, reference tables reported in the Appendix A.5.

To support traceability at material level, the entity also includes information on origin and supply. Specifically, `RawMaterialOrigin` indicates the country where the raw material is grown or extracted, while `SupplierCountry` identifies the country where the material is processed and/or supplied. Both attributes are represented through ISO 3166-1 alpha-2 country codes and rely on a dedicated country reference table provided Appendix A.6.

The Material entity further captures catalogue-level quantitative information as provided by suppliers. The declared weight is recorded through `CatalogueWeightValue`, complemented by the corresponding unit of measurement (`CatalogueWeightUOM`), constrained to a limited set of values (g, kg, g/m², g/m). The declared weight is associated with a corresponding quantity,

represented by CatalogueQtyForWeight and its unit (CatalogueQtyUOM), constrained to: piece, m, m² and roll. Based on these inputs, the attribute UnitWeightValue is automatically calculated as the weight per single unit of material, computed as CatalogueWeightValue ÷ CatalogueQtyForWeight. This derived value supports consistent weight-based calculations across different material formats and units.

In addition, the entity includes attributes describing the material's content composition in terms of recycled and virgin shares. RecycledContentPercentage and VirginMaterialPercentage are mandatory and expressed as percentages (0–100), providing a structured representation of the relative contribution of recycled and virgin inputs. The RenewableContentPercentage attribute is included as optional, as renewable content information may not be available for all material types or supply contexts. This attribute is independent of the recycled and virgin content percentages.

Finally, two Boolean attributes, hasAnimalOrigin and isSubstanceOfConcernPresent, are used to conditionally activate additional information domains. When set to Yes, they indicate respectively the presence of animal-origin material or substances of concern and require the association of at least one corresponding Animal-Origin Presence or Substance of Concern Presence record. This approach ensures internal consistency of the data model while limiting additional data structures to cases in which they are relevant.

5.1.8 Disposable Feature

The UML model includes the DisposableFeature entity to capture material-related attributes relevant for end-of-life handling. This entity stores structured information describing predefined disposal features associated with a given material, using standardised codes and descriptions to support consistent interpretation in downstream processes.

DisposableFeature is linked to the Material entity through an optional one-to-many relationship, meaning that a single material may be associated with zero, one, or multiple disposal features depending on whether specific disposal-related properties are applicable. The linkage is implemented through MaterialID, ensuring that each disposal feature refers to an existing material definition.

Each record is uniquely identified by DisposableFeatureID. The attributes Code and Description are constrained to predefined values managed through a controlled “Disposable Features” reference table reported in Appendix A.7, avoiding the introduction of free-text variations and ensuring consistent representation.

5.1.9 Animal-Origin Presence

The UML model includes the Animal-Origin Presence entity to represent information related to animal-derived materials.

Animal-Origin Presence is linked to the Material entity through an optional one-to-many relationship, reflecting the fact that animal-origin information is relevant only for specific material types. When animal origin is not applicable, no associated record is required; conversely, when such information is provided, the relationship allows the model to store additional detail without overloading the base Material entity. This behaviour is consistent with the Boolean attribute `hasAnimalOrigin` defined in the Material entity, which acts as a flag: when set to Yes, at least one corresponding Animal-Origin Presence record is expected.

Each record is uniquely identified by `AnimalOriginPresenceID`. The main descriptive attribute is `AnimalSpecies`, which becomes mandatory when animal-origin information is applicable. This attribute allows the model to capture the animal source (e.g., sheep, cow, goat) in a structured manner, supporting transparency and potential compliance needs.

5.1.10 Substance of Concern Presence

To support health- and compliance-related information, the UML model includes the Substance of Concern Presence entity, which captures cases in which a material is associated with hazardous or regulated substances. This entity allows substance-related information to be recorded in a structured way, supporting transparency and regulatory assessment.

Substance of Concern Presence is linked to the Material entity through an optional one-to-many relationship. A material may therefore have no associated records when no substances of concern are present, or multiple records when several relevant substances apply. This modelling choice is aligned with the Boolean attribute `isSubstanceOfConcernPresent` defined in the Material entity, which acts as an applicability flag and requires at least one associated record when set to Yes.

Each record is uniquely identified by `SubstanceOfConcernPresenceID`. The `SubstanceName` attribute is mandatory and selected from a controlled “Substance of Concern” reference table reported Appendix A.9. Based on the selected substance, additional attributes—`CASNumber`, `Category`, `MaterialType` and `Process`—are automatically populated through lookup

mechanisms and are not editable, ensuring consistency with the reference dataset. Finally, Concentration is recorded as a mandatory numeric value (expressed in mg/kg or ppm), enabling the representation of quantitative information related to the identified substance.

5.1.11 Material Documentation

The UML model includes the Material Documentation entity to represent documentary evidence associated with materials. This entity stores certifications, declarations and other formal documents that support the verification, traceability and compliance of material-related information within the Digital Product Passport.

Material Documentation is linked to the Material entity through a one-to-many relationship, allowing a single material to be associated with multiple documentation records. This reflects the fact that different documents—issued by different organisations and with different validity periods—may coexist for the same material.

Each documentation record is uniquely identified by MaterialDocumentID. The DocumentationType attribute classifies the nature of the document and is constrained to a predefined set of values, including material, chemical, animal welfare and traceability certifications, as well as social audits, compliance declarations, management system certifications and environmental certifications. This classification enables heterogeneous documentary evidence to be managed within a unified structure.

The Name attribute identifies the specific certification or document and is constrained to a controlled reference table (Fashion Certification), reported Appendix A.10. The issuing body is captured through the IssuingOrganization attribute, which records the name of the certifier, auditor or issuing authority responsible for the document.

Temporal validity is managed through the ValidFrom and ValidUntil attributes. ValidFrom is mandatory for certificates, audits and regulated documents, while it may be optional for self-declarations or documents without a defined expiration date. ValidUntil is required only when an expiry date applies and must be later than ValidFrom.

Finally, the Status attribute indicates the current state of the document and is constrained to a predefined set of values (Active, Expired, PendingVerification, Revoked and UnderReview), supporting the interpretation of documentation over time.

5.1.12 Supply Chain Traceability

The UML model includes the Supply Chain Traceability entity to represent information related to the traceability of manufacturing processes across different stages of the supply chain. This entity captures where and how specific production steps are carried out, supporting transparency across multiple tiers.

Supply Chain Traceability is linked to the Company entity through a one-to-many relationship, meaning that a single company may be associated with multiple traceability records corresponding to different production activities. Each record is uniquely identified by SupplyChainTraceabilityID and represents a specific manufacturing step performed at a given stage of the supply chain.

The TierLevel attribute identifies the position of the company within the supply chain hierarchy relative to the focal company placing the product on the market. It is defined as the number of supply chain links separating a supplier from the focal company and is constrained to a predefined set of values (Tier 1, Tier 2, Tier 3 and Tier 4). This definition is independent of the specific activities performed by suppliers, allowing the model to accommodate both specialised and vertically integrated companies.

This enables the model to distinguish between direct suppliers and upstream actors. The ManufacturingProcess attribute provides a textual description of the activity performed by the company at the specified tier, enabling the documentation of production processes in a flexible yet structured way.

5.1.13 Transportation

The Transportation entity is included in the UML model to represent logistics activities associated with the movement of goods between supply chain actors. This entity captures transport-related information at the level of individual transport legs.

Transportation is linked to the Supply Chain Traceability entity through a one-to-many relationship, meaning that each traceability step may involve multiple transportation legs. This structure reflects the fact that goods often move through several transport stages between production sites.

Each transport leg is uniquely identified by TransportationID. The TransportMode attribute specifies the means of transportation and is constrained to a predefined list of values (Road, Air, Rail, Maritime and Inland waterways). The Distance attribute records the length of the

transport leg in kilometres and is constrained to non-negative values. Together, these attributes provide the basis for analysing logistics-related aspects of the supply chain.

5.1.14 Company

Company entity represents the economic operators involved in the product lifecycle and acts as a central organisational node within the data model. Rather than modelling a generic actor, the Company entity is used to explicitly represent the different roles that companies may assume in relation to a product through distinct, role-specific relationships with the Product Identification Data entity.

In particular, the model defines separate associations for manufacturer, brand owner, and importer, each representing a specific responsibility along the product lifecycle. The manufacturer relationship identifies the company responsible for the production of the final product, the brand owner relationship captures ownership and branding responsibility, while the importer relationship represents the company responsible for placing the product on a given market.

The model allows responsibilities to be clearly differentiated and supports scenarios in which multiple companies may fulfill different roles for the same product, or a single company may assume multiple roles across different products.

Each company is uniquely identified by CompanyID. Core identification attributes include CompanyName and CompanyRegistrationNumber, which records a VAT number or other official registration identifier. Optional attributes such as EmailAddress and EmployeeCount support basic organisational profiling without imposing unnecessary data requirements.

The entity also includes optional attributes related to workforce composition, namely PercentageOfWomen, PercentageOfMen and PercentageOfNotSpecified, expressed as percentages. These attributes enable the inclusion of social-related information at company level when available, while maintaining flexibility for cases in which such data is not provided.

In addition to its role-based association with the product, the Company entity is linked to Supply Chain Traceability through a one-to-many relationship, allowing a company to be associated with multiple manufacturing or processing steps related to the product.

5.1.15 Company Documentation

The UML model includes the Company Documentation entity to store documentary evidence related to companies involved in the supply chain. This entity is designed to represent audits, certifications, declarations and other documents that support compliance, due diligence and transparency at organisational level.

Company Documentation is linked to the Company entity through a one-to-many relationship, indicating that a single company may be associated with multiple documentation records. Each record is uniquely identified by CompanyDocumentID.

The DocumentationType attribute classifies the nature of the document and is constrained to a predefined list of values, including Social Audit, Ethical Certification, Management System Certification, Environmental Management, Safety Audit, ESG Reporting Framework, Compliance Declaration and Due Diligence Documentation. The Name attribute identifies the specific document or certification and refers to a controlled reference table of company documentation reported in Appendix A.11, ensuring consistent naming and standardised interpretation across records.

The issuing body is captured through the IssuingOrganization attribute. Temporal validity is managed through ValidFrom and ValidUntil, following the same logic adopted for material documentation. The Status attribute indicates the current validity state of the document (Active, Expired, PendingVerification, Revoked or UnderReview).

5.1.16 Address

The Address entity is included to represent the geographical location of companies involved in the supply chain. This entity enables the association of organisational actors with one or more physical locations.

Address is linked to the Company entity through a one-to-many relationship, meaning that a company may operate across multiple locations. Each address is uniquely identified by AddressID.

The entity includes standard address attributes such as StreetName, StreetNumber, City and PostalCode. The Country attribute is represented using ISO 3166-1 alpha-2 country codes, ensuring consistency and interoperability; the corresponding reference table is reported in the appendix. Geographic coordinates are captured through Latitude and Longitude, allowing spatial analyses and supporting location-based assessments.

The AddressType attribute classifies the nature of the location (e.g. headquarters, production site, warehouse) and refers to a controlled reference table reported in Appendix A.8. The attribute is single-valued, meaning that each address can be associated with only one location type.

5.1.17 Care Instructions

The UML model includes a Care Instructions entity to represent information related to product use, maintenance and end-of-life guidance. This entity formalises typical care label information in a structured format and complements the product description by supporting correct use and maintenance practices, which are relevant both for consumer guidance and for extending product lifetime.

Care Instructions are modelled as a complementary information entity associated with the product through a one-to-one relationship. This modelling choice reflects the fact that care and maintenance recommendations are typically defined at product model level and remain consistent across size and colour variants. In industrial practice, products requiring different care treatments are usually managed as distinct product references rather than as variants of the same product. As a result, care instructions do not contribute to product identification or classification, but rather provide additional information that completes the Digital Product Passport.

The entity captures washing and drying information through predefined attributes. WashingMethod is constrained to a limited set of values (MachineWash, HandWash, DoNotWash, DryCleanOnly, SpotCleanOnly, NotApplicable). Where washing by the end user is applicable, MaxWashingTemperature specifies the maximum allowed temperature (°C); this attribute is mandatory only when the washing method is MachineWash or HandWash. Similarly, DryingMethod is defined through a predefined set of values (TumbleDryLow, TumbleDryMedium, TumbleDryHigh, LineDry, FlatDry, DoNotTumbleDry), ensuring consistent representation of drying recommendations.

Ironing and bleaching instructions are captured through Boolean attributes. IroningAllowed and BleachAllowed are both mandatory and constrained to Yes/No. When ironing is allowed, MaxIroningTemperature becomes mandatory and records the maximum recommended temperature (°C), introducing a conditional rule that prevents inconsistent combinations of values.

In addition to structured care parameters, the entity includes optional descriptive attributes to support more detailed user guidance. CareDescription allows the inclusion of human-readable instructions, while RepairOptionsDescription can be used to document available repair services or options associated with the product. End-of-life guidance is represented through EndOfLifeGuidanceDescription, which provides information on disposal, recycling or return pathways. Finally, take-back information is captured through the TakeBackProgramAvailable attribute (Yes/No); when a take-back programme is available, TakeBackProgramDetails becomes mandatory and describes the associated conditions and procedures.

5.2 Data Ownership and Data Flows

This section presents the results of the analysis of data ownership and data flows resulting from the application of the proposed Digital Product Passport data model.

The data model was developed and subsequently applied to three product types characterised by increasing levels of structural complexity—a T-shirt, a jacket, and a pair of shoes—in order to ensure that it could accommodate different product architectures and degrees of supply chain articulation.

Building on this application, the analysis of data ownership and data flows focuses on a single low-complexity product (the T-shirt). For this product, data ownership mapping is conducted under two alternative manufacturing configurations—outsourced and in-house manufacturing—to examine how differences in production organisation are reflected in data ownership while keeping product characteristics and material inputs constant.

The results presented in this section do not aim to define normative responsibilities for data provision. Instead, they describe observed patterns of data availability across the supply chain.

For the purpose of interpreting the results, supply chain actors are grouped into tiers according to their position along the textile value chain. Each tier represents the companies responsible for a given stage of production, ranging from the brand placing the product on the market (Tier 0) to upstream raw material suppliers (Tier 4). This tiered representation provides a common analytical framework for describing how information is positioned along the supply chain within the proposed Digital Product Passport model.

5.2.1 Comparison of Data Ownership in In-House vs. Outsourced Manufacturing

This subsection presents the comparative mapping of data ownership for the T-shirt case study under the two alternative manufacturing configurations. The comparison is based on an attribute-level allocation of each data field defined in the Digital Product Passport data model to the corresponding supply-chain tier.

The complete mapping tables for both configurations are reported in Appendix B.1 (Data Ownership Attribute Mapping), which provide the underlying dataset supporting the observations discussed below.

The two configurations differ exclusively in the organisation of the final assembly stage. All other product characteristics and material inputs remain unchanged. The comparison therefore focuses on how this organisational difference is reflected in the data ownership mapping.

Product Generic Data remain consistently associated with the brand (Tier 0) in both configurations. The attributes belonging to this entity do not vary across manufacturing arrangements, as they are defined by the brand as part of product design and market positioning and are therefore not affected by the organisation of assembly.

A partial shift is observed in Product Identification Data. While core identifiers such as ProductID, GTIN, colour attributes, and naming conventions remain associated with Tier 0 in both configurations, ProductWeight and ProductWeightUnit are associated with Tier 1 in the outsourced configuration and with Tier 0 in the in-house configuration. This reflects the fact that product weight is determined at the final manufacturing stage and is therefore associated with the actor responsible for final assembly.

Size Data are consistently associated with Tier 0 in both configurations. Attributes related to this class remain under brand ownership, as they are defined at product specification level and are independent of the organisation of manufacturing activities.

A shift is observed in the Bill of Material. In the outsourced configuration, all BOM-related attributes are associated with Tier 1. In the in-house configuration, ownership of the same attributes shifts to Tier 0. This reflects the internalisation of final assembly and the associated consolidation of responsibility for defining and managing product-level material composition.

In addition to finished-product information, the comparison highlights tier shifts in data domains associated with material composition, fibre breakdown, and upstream processing stages. In the Material Fiber Breakdown domain, data ownership in the outsourced configuration is split across two tiers: attributes related to component identification are

associated with Tier 2, while fibre-related attributes are associated with Tier 3. In the in-house configuration, the same distinction remains, but ownership shifts one tier downward, with component-related data associated with Tier 1 and fibre-related data associated with Tier 2.

A similar pattern is observed in the Material domain. In the outsourced configuration, material identification and catalogue-related information are associated with Tier 3, while data related to raw material origin and material composition are associated with Tier 4. In the in-house configuration, these two groups of information shift respectively to Tier 2 and Tier 3, resulting in a consistent one-tier compaction across the domain.

Comparable one-tier downward shifts are observed in other upstream-related domains. In the Disposable Feature domain, all attributes shift from Tier 3 in the outsourced configuration to Tier 2 in the in-house configuration. Animal-Origin Presence data move from Tier 4 to Tier 3, while Substance of Concern Presence and Material Documentation data shift from Tier 3 to Tier 2 across all listed attributes.

Multi-actor information domains also differ across configurations in terms of the number of tiers involved. In the outsourced configuration, Supply Chain Traceability and Transportation data span Tier 1 to Tier 4, whereas in the in-house configuration they span Tier 1 to Tier 3. The same reduction in tier range is observed for Company, Company Documentation, and Address data.

Overall, the comparison shows that changing the organisation of final assembly does not lead to a centralisation of data ownership at brand level, but rather to a reconfiguration of how data ownership is distributed across supply chain tiers. While several finished-product information domains shift from Tier 1 to Tier 0 when assembly is internalised, a substantial share of material-related and upstream information remains dependent on non-brand actors. At the same time, the in-house configuration is characterised by a systematic compaction of the tier structure, reflected in one-tier downward shifts across multiple information domains and in a reduction in the number of tiers involved in multi-actor data categories.

This indicates that data ownership patterns are domain-specific, meaning that the distribution of data ownership depends on the type of information considered. Product-level and assembly-related data tend to shift with changes in production organisation, while material- and fibre-related information remains structurally positioned upstream in the supply chain, regardless of whether final assembly is outsourced or performed in-house.

5.2.2 Data Flows in Relation to Production Stages

The comparison between in-house and outsourced manufacturing configurations can be further interpreted by considering how information is generated along the production stages illustrated in the supply chain representation developed for the T-shirt case (**Figure 7**). The visual representation supports the results by showing where different types of information originate along the value chain, in relation to specific material transformations and production processes.

As illustrated in the diagram (**Figure 7**), material- and fibre-related information is generated at early stages of the supply chain and is associated with upstream actors. Data related to raw material production, fibre processing and intermediate material manufacturing are linked to specific components and remain positioned at higher supply chain tiers. This helps explain why material- and fibre-related information domains remain upstream in both manufacturing configurations discussed in Section 5.2.1.

Information related to component manufacturing and intermediate processing stages, such as knitting and finishing, is generated at midstream stages of the supply chain and is associated with the actors responsible for these processes in the case considered, although the exact positioning of these activities may vary across different supply chain configurations.. These data contribute to defining component-level characteristics that are later combined during final assembly.

Final product-related information is consolidated at the assembly stage, where individual components are combined to create the finished product. At this point, product-level attributes and identification data become associated with the brand. However, as shown by the comparison, upstream information related to materials, fibres and intermediate processes remains distributed across the supply chain and does not shift downstream, even when final assembly is performed by the focal company.

Overall, the representation helps clarify that the differences observed between manufacturing configurations are not the result of changes in product characteristics, but of the point along the supply chain at which different types of information are generated. This supports the interpretation of data ownership patterns as domain-specific and structurally linked to production stages rather than fully centralised at brand level.

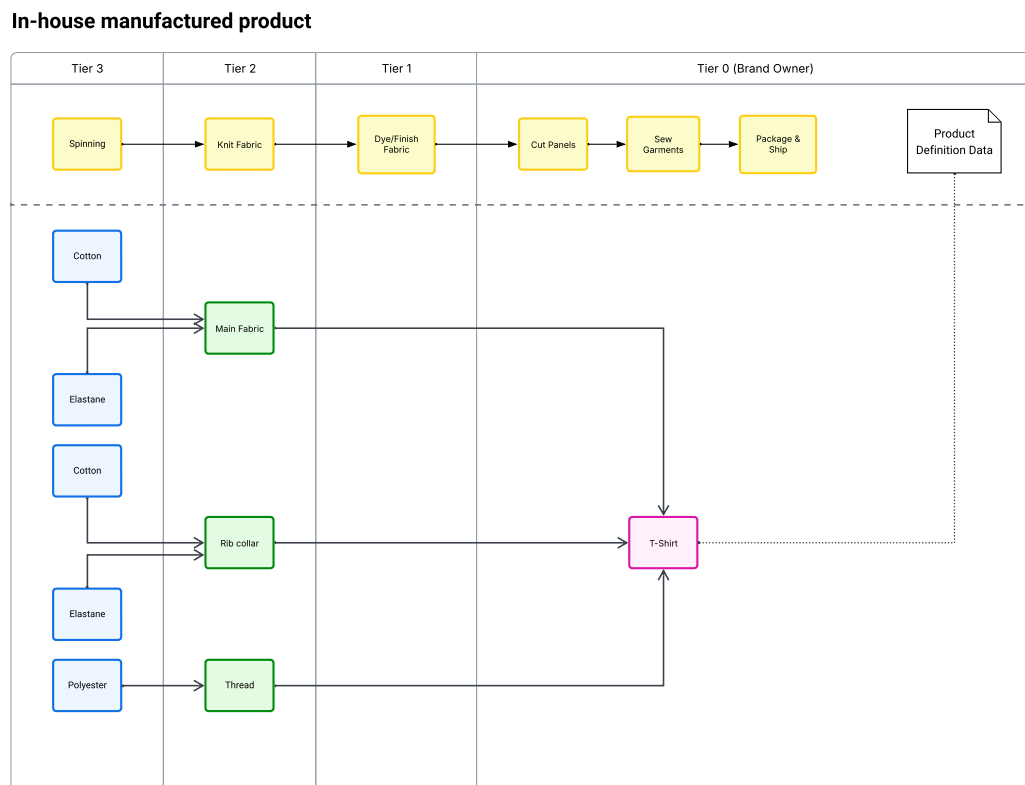
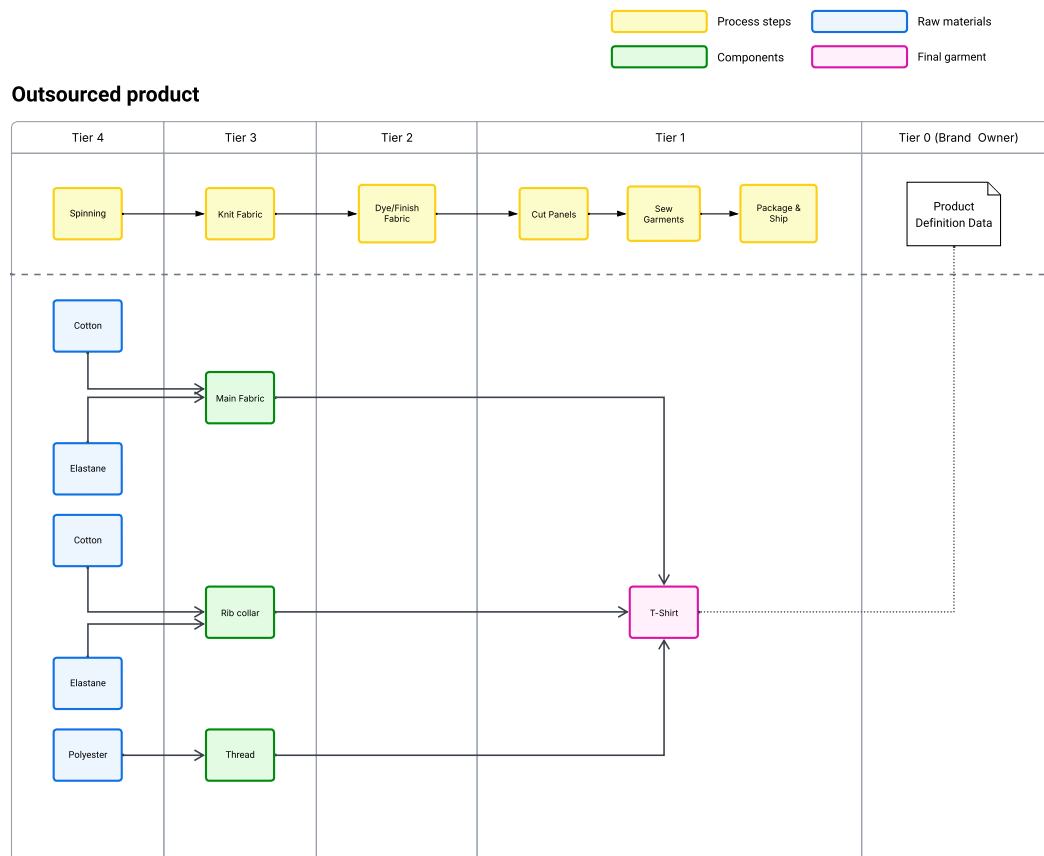


Figure 7. Supply-chain production stages and information generation for outsourced and in-house configurations (T-shirt case study)

5.3 Operational Validation of the Digital Product Passport Model

The data model was implemented on the Surge platform, where the fields and attributes defined in the proposed structure were incorporated into the system with the support of the development team. During this phase, the entities and attributes of the conceptual model were mapped into the digital environment so that the platform's information structure reflected the organisation of data defined by the model.

Following the configuration of the data structure, the platform was used to simulate the information exchange required for the creation of a Digital Product Passport (DPP). To observe the model's operation in practice, the outsourced production of a T-shirt was selected as the reference case.

Figure 8. *Operational workflow of product data compilation and validation between brand and suppliers* provides an overview of the operational workflow, while figures 8 to 10 illustrate the main interaction steps on the platform interface.

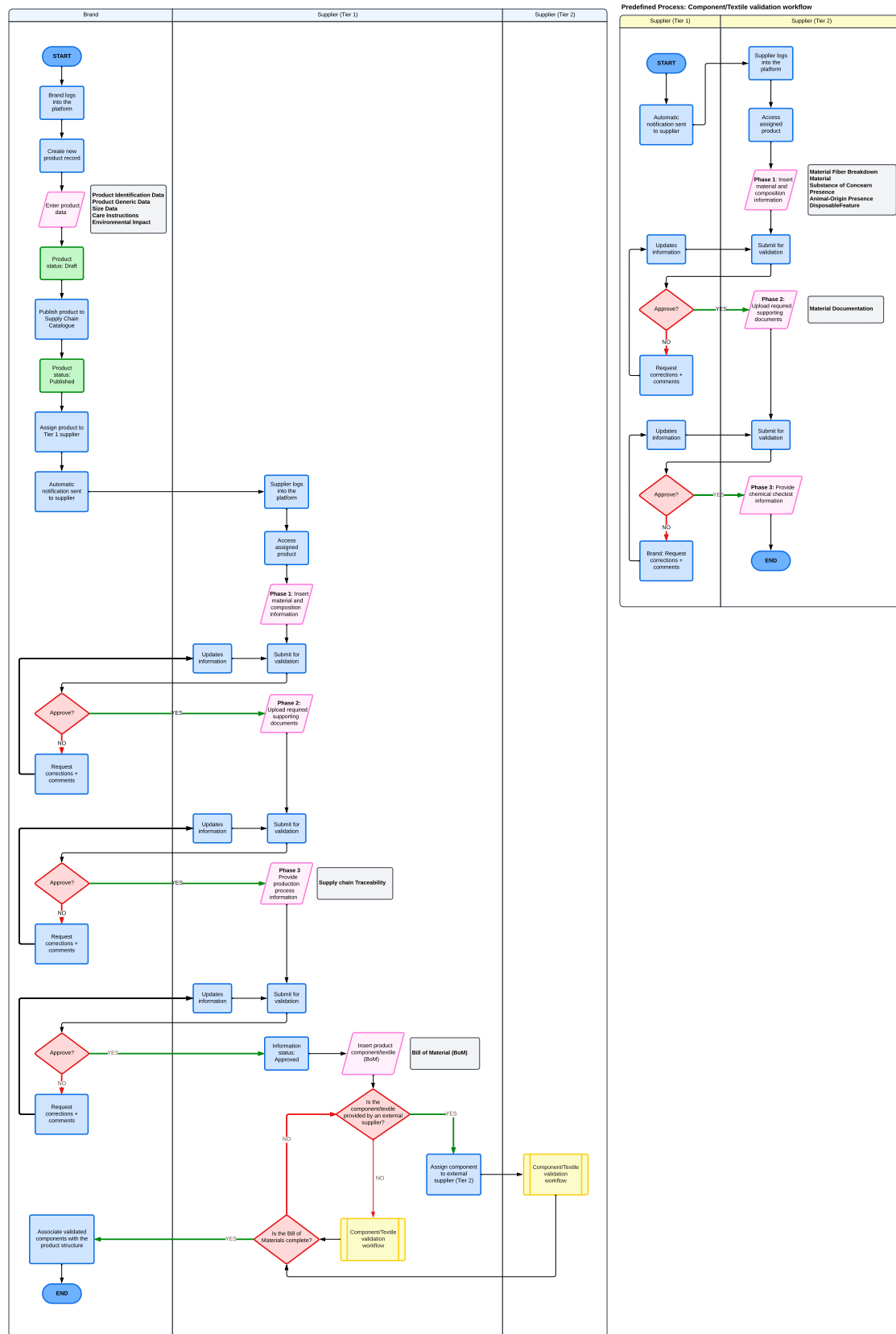


Figure 8. Operational workflow of product data compilation and validation between brand and suppliers

The process begins with the brand creating a new product record by inserting identification data. Once created, the product is registered in the supply-chain catalogue in draft status and then published (**Figure 9**). After publication, the product is assigned to a supplier through the supplier management section (manage supplier), who receives an automatic notification and accesses the product page.

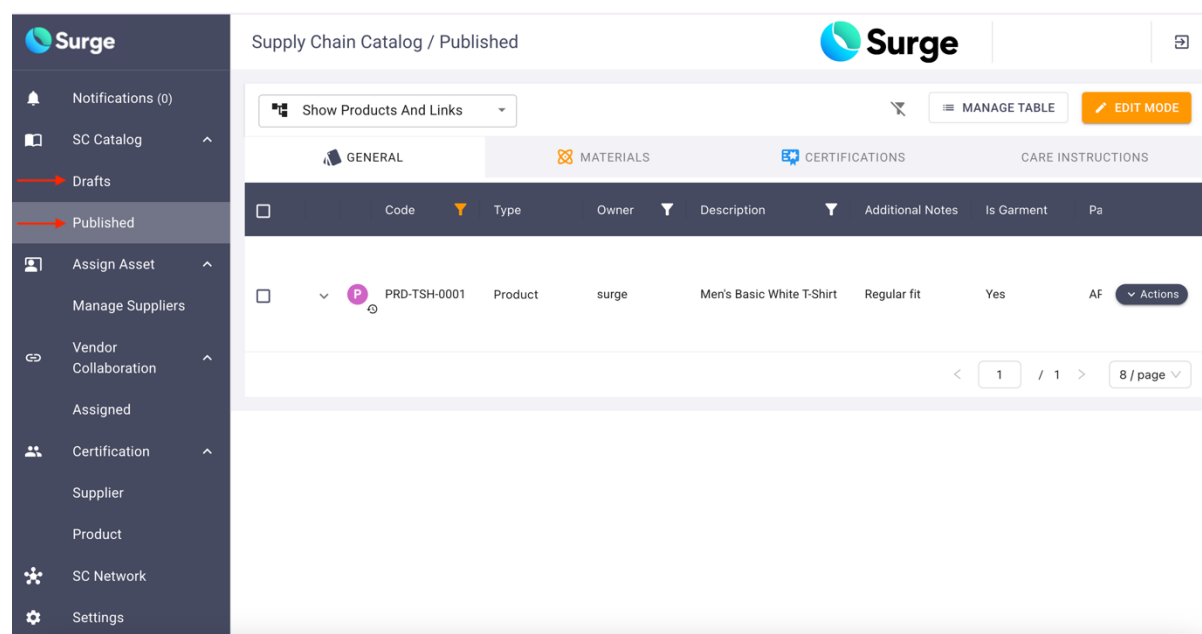


Figure 9. Product published in the supply-chain catalogue and made available to the supplier

Following the assignment, the supplier proceeds with the compilation of the first set of information. In this phase, the supplier provides basic information on the overall composition of the product, including the main material-related details. Once entered, the information is submitted to the brand for validation. The brand may either approve the submitted data or request modifications, leaving comments when clarification or correction is required (**Figure 10**). The supplier then updates the information and resubmits it for approval.

As illustrated in **Figure 8. Operational workflow of product data compilation and validation between brand and suppliers**, the workflow proceeds through successive validation cycles. After approval of the first stage, the workflow continues through subsequent phases following the same validation mechanism. The second stage (Phase 2 – Documents) concerns the upload of supporting documentation when required, including mandatory documents associated with the product or its components. The third stage (Phase 3 – Processes) requires the supplier to provide additional information related to production processes. Each phase must be validated by the brand before the process can proceed.

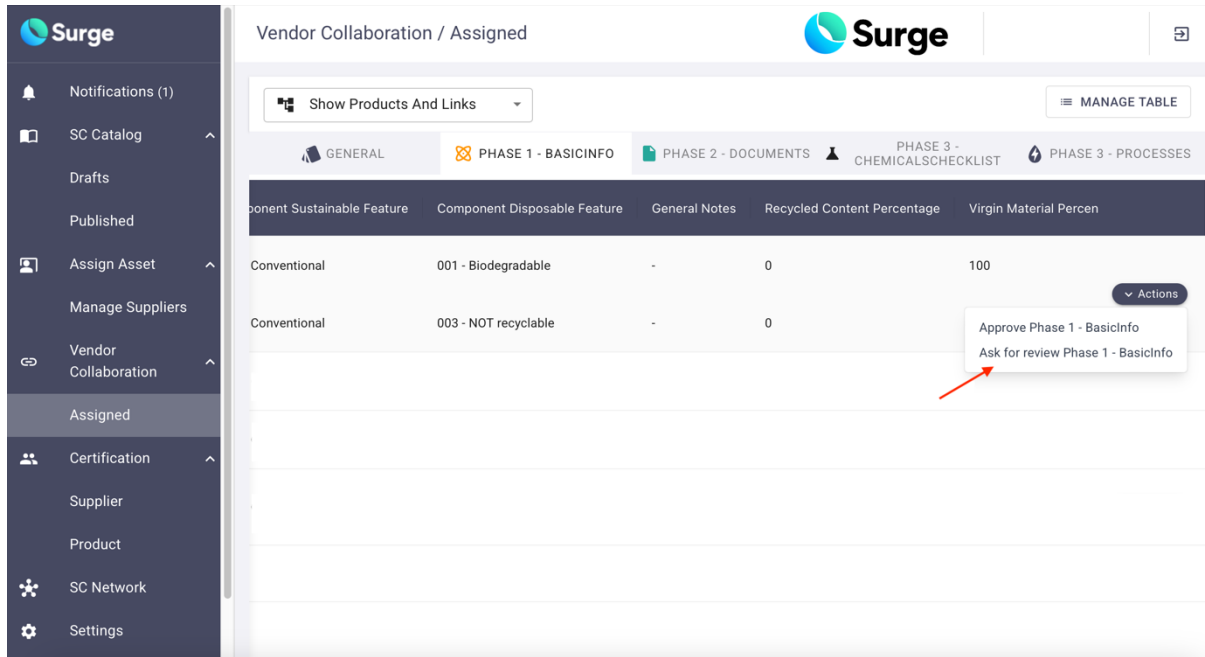


Figure 10. Supplier-submitted information under brand review and validation in the platform

After completing the progressive compilation phases (materials and composition, supporting documents, and production-related information) the supplier builds the product structure by inserting product components/textiles into the Bill of Materials (BoM).

Component data follow the same approval logic: information is submitted to the brand for validation and may be approved or returned with requested corrections. Only once the relevant component information is validated can it be formally associated with the overall product structure, enabling the passport to be assembled from verified building blocks rather than from unconfirmed inputs (**Figure 11**).

In the workflow representation, phase 3, chemical checklist, is illustrated at the Tier 1–Tier 2 interface as a simplified example of the interaction logic. However, the same mechanism is applied to other interactions across the supply chain (e.g., Brand–Tier 1 or Tier 2–Tier 3), depending on which actor is responsible for producing the component and providing the related information.

The diagram also shows that the process is not limited to a bilateral interaction. When a specific component is produced by another actor, the Tier-1 supplier can assign the corresponding Bill of Materials element to a Tier-2 supplier. The additional supplier accesses the platform and follows the same validation mechanism, contributing only the information related to its production stage, which is then validated by the Tier-1 supplier responsible for that component.

The observed workflow demonstrates that the Digital Product Passport functions as a distributed data collection system. The dataset is assembled incrementally across multiple supply chain tiers, while the brand maintains a supervisory role. Consequently, the platform operates not merely as a repository of documentation but as a structured data governance mechanism that coordinates responsibilities and ensures the reliability of product information.

Code	Type	Owner	Description	Additional Notes	Is Garment	Part
PRD-TSH-0001	Product	surge	Men's Basic White T-Shirt	Regular fit	Yes	APPA
BOM-002	Textile	surge	Rib Collar	-	No	FABR
BOM-001	Textile	surge	Main Fabric	-	No	FABR
BOM-003	Component	surge	Sewing Thread	-	No	OTHE

Figure 11. Product structure defined through the Bill of Materials (BoM) in the platform

5.4 Access to the Digital Product Passport: QR Code and Landing Page

To enable access to the Digital Product Passport outside the platform environment, a QR code is automatically generated for each registered product. The code is created directly by the system from the product record and can be downloaded from the platform interface (**Figure 12**).

The QR code can be scanned using a standard smartphone camera. Scanning the code redirects the user to a dedicated landing page associated with the specific product. The URL contains the product identifier and uniquely corresponds to a single product record, establishing the connection between the physical garment and its digital information page.

The landing page of the T-shirt reference case is accessible at <https://ac.demo.surge.eu/landing/01/PRD-TSH-0001>, allowing the product information to be consulted directly.

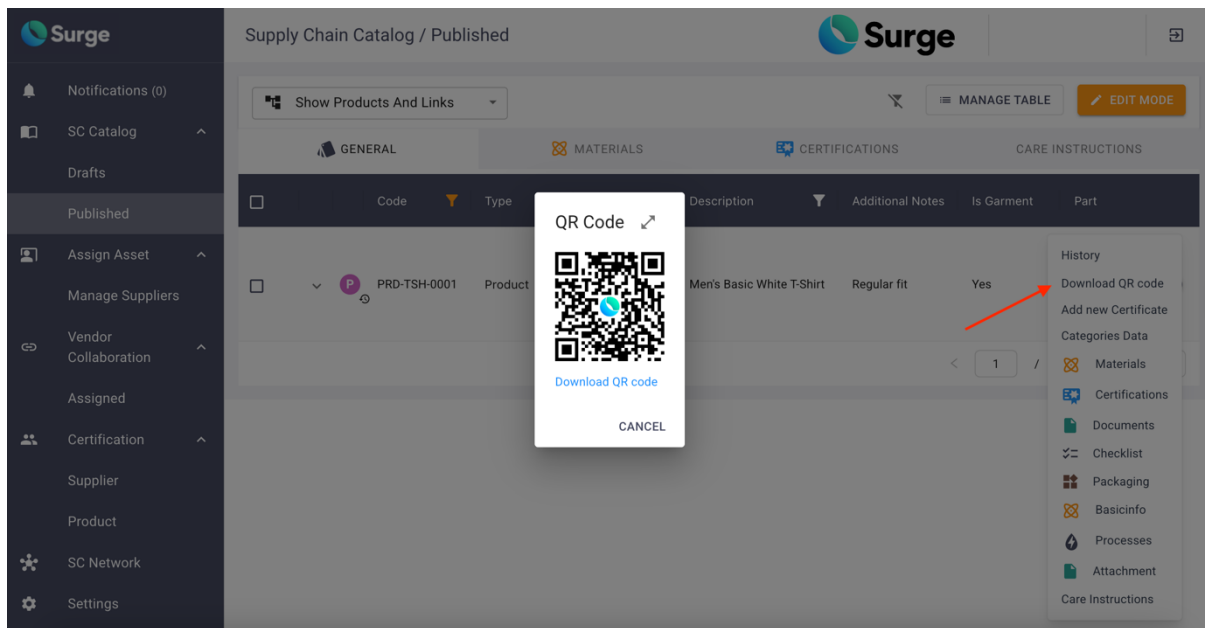


Figure 12. Automatically generated QR code associated with the T-shirt product

The same procedure was applied to the other products analysed in this study, namely a jacket and a pair of shoes. The landing pages associated with these additional products are also available through dedicated QR codes.

<https://ac.demo.surge.eu/landing/01/PRD-2026-00002>

<https://ac.demo.surge.eu/landing/01/PRD-SH-2025>

Figure 13 presents the landing pages associated with the analysed products. These pages constitute the external interface through which the Digital Product Passport (DPP) information can be accessed. While the platform internally stores product data within structured database fields, the landing page presents the same information in a human-readable format accessible without authentication, allowing product information to be consulted directly without entering the internal platform environment.

The interface organises the passport data into macro-categories reflecting the logical structure of the underlying data model. Rather than displaying all attributes simultaneously, the information is grouped into thematic sections that users can expand on demand. This expandable layout preserves readability while still enabling access to detailed product attributes.

Each section corresponds to a specific information domain of the passport. By selecting a category, users can visualise the related attributes without interacting with the internal database architecture. This design enables progressive access to information. The landing page therefore

acts as a user-oriented representation of the data model, translating structured product data into accessible information.

Figure 14 shows the Material Composition Data section, where the bill of materials and the associated material characteristics are displayed, including material percentages, country of origin, and provenance information.

Figure 15 presents the Care and Maintenance section, which provides guidance aimed at extending the product lifecycle. The information includes washing instructions, repair services offered by the brand, and end-of-life disposal recommendations.

Figure 16 illustrates the Supply Chain Traceability and Supply Chain Certification section, where the different production stages are documented together with information regarding the country of processing, water consumption, and energy consumption. The interface also provides a geographical visualisation of the supply chain through an interactive map and a section with the relative certifications.

Figure 17 shows the Environmental Impact Data section, where environmental indicators associated with the product are presented. In the reference case, the carbon footprint of the product is displayed together with the calculation methodology used.

The introduction of the QR code enables access to the Digital Product Passport outside the platform environment. By scanning the code, the user is redirected to the landing page associated with the specific product record, where the available information can be consulted without accessing the internal system interface.

In this way, the product information is no longer confined to the platform database but becomes accessible through the identified product itself. The QR code therefore establishes the connection between the physical garment and its corresponding digital information page.

Because the landing page retrieves the information directly from the platform database, any modification of the product record is reflected in the displayed content. The information associated with the Digital Product Passport can therefore be updated over time without generating a new document.




Men's Basic White T-Shirt

Product Identification Data ^

Brand Logo	
Type	APPAREL / TOPS / T-SHIRT
Season/Year	SPRING SUMMER - 2025
Color	WHITE
Gender	MALE
GTIN	00129348
Unit Weight (gr)	176
Fitting	Regular Fit




Women's Down Jacket

Product Identification Data ^

Brand Logo	
Type	APPAREL / Jackets & Blazers / Down-Jacket
Season/Year	FALL WINTER - 2026
Color	OLIVE
Gender	FEMALE
GTIN	88000322
Unit Weight (gr)	863
Fitting	Hooded, padded, front zip closure




Women's Low-top sneakers

Product Identification Data ^

Brand Logo	
Type	FOOTWEAR / Sneakers / Low-top
Season/Year	SPRING SUMMER - 2025
Color	DARK BLUE
Gender	FEMALE
GTIN	80512345
Unit Weight (gr)	422
Fitting	Comfort-focused fit designed for daily use

Figure 13. Digital Product Passport landing pages for the analysed products

Material Composition Data ^

Bill Of Material	Type	Description	Material %	Country Origin	Material Provenance
BOM-002	Textile	Rib Collar	Cotton 95%, Elastan 5%	PT - Portugal	BR - Brazil, CN - China, PLF - Plar
BOM-001	Textile	Main Fabric	Cotton 98%, Elastan 2%	PT - Portugal	BR - Brazil, CN - China, PLF - Plar
BOM-003	Component	Sewing Thread	Polyester 100%	CN - China	CN - China

Figure 14. Material Composition information displayed in the Digital Product Passport

Care & Maintenance ^

CARE & END-OF-LIFE

Guidance for longer product life



Drying

Hang to air dry for longer life.



Repair service

The brand provides repair services for minor damages such as loose seams or small tears. Contact our team at repairservice@whitebasics.com to ask more.



Disposal

Where available, dispose of via local textile collection systems; otherwise follow general waste guidelines.



No Take Back Program Available



Figure 15. Care and Maintenance information available in the Digital Product Passport

Supply Chain Traceability ^

Process	Country of Process	Water Consumption	Water Unit	Energy Consumption	Energy Unit
Spinning	IN - India	1.2	L/Kg	0.5	kWh/Kg
Knitting (flat or circular)	PT - Portugal	1	L/Kg	0.4	kWh/Kg
Dyeing and finishing	PT - Portugal	40	L/Kg	1.2	kWh/Kg
Cutting	PT - Portugal	0	L/Kg	0.05	kWh/Kg
Linking / Sewing	PT - Portugal	0	L/Kg	0.2	kWh/Kg
Packaging	PT - Portugal	0.2	L/Kg	0.1	kWh/Kg



Supply Chain Certification v

Figure 16. Supply Chain Traceability and Certification information within the Digital Product Passport

Environmental Impact Data ^

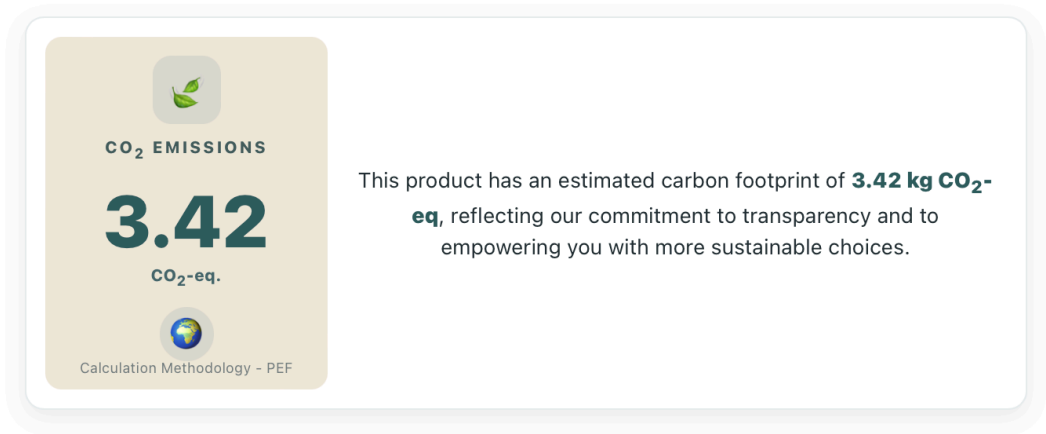


Figure 17. Environmental impact information displayed in the Digital Product Passport

6. Conclusion

This thesis adopted an exploratory approach to investigate how product-related information for the Digital Product Passport (DPP) can be structured and represented in the textile sector. Rather than aiming at a fully operational solution, the study focused on the development and application of a conceptual data model, as well as on the analysis of data ownership and information positioning along the supply chain.

The application of the proposed data model at product level highlighted both its potential and its limitations. While the model proved suitable for organising heterogeneous information domains and supporting a structured digital representation of product-related data, the results showed that information related to materials, fibres and upstream processing stages is generated and held by different supply chain actors, rather than being centrally available at product or brand level (CIRPASS-2 Consortium, 2023).

These findings indicate that a product-level Digital Product Passport may represent a feasible initial implementation under current regulatory and operational conditions, but it is not sufficient to fully support advanced traceability and lifecycle-oriented use cases. In particular, product-level granularity limits the possibility to associate information with individual product histories, as well as to record and update events occurring after the product is placed on the market, such as repair, reuse or resale (CIRPASS-2 Consortium, 2023).

In this context, the results of the study support the view that an item-level approach represents the most robust long-term direction for the implementation of the Digital Product Passport in the textile sector. Item-level granularity enables the linkage of information to individual physical products, while still allowing certain data—such as aggregated environmental indicators—to be managed at higher levels when appropriate (CIRPASS-2 Consortium, 2023).

Importantly, the adoption of item-level granularity does not imply that all information must be collected or disclosed at the same level of detail. Different information domains naturally operate at different granularities, and the coexistence of multiple levels of aggregation appears necessary to balance feasibility, data quality and system scalability. From this perspective, DPP systems should be designed to accommodate both item-level identification and aggregated data structures, rather than enforcing a single uniform level of granularity (CIRPASS-2 Consortium, 2023).

Beyond data granularity, an additional limitation concerns the physical data carrier used to access the Digital Product Passport. In this study, access to the DPP was enabled through a QR

code. However, reliance on a physical carrier introduces vulnerabilities related to product use and wear. Over time, labels or printed codes may deteriorate, be removed, or become unreadable, potentially preventing access to the digital information even when the underlying data remain available. This highlights that the effectiveness of a Digital Product Passport depends not only on data modelling and governance choices, but also on the durability and reliability of the physical–digital link throughout the product lifecycle.

This study has several limitations. The data used to populate the model were example data, and the analysis was conducted at product level. The current modelling approach mainly captures material-related attributes relevant for recycling processes. While this focus reflects the importance of material composition for end-of-life management in the textile sector, it also represents a limitation of the present approach. Some circular economy aspects are only partially represented. For instance, repair-related information can be included through descriptive attributes within the Care Instructions entity, but repair, reuse or remanufacturing activities are not represented as lifecycle events associated with individual product items. Similarly, information related to product disassembly or material separation prior to recycling is not explicitly represented. As a result, the current structure only partially supports the broader range of circular economy strategies that Digital Product Passports are expected to enable.

In addition, technical implementation aspects, real-world data availability and enforcement mechanisms were outside the scope of the research. Nevertheless, the findings provide useful insights into how data modelling choices influence the governance and evolution of Digital Product Passports.

As illustrated in **Figure 8**, the cascading structure reflects the distributed generation of product-related information across supply chain tiers. In this context, it can represent a possible mechanism to organise the flow of information across supply chain tiers. In such a model, data requests and data forwarding occur progressively between actors generating the relevant information. However, the effectiveness of this approach depends on specific enabling conditions. In the absence of a comprehensive regulatory obligation requiring all actors to share data, the functioning of the model would rely either on the willingness of supply chain partners to collaborate or on asymmetric power relations that enable dominant actors, such as brands, to request information from upstream suppliers.

Future research could extend this work by implementing the proposed data model at item level, testing it with real supply chain data, and further exploring the governance implications of distributed data ownership in Digital Product Passport systems. Such developments would

support the transition from initial, compliance-oriented DPP implementations towards more dynamic solutions aligned with circular economy objectives (CIRPASS-2 Consortium, 2023).

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Appendix A

A.1 UML Data Definition

Table A.1 Product Data Model Data Dictionary

Data Category Type	Field Name	Data Type	Validation logic
Product Generic Data	GenericID	String	Mandatory. System-generated unique key
Product Generic Data	ProductType	List of values (ENUM) - Apparel / Footwear / Accessories / Sport	Mandatory.
Product Generic Data	ProductCategory	List of values (ENUM)	Mandatory. Must match value from "Product Category" Table.
Product Generic Data	ProductSubCategory	List of values (ENUM)	Mandatory. Must match value from "Product Category" Table.
Product Generic Data	ProductName	String	Mandatory.
Product Generic Data	ProductModel	String	Mandatory.
Product Generic Data	Season	List of values (ENUM) - SpringSummer / FallWinter / Carryover - (SS / FW / CO)	Mandatory.
Product Generic Data	Year	Integer	Mandatory. Must be 4 digits (YYYY). Allowed range: 1900–current year + 1
Product Generic Data	KeyFeatures	Text	Optional.
Product Generic Data	CE Marking Information	List of values (ENUM) - Yes / No / Not applicable	Mandatory. Based on product category.
Product Generic Data	hasSize()	Boolean	Mandatory. Default = No. Must be "Yes" if ProductType = Apparel / Footwear / Sport
Data Category Type	Field Name	Data Type	Validation logic
Product Identification Data	ProductID	String	Mandatory. System-generated unique key
Product Identification Data	GTIN	String	Mandatory. Digits only, must follow GS1 format (8–14 digits)
Product Identification Data	ColorName	List of values (ENUM)	Mandatory. Must match value from "Colors" Table.
Product Identification Data	ColorCode	List of values (ENUM)	Mandatory. Must match value from "Colors" Table.
Product Identification Data	ProductWeight	Decimal	Mandatory.
Product Identification Data	ProductWeightUnit	List of values (ENUM) - g / Kg / lb	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
Size Data	SizeDataID	String	Mandatory. System-generated unique key
Size Data	Gender	List of values (ENUM) - Male / Female / Kids	Mandatory.
Size Data	GarmentType	List of values (ENUM) - Top / Bottom / General / Footwear	Mandatory.
Size Data	SizeStandard	List of values (ENUM) - IT / INT / EU / FR / US / UK	Mandatory.
Size Data	SizeValue	String	Mandatory. Must match a value from SizeTable sheet for the same (Gender + GarmentType + SizeStandard).
Data Category Type	Field Name	Data Type	Validation logic
Bill of Material	BOMItemID	String	Mandatory. System-generated unique key
Bill of Material	ComponentName	String	Mandatory.
Bill of Material	CompositionPercentageofProduct	Decimal (0–100)	Mandatory. Sum of all materials for a product must = 100%.
Bill of Material	QuantityUsed	Decimal	Mandatory. How many pieces / meters / m2 of the material are used
Bill of Material	QuantityUOM	List of values (ENUM) - piece / m / m2	Mandatory. UoM of the quantity used
Bill of Material	BOMItemWeight	Decimal	Auto-calculated: ProductWeight x CompositionPercentageofProduct
Bill of Material	BOMItemWeightUnit	List of values (ENUM) - g / kg	Mandatory. Weight UoM
Data Category Type	Field Name	Data Type	Validation logic
Material Fiber Breakdown	BOMItemID	String	Mandatory. System-generated unique key
Material Fiber Breakdown	MaterialID	String	Mandatory. Must match an existing MaterialID.
Material Fiber Breakdown	ComponentName	String	Mandatory.
Material Fiber Breakdown	FiberName	List values (ENUM)	Mandatory. Refer to "MaterialFamily" Table.
Material Fiber Breakdown	PercentageOfMaterial	Decimal (0–100)	Mandatory.
Material Fiber Breakdown	MaterialWeight	Decimal	Auto-calculated: BOMItemWeight x PercentageOfMaterial

Table A.1 (continued)

Data Category Type	Field Name	Data Type	Validation logic
Material	MaterialID	String	Mandatory. System-generated unique key
Material	MaterialName	List values (ENUM)	Mandatory. Refer to "MaterialFamily" Table.
Material	MaterialFamily	List values (ENUM)	Mandatory. Refer to "MaterialFamily" Table.
Material	RawMaterialOrigin	List of values (ENUM) (ISO 3166-1 alpha-2 code)	Mandatory. Where the material is grown/extracted. Refer to "ISO_CountryCodes" Table.
Material	SupplierCountry	List of values (ENUM) (ISO 3166-1 alpha-2 code)	Mandatory. Country where the material is processed / supplied. Refer to "ISO_CountryCodes" Table.
Material	CatalogueWeightValue	Decimal	Mandatory. The declared weight of the material as provided by the supplier.
Material	CatalogueWeightUOM	List values (ENUM) - g / kg / gsm / g/m	Mandatory. The unit of measurement for the declared weight.
Material	CatalogueQtyForWeight	Decimal	Mandatory. The quantity of material associated with the declared weight.
Material	CatalogueQtyUOM	List values (ENUM) - piece / m / m2 / roll	Mandatory. The unit of measurement for the declared quantity.
Material	UnitWeightValue	Decimal	Auto-calculated: Weight per single unit of material, calculated as: CatalogueWeightValue ÷ CatalogueQtyForWeight
Material	RecycledContentPercentage	Decimal (0–100)	Mandatory.
Material	VirginMaterialPercentage	Decimal (0–100)	Mandatory.
Material	RenewableContentPercentage	Decimal (0–100)	Optional. % of renewable content
Material	hasAnimalOrigin	Boolean	Mandatory. Default = No. Must be "Yes" if Animal-Origin data is supplied.
Material	isSubstanceOfConcernPresent	Boolean	Mandatory. Default = No. Must be "Yes" if hazardous substances are listed.
Data Category Type	Field Name	Data Type	Validation logic
DisposableFeature	DisposableFeatureID	String	Mandatory. System-generated unique key
DisposableFeature	MaterialID	String	Mandatory. Must match an existing MaterialID.
DisposableFeature	Code	List values (ENUM)	Mandatory. Must match value from "Disposable Features" Table.
DisposableFeature	Description	List values (ENUM)	Mandatory. Must match value from "Disposable Features" Table.
Data Category Type	Field Name	Data Type	Validation logic
Animal-Origin Presence	AnimalOriginPresenceID	String	Mandatory. System-generated unique key
Animal-Origin Presence	MaterialID	String	Mandatory. Must match an existing MaterialID.
Animal-Origin Presence	AnimalSpecies	String	Mandatory if AnimalOriginPresence = Yes.
Data Category Type	Field Name	Data Type	Validation logic
Substance of ConcernPresence	SubstanceOfConcernPresenceID	String	Mandatory. System-generated unique key
Substance of ConcernPresence	MaterialID	String	Mandatory. Must match an existing MaterialID.
Substance of ConcernPresence	SubstanceName	List of values (ENUM)	Mandatory. Refer to "Substance of Concern" Table.
Substance of ConcernPresence	CASNumber	Lookup (derived)	Auto-filled according to selected substance. Not editable.
Substance of ConcernPresence	Category	Lookup (derived)	Auto-filled according to selected substance. Not editable.
Substance of ConcernPresence	MaterialType	Lookup (derived)	Auto-filled according to selected substance. Not editable.
Substance of ConcernPresence	Process	Lookup (derived)	Auto-filled according to selected substance. Not editable.
Substance of ConcernPresence	Concentration	Decimal (mg/kg (ppm))	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
MaterialDocumentation	MaterialDocumentID	String	Mandatory. System-generated unique key
MaterialDocumentation	MaterialID	String	Mandatory. Must match an existing MaterialID.
MaterialDocumentation	DocumentationType	List of values (ENUM) - MaterialCertification / ChemicalCertification / AnimalWelfareCertification / TraceabilityCertification / SocialAudit / ComplianceDeclaration / ManagementSystemCertification / EnvironmentalCertification	Mandatory.

Table A.1 (continued)

Data Category Type	Field Name	Data Type	Validation logic
MaterialDocumentation	Name	List of values (ENUM)	Mandatory. Refer to "Fashion Certification" Table.
MaterialDocumentation	IssuingOrganization	String	Mandatory. Name of certifier / issuer.
MaterialDocumentation	ValidFrom	Date (YYYY-MM-DD)	Mandatory for certificates, audits or regulated documents. Optional for self-declarations or non-expiring documents.
MaterialDocumentation	ValidUntil	Date (YYYY-MM-DD)	Optional. Required if the document has an expiry date. Must be later than ValidFrom.
MaterialDocumentation	Status	List of values (ENUM) - Active / Expired / PendingVerification / Revoked / UnderReview	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
Supply Chain Traceability	SupplyChainTraceabilityID	String	Mandatory. System-generated unique key
Supply Chain Traceability	CompanyID	String	Mandatory. Must match an existing CompanyID.
Supply Chain Traceability	TierLevel	List of values (ENUM) - Tier1 / Tier2 / Tier3 / Tier4	Mandatory.
Supply Chain Traceability	ManufacturingProcess	String	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
Transportation	TransportationID	String	Mandatory. System-generated unique key
Transportation	TransportMode	List of values (ENUM) - Road / Air / Rail / Maritime / Inland waterways	Mandatory.
Transportation	Distance	Decimal (km)	Mandatory. ≥ 0.
Data Category Type	Field Name	Data Type	Validation logic
Company	CompanyID	String	Mandatory. System-generated unique key
Company	CompanyName	String	Mandatory.
Company	CompanyRegistrationNumber	String	Mandatory. VAT or company registration number.
Company	EmailAddress	String	Optional. Must be valid email format.
Company	EmployeeCount	Integer	Optional. ≥ 0.
Company	PercentageOfWomen	Decimal (0–100)	Optional.
Company	PercentageOfMen	Decimal (0–100)	Optional.
Company	PercentageOfNotSpecified	Decimal (0–100)	Optional.
Data Category Type	Field Name	Data Type	Validation logic
CompanyDocumentation	CompanyDocumentID	String	Mandatory. System-generated unique key
CompanyDocumentation	CompanyID	String	Mandatory. Must match an existing CompanyID.
CompanyDocumentation	DocumentationType	List of values (ENUM) - SocialAudit / EthicalCertification / ManagementSystemCertification / EnvironmentalManagement / SafetyAudit / ESGReportingFramework / ComplianceDeclaration / DueDiligenceDocumentation	Mandatory.
CompanyDocumentation	Name	List of values (ENUM)	Mandatory. Refer to "Company Documentation" Table.
CompanyDocumentation	IssuingOrganization	String	Mandatory. Name of certifier / issuer.
CompanyDocumentation	ValidFrom	Date (YYYY-MM-DD)	Mandatory for certificates, audits or regulated documents. Optional for self-declarations or non-expiring documents.
CompanyDocumentation	ValidUntil	Date (YYYY-MM-DD)	Optional. Required if the document has an expiry date. Must be later than ValidFrom.
CompanyDocumentation	Status	List of values (ENUM) - Active / Expired / PendingVerification / Revoked / UnderReview	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
Address	AddressID	String	Mandatory. System-generated unique key
Address	CompanyID	String	Mandatory. Must match an existing CompanyID.
Address	AddressType	List of values (ENUM)	Mandatory. See "AddressType" Table.
Address	StreetName	String	Mandatory.

Table A.1 (continued)

Data Category Type	Field Name	Data Type	Validation logic
Address	StreetNumber	String	Mandatory.
Address	City	String	Mandatory.
Address	PostalCode	String	Mandatory.
Address	Country	List of values (ENUM) (ISO 3166-1 alpha-2 code)	Mandatory. Refer to "ISO_CountryCodes" Table.
Address	Latitude	Double/Float	Mandatory. Between -90 and 90.
Address	Longitude	Double/Float	Mandatory. Between -180 and 180.
Data Category Type	Field Name	Data Type	Validation logic
Environmental Impact	EnvironmentalImpactID	String	Mandatory. System-generated unique key
Environmental Impact	ProductID	String	Mandatory. Must match an existing ProductID.
Environmental Impact	Cradle-to-gateCO2eEmissions	Decimal (kg CO ₂ e)	Mandatory if LCA data available; ≥ 0.
Environmental Impact	BreakdownByLCStage	Structured text / free text	Mandatory. Used to store emissions allocation across life cycle stages (e.g., raw materials, manufacturing, transport, packaging). Format is flexible.
Environmental Impact	CalculationMethodology	List of values (ENUM) - PEF / ISO14067 / GHG Protocol / Ecoinvent / Other	Mandatory.
Data Category Type	Field Name	Data Type	Validation logic
Care Instructions	CareInstructionsID	String	Mandatory. System-generated unique key
Care Instructions	ProductID	String	Mandatory. Must match an existing ProductID.
Care Instructions	WashingMethod	List of values (ENUM) - MachineWash / HandWash / DoNotWash / DryCleanOnly / SpotCleanOnly / NotApplicable	Mandatory if the product is intended to be washed by the end user; otherwise set to NotApplicable.
Care Instructions	MaxWashingTemperature	Integer (°C)	Mandatory if WashingMethod = Machine/Hand; otherwise null/NA.
Care Instructions	DryingMethod	List of values (ENUM) - TumbleDryLow / TumbleDryMedium / TumbleDryHigh / LineDry / FlatDry / DoNotTumbleDry	Mandatory.
Care Instructions	IroningAllowed	Boolean - Yes / No	Mandatory.
Care Instructions	MaxIroningTemperature	Integer (°C)	Mandatory if IroningAllowed = Yes.
Care Instructions	BleachAllowed	Boolean - Yes / No	Mandatory.
Care Instructions	CareDescription	String	Optional. Human-readable care instructions.
Care Instructions	RepairOptionsDescription	String	Optional. Available repair services/options.
Care Instructions	EndOfLifeGuidanceDescription	String	Optional. How to dispose, recycle or return the product.
Care Instructions	TakeBackProgramAvailable	Boolean - Yes / No	Mandatory.
Care Instructions	TakeBackProgramDetails	String	Mandatory if TakeBackProgramAvailable = Yes.

A.2 Colors and Patterns Definition

Table A.2 Controlled vocabulary for color attributes

Code	Name	Colors
		Description
BLK	Black	Pure black
CBL	Carbon Black	Deep matte black
CHR	Charcoal	Very dark grey
DGY	Dark Grey	Dark neutral grey
GRY	Grey	Mid grey
LGY	Light Grey	Pale grey
AGY	Ash Grey	Warm-toned grey
SGY	Silver Grey	Cool grey
WHT	White	Pure white
NAT	Natural	Undyed fiber shade
ECR	Ecru	Raw beige-white
IVO	Ivory	Soft warm white
CRM	Cream	Slight yellow tone
OWT	Off White	Slightly toned white
BEI	Beige	Light neutral
SND	Sand	Light beige
TAN	Tan	Camel-like brown
CAM	Camel	Classic camel tone
TBK	Taupe	Grey-brown
BRN	Brown	Mid neutral brown
DBR	Dark Brown	Espresso brown
CHC	Chocolate	Warm dark brown
COP	Copper	Metallic orange-brown
RST	Rust	Burnt orange-brown
RED	Red	Standard red
DRD	Dark Red	Deep red
BUR	Burgundy	Wine colour
MAR	Maroon	Brown-red tone
RBR	Ruby Red	Jewel-tone red
CRL	Coral	Red-pink-orange
PNK	Pink	Neutral pink
HPK	Hot Pink	Fuchsia bright
LPK	Light Pink	Pastel baby pink
ROS	Rose	Dusty soft pink
SAL	Salmon	Peach-pink
ORG	Orange	Standard orange
BRG	Burnt Orange	Deep warm orange
DSP	Deep Spice	Earthy fashion orange

Table A.2 (continued)

Code	Name	Description
YLW	Yellow	Standard yellow
MTD	Mustard	Warm brown-yellow
GLD	Gold	Metallic yellow
GRN	Green	True green
OLV	Olive	Military green
KHK	Khaki	Beige green
EMR	Emerald	Vivid jewel green
FOR	Forest Green	Dark nature green
MNT	Mint	Soft pastel green
LME	Lime	Neon yellow-green
SEA	Sea Green	Blue-green tone
NAV	Navy	Very dark blue
DBL	Dark Blue	Deep blue
BLU	Blue	Mid blue
IND	Indigo	Denim tone
SKY	Sky Blue	Pale pastel blue
AQ	Aqua	Light blue-green
TQS	Turquoise	Bright aqua
CYN	Cyan	Technical bright blue
PUR	Purple	Mid-purple
VIO	Violet	Blue-purple
PLU	Plum	Deep purple
LAV	Lavender	Light purple
LIL	Lilac	Pale pastel purple
SIL	Silver	Metallic grey
BRS	Brass	Antique gold
RGD	Rose Gold	Pink-gold metallic
MLT	Multicolour	Multiple colors combined
PRN	Printed	Printed design or motif
STR	Striped	Stripe pattern
CHK	Checkered / Tartan	Check or tartan patterned design
ANM	Animal Print	Inspired by animal skin or fur
CMO	Camouflage	Military-inspired
HTH	Heather / Mélange	Mixed-fiber or mixed-colour melange effect
DYE	Tie-Dye	Tie-dye dyed fabric

A.3 Product Categories

This appendix defines the controlled vocabulary adopted to classify products in the dataset. Each item is assigned to a Category and, where applicable, to a more specific SubCategory. The classification follows a hierarchical structure and is organised into three main groups: Apparel, Accessories, and Footwear.

Apparel

Tops

- T-shirts
- Polo shirts
- Blouses
- Long-sleeve tops
- Tank tops
- Overshirts

Knitwear

- Sweaters / Jumpers
- Cardigans
- Knit pullovers

Dresses & One-Pieces

- Jumpsuits
- Casual dresses
- Evening dresses
- Occasion dresses
- Shirt dresses
- Jersey dresses
- Maxi dresses
- Denim dresses
- Knitted dresses
- Overalls

Jeans

- Wide Leg
- Relaxed
- Baggy & Loose

- Bootcut & Flared
- Straight
- Skinny
- Mom Jeans
- Slim
- Jumpsuits & Overalls
- Denim Shorts

Trousers

- Chinos
- Slacks
- Leggings
- Leather Trousers
- Cargo Trousers
- Jogging Trousers

Skirts

- Denim skirts
- A-line skirts
- Pencil skirts
- Maxi skirts
- Mini skirts
- Pleated skirts
- Leather skirts

Swimwear

- Bikinis
- Swimsuits
- Beach accessories
- Swim shorts

Nightwear & Loungewear

- Night shirts
- Pyjamas
- Shirts
- Trousers
- Bathrobes

Socks & Tights

Tights

Socks

Sports socks

Stay-ups

Underwear

Bras

Bodysuits

Shapewear

Panties

Boxer briefs

Trunks

Briefs

Undershirts

Suits & Formalwear

Suits

Suit jackets

Suit trousers

Waistcoats

Sweatshirts & Hoodies

Sweatshirts

Hoodies

Sweat jackets

Fleece Jackets & Pullovers

Jackets & Blazers

Lightweight Jackets

Waterproof Jackets

Leather Jackets

Denim Jackets

Blazers

Capes

Waistcoats

Outdoor Jackets

Training Jackets

- Winter Jackets
- Down Jackets
- Bomber Jackets

Coats

- Parkas
- Trench coats
- Short coats
- Classic Coats
- Winter coats
- Down coats

Accessories

Bags & cases

- Handbags
- Clutches & evening bags
- Shopper bags
- Shoulder & cross body bags
- Business & laptop bags
- Sports bags
- Bum bags
- Pencil cases
- Backpacks
- Travel bags & cases
- Diaper Bags
- Bag Charms and Keyrings
- Messenger bags
- Briefcases

Jewellery

- Necklaces
- Bracelets
- Earrings
- Rings
- Pendants
- Hair accessories
- Anklets

Charms

Cufflinks

Belts

Casual belts

Waist belt

Braided belt

Umbrellas

Wallets & card holders

Wallets

Bag Charms and Keyrings

Card cases

Passport holders

Hats & caps

Caps

Hats

Beanies

Ear warmers

Balaclavas

Scarves

Scarves

Light scarves

Loop scarves

Gloves

Mittens

Gloves

Fingerless gloves

Sportswear

Training tops

Training bottoms

Running apparel

Compression wear

Base layers

Skiwear

Cycling apparel

Footwear

Sneakers

Low-top sneakers

High-top sneakers

Ankle boots

Ankle boots

Lace-up ankle boots

Cowboy & Biker ankle boots

Platform ankle boots

Wedge ankle boots

Boots

Classic boots

Winter Boots

Lace-up boots

Cowboy & Biker boots

Overknee Boots

Platform boots

High Heel Boots

Wellies

Pumps

Classic pumps

Peep toes

Wedge pumps

Platform pumps

Lace-up pumps

Flat shoes

Loafers

Espadrilles

Lace-up shoes

Moccasins

Ballerinas

Classic Ballerinas

Ankle Strap Ballerinas

- Slingback Ballerinas
- High heels
 - Pumps
 - Peep toes
 - Sandals
- Mules
 - Flat mules
 - Heeled Mules
 - Clogs
- House shoes
- Sandals
 - Strap sandals
 - Wedge sandals
 - Thong sandals
 - Platform sandals
- Sports shoes
 - Running shoes
 - Training shoes
 - Sandals & slides
 - Hiking & mountaineering shoes
 - Tennis shoes
 - Indoor shoes
 - Football boots
 - Golf shoes
 - Cycling shoes
 - Padel Tennis Shoes
 - Boots
 - Ski & snowboard boots
- Beach shoes
 - Thong sandals
 - Pool slides
- Lace-up shoes
 - Classic Lace ups

Sporty lace-ups

Boat shoes

A.4 Size Table

This appendix presents the international size conversion tables used to standardize product size information within the dataset. The correspondence among different sizing systems (IT, EU, FR, UK, US) allows the comparison of items across categories and measurement conventions.

A.4.1 Apparel - Top

Table A.3 International apparel size conversion table for tops

Women sizing system						
Type	Gender	IT	INT	EU	FR	UK
TOP	WOMAN	38	XXS	32	34	4
TOP	WOMAN	40	XS	34	36	6
TOP	WOMAN	42	S	36	38	8
TOP	WOMAN	44	M	38	40	10
TOP	WOMAN	46	L	40	42	12
TOP	WOMAN	48	XL	42	44	14
TOP	WOMAN	50	XXL	44	46	16
TOP	WOMAN	52	3XL	46	48	18
TOP	WOMAN	54	4XL	48	50	20
TOP	WOMAN	56	5XL	50	52	22
TOP	WOMAN	58	6XL	52	54	24
TOP	WOMAN	60	7XL	54	56	26
TOP	WOMAN	62	8XL	56	58	28
TOP	WOMAN	64	9XL	58	60	30
TOP	WOMAN	66	10XL	60	62	32

Table A.3 (continued)

Men sizing system						
Type	Gender	IT	INT	EU	FR	UK
TOP	MAN	42	XS	42	42	32R
TOP	MAN	44	S	44	44	34R
TOP	MAN	46	S	46	46	36R
TOP	MAN	48	M	48	48	38R
TOP	MAN	50	M	50	50	40R
TOP	MAN	52	L	52	52	42R
TOP	MAN	54	XL	54	54	44R
TOP	MAN	56	XXL	56	56	46R
TOP	MAN	58	3XL	58	58	48R
TOP	MAN	60	3XL	60	60	50R
TOP	MAN	62	4XL	62	62	52R

TOP	MAN	64	4XL	64	64	54R
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Table A.3 (continued)

Type	Gender	IT	INT	EU	FR	UK
TOP	MAN	66	5XL	66	66	56R
TOP	MAN	68	5XL	68	68	58R
TOP	MAN	70	6XL	70	70	60R
TOP	MAN	72	6XL	72	72	62R
TOP	MAN	74	7XL	74	74	64R
TOP	MAN	76	8XL	76	76	66R
TOP	MAN	78	8XL	78	78	68R
TOP	MAN	90	XS	90	90	36L
TOP	MAN	94	S	94	94	38L
TOP	MAN	98	M	98	98	40L
TOP	MAN	102	L	102	102	42L
TOP	MAN	106	XL	106	106	44L
TOP	MAN	110	XXL	110	110	46L
TOP	MAN	114	3XL	114	114	48L
TOP	MAN	118	3XL	118	118	50L

A.4.2 Apparel – Bottoms

Table A.4 International apparel size conversion table for bottoms

Women sizing system						
Type	Gender	IT	INT	EU	FR	UK
BOTTOM	WOMAN	36	XS	30	32	2
BOTTOM	WOMAN	38	XS	32	34	4
BOTTOM	WOMAN	38	XS	32	34	4
BOTTOM	WOMAN	40	S	34	36	6
BOTTOM	WOMAN	40	S	34	36	6
BOTTOM	WOMAN	42	S	36	38	8
BOTTOM	WOMAN	42	M	36	38	8
BOTTOM	WOMAN	44	M	38	40	10
BOTTOM	WOMAN	44	M	38	40	10
BOTTOM	WOMAN	46	L	40	42	12
BOTTOM	WOMAN	46	L	40	42	12
BOTTOM	WOMAN	48	L	42	44	14

Table A.4 (continued)

Men sizing system						
Type	Gender	IT	INT	EU	FR	UK
BOTTOM	MAN	44	S	44	44	34
BOTTOM	MAN	46	S/M	46	46	36

Table A.4 (continued)

Type	Gender	IT	INT	EU	FR	UK
BOTTOM	MAN	46	S/M	46	46	36
BOTTOM	MAN	48	M	48	48	38
BOTTOM	MAN	48	M	48	48	38
BOTTOM	MAN	50	L	50	50	40
BOTTOM	MAN	50	L	50	50	40
BOTTOM	MAN	52	XL	52	52	42
BOTTOM	MAN	54	XL	54	54	44
BOTTOM	MAN	56	XXL	56	56	46
BOTTOM	MAN	58	3XL	58	58	48

A.4.3 General – Kids

Table A.5 International apparel size conversion table for kids

Type	SIZE	
	Gender	INT
GENERAL	KIDS	3-6M
GENERAL	KIDS	6-9M
GENERAL	KIDS	12-18M
GENERAL	KIDS	3Y
GENERAL	KIDS	6Y
GENERAL	KIDS	10Y
GENERAL	KIDS	12Y

A.4.3 Footwear

Table A.6 International footwear size conversion table

Women sizing system					
Type	Gender	IT	EU	UK	US
FOOTWEAR	WOMAN	36	36	3	5
FOOTWEAR	WOMAN	36,5	36,5	3,5	5,5
FOOTWEAR	WOMAN	37	37	4	6
FOOTWEAR	WOMAN	38	38	5	6,5
FOOTWEAR	WOMAN	38,5	38,5	5,5	7
FOOTWEAR	WOMAN	39	39	6	7,5
FOOTWEAR	WOMAN	40	40	7	8
FOOTWEAR	WOMAN	40,5	40,5	7,5	8,5

FOOTWEAR	WOMAN	41	41	8	9
FOOTWEAR	WOMAN	42	42	9	9,5

Table A.6 (continued)

Type	Gender	Men sizing system			
		IT	EU	UK	US
FOOTWEAR	MAN	39	39	5	7
FOOTWEAR	MAN	40	40	6	7,5
FOOTWEAR	MAN	40,5	40,5	6,5	8
FOOTWEAR	MAN	41	41	7	8,5
FOOTWEAR	MAN	42	42	8	9
FOOTWEAR	MAN	42,5	42,5	8,5	9,5
FOOTWEAR	MAN	43	43	9	10
FOOTWEAR	MAN	44	44	10	10,5
FOOTWEAR	MAN	44,5	44,5	10,5	11
FOOTWEAR	MAN	45	45	11	11,5
FOOTWEAR	MAN	46	46	12	12
FOOTWEAR	MAN	46,5	46,5	12,5	12,5
FOOTWEAR	MAN	47	47	13	13
FOOTWEAR	MAN	48	48	14	13,5

Table A.6 (continued)

Type	Gender	Kids sizing system			
		IT	EU	UK	US
FOOTWEAR	KIDS	16	16	0.5	1
FOOTWEAR	KIDS	17	17	1.5	2
FOOTWEAR	KIDS	18	18	2.5	3
FOOTWEAR	KIDS	19	19	3	4
FOOTWEAR	KIDS	20	20	4	5
FOOTWEAR	KIDS	21	21	4.5	5.5
FOOTWEAR	KIDS	22	22	5	6
FOOTWEAR	KIDS	23	23	6	7
FOOTWEAR	KIDS	24	24	7	8
FOOTWEAR	KIDS	25	25	7.5	8.5
FOOTWEAR	KIDS	26	26	8.5	9.5
FOOTWEAR	KIDS	27	27	9	10
FOOTWEAR	KIDS	28	28	10	11
FOOTWEAR	KIDS	29	29	10.5	11.5
FOOTWEAR	KIDS	30	30	11.5	12.5
FOOTWEAR	KIDS	31	31	12	13
FOOTWEAR	KIDS	32	32	13	1 (Youth)
FOOTWEAR	KIDS	33	33	1	2 (Youth)
FOOTWEAR	KIDS	34	34	2	3 (Youth)
FOOTWEAR	KIDS	35	35	2.5	4 (Youth)

A.5 Material Family

Table A.7 Material family classification

Code	Name	Family	Description
AB	ABACA (MANILA HEMP)	AFV	Other vegetable fibres
AC	ACETATE	AFS	Other synthetic fibres
ACC	STEEL	AF	Other fibres and materials (including metals)
AF	OTHER FIBRES	AF	Other fibres and materials (including metals)
AG	ALGINATE	FCC	Circular cellulosic fibres
AL	ALFA	AFV	Other vegetable fibres
APP	DRIED APPLE WASTE	FCC	Circular cellulosic fibres
AR	ARAMID	AFS	Other synthetic fibres
CA	TRUE HEMP	AFV	Other vegetable fibres
CAC	CALCIUM CARBONATE	AF	Other fibres and materials (including metals)
CC	COIR	AFV	Other vegetable fibres
CER	CERAMIC FIBER	AF	Other fibres and materials (including metals)
CL	CHLOROFIBRE	AFS	Other synthetic fibres
CO	COTTON	CO	Cotton
CT	PAPER	AFC	Other cellulosic fibres
CU	CUPRO	FCC	Circular cellulosic fibres
EA	ELASTANE	AFS	Other synthetic fibres
EE	ELASTOMULTIESTER	AFS	Other synthetic fibres
EF	ELASTOLEFIN / LASTOL	AFS	Other synthetic fibres
EL	ELASTODIENE	AF	Other fibres and materials (including metals)
EVA	ETHYLENE-VINYL ACETATE	AFS	Other synthetic fibres
FL	FLUOROFIBRE	AFS	Other synthetic fibres
FR	ROSE FIBER	AFV	Other vegetable fibres
GI	BROOM	AFV	Other vegetable fibres
GL	GLASS FIBRE	AF	Other fibres and materials (including metals)
HB	BUFFALO LEATHER	AP	Other leathers
HC	HORSE LEATHER	AP	Other leathers
HD	LAMB LEATHER	AP	Other leathers
HE	HENEQUEN	AFV	Other vegetable fibres
HF	SHEEP LEATHER	AP	Other leathers
HG	CALF LEATHER	AP	Other leathers
HH	PIG LEATHER	AP	Other leathers
HK	RAM LEATHER	VP	Cow and sheep leather
HW	SNAKESKIN	AP	Other leathers
HY	GOAT	FA	Animal fibres
HZ	BOVINE SKIN	VP	Cow and sheep leather

Table A.7 (continued)

Code	Name	Family	Description
JU	JUTE	AFV	Other vegetable fibres
KE	KENAF	AFV	Other vegetable fibres
KP	KAPOK	AFV	Other vegetable fibres
LG	WOOD	AF	Other fibres and materials (including metals)
LI	LINEN	AFV	Other vegetable fibres
LY	LYOCELL	FCC	Circular cellulosic fibres
MA	MODACRYLIC	AFC	Other cellulosic fibres
MD	MODAL	AFC	Other cellulosic fibres
ME	METALLISED FIBRE	AF	Other fibres and materials (including metals)
MG	MAGUEY	AFV	Other vegetable fibres
MM	MELAMINE	AFS	Other synthetic fibres
MT	METAL	AF	Other fibres and materials (including metals)
MZ	METALLIC	AF	Other fibres and materials (including metals)
PA	POLYAMIDE	AFS	Other synthetic fibres
PB	POLYCARBAMIDE	AFS	Other synthetic fibres
PC	ACRYLIC	AFS	Other synthetic fibres
PD	POLYLACTIDE / PLA	AFS	Other synthetic fibres
PDE	EMU'S FEATHERS	PPI	Feathers and down
PDM	MARABU FEATHER	PPI	Feathers and down
PDP	CHICKEN'S FEATHERS	PPI	Feathers and down
PDT	TURCKEY FEATHERS	PPI	Feathers and down
PE	POLYETHYLENE	AFS	Other synthetic fibres
PG	STRAW	AFV	Other vegetable fibres
PI	POLYIMIDE	AFS	Other synthetic fibres
PIE	STONE	AF	Other fibres and materials (including metals)
PL	POLYESTER	PL	Polyester
POG	GREY GOOSE DOWN	PPI	Feathers and down
PP	POLYPROPYL	AFS	Other synthetic fibres
PR	PROTEIN	AF	Other fibres and materials (including metals)
PU	POLYURETHANE	AFS	Other synthetic fibres
PVC	POLYVINYL CHLORIDE	AFS	Other synthetic fibres
RA	RAMIE	AFV	Other vegetable fibres
RC	BONDED LEATHER	AF	Other fibres and materials (including metals)
RM	COPPER	AF	Other fibres and materials (including metals)
RS	ACRYL.RES.	AFS	Other synthetic fibres
SE	SILK	FA	Animal fibres

Table A.7 (continued)

Code	Name	Family	Description
SI	SISAL	AFV	Other vegetable fibres
SN	SUN	AFV	Other vegetable fibres
TA	TRIACETATE	AFS	Other synthetic fibres
TV	TRIVINYL	AFS	Other synthetic fibres
VI	VISCOSE	AFC	Other cellulosic fibres
VT	GLASS	AF	Other fibres and materials (including metals)
VY	VINYAL	AFS	Other synthetic fibres
WG	VICUNA	FA	Animal fibres
WH	CASHGORA	FA	Animal fibres
WK	CAMELHAIR	FA	Animal fibres
WL	LAMA	FA	Animal fibres
WM	MOHAIR	FA	Animal fibres
WN	LAMB	FA	Animal fibres
WO	WOOL	FA	Animal fibres
WP	ALPACA	FA	Animal fibres
WS	CASHMERE	FA	Animal fibres
WU	GUANACO	FA	Animal fibres
WV	VIRGIN WOOL	FA	Animal fibres
WY	YAK	FA	Animal fibres
WZ	STYRENE FLOCKED	AFS	Other synthetic fibres
ZC	BAMBOO	AFC	Other cellulosic fibres
ZD	CORK	AFC	Other cellulosic fibres
ZE	BRASS	AF	Other fibres and materials (including metals)
ZG	ALUMINIUM	AF	Other fibres and materials (including metals)
ZH	SHELLAC	AF	Other fibres and materials (including metals)
ZJ	PLEXIGLASS	AF	Other fibres and materials (including metals)
ZK	ZINC ALLOY	AF	Other fibres and materials (including metals)
ZL	OSTRICH FEATHER	PPI	Feathers and down
ZM	CRYSTAL	AF	Other fibres and materials (including metals)
ZN	ZINC	AF	Other fibres and materials (including metals)
ZP	SILICA	AF	Other fibres and materials (including metals)
ZQ	IRON	AF	Other fibres and materials (including metals)

A.6 ISO Country Codes

Table A.8 ISO 3166-1 alpha-2 country codes used in the data model

Code	Country
AF	Afghanistan
AL	Albania
DZ	Algeria
AS	American Samoa
AD	Andorra
AO	Angola
AI	Anguilla
AQ	Antarctica
AG	Antigua and Barbuda
AR	Argentina
AM	Armenia
AW	Aruba
AU	Australia
AT	Austria
AZ	Azerbaijan
BS	Bahamas
BH	Bahrain
BD	Bangladesh
BB	Barbados
BY	Belarus
BE	Belgium
BZ	Belize
BJ	Benin
BM	Bermuda
BT	Bhutan
BO	Bolivia
BA	Bosnia and Herzegovina
BW	Botswana
BV	Bouvet Island
BR	Brazil
IO	British Indian Ocean Territory
BN	Brunei Darussalam
BG	Bulgaria
BF	Burkina Faso
BI	Burundi
KH	Cambodia
CM	Cameroon
CA	Canada
CV	Cape Verde
KY	Cayman Islands
CF	Central African Republic

Table A.8 (continued)

Code	Country
TD	Chad
CL	Chile
CN	China
CX	Christmas Island
CC	Cocos (Keeling) Islands
CO	Colombia
KM	Comoros
CG	Congo
CD	Congo, Democratic Republic
CK	Cook Islands
CR	Costa Rica
CI	Côte d'Ivoire
HR	Croatia
CU	Cuba
CY	Cyprus
CZ	Czech Republic
DK	Denmark
DJ	Djibouti
DM	Dominica
DO	Dominican Republic
EC	Ecuador
EG	Egypt
SV	El Salvador
GQ	Equatorial Guinea
ER	Eritrea
EE	Estonia
ET	Ethiopia
FK	Falkland Islands
FO	Faroe Islands
FJ	Fiji
FI	Finland
FR	France
GF	French Guiana
PF	French Polynesia
TF	French Southern Territories
GA	Gabon
GM	Gambia
GE	Georgia
DE	Germany
GH	Ghana
GI	Gibraltar
GR	Greece

Table A.8 (continued)

Code	Country
GL	Greenland
GD	Grenada
GP	Guadeloupe
GU	Guam
GT	Guatemala
GG	Guernsey
GN	Guinea
GW	Guinea-Bissau
GY	Guyana
HT	Haiti
HM	Heard Island and McDonald Islands
VA	Holy See
HN	Honduras
HK	Hong Kong
HU	Hungary
IS	Iceland
IN	India
ID	Indonesia
IR	Iran
IQ	Iraq
IE	Ireland
IM	Isle of Man
IL	Israel
IT	Italy
JM	Jamaica
JP	Japan
JE	Jersey
JO	Jordan
KZ	Kazakhstan
KE	Kenya
KI	Kiribati
KP	North Korea
KR	South Korea
KW	Kuwait
KG	Kyrgyzstan
LA	Laos
LV	Latvia
LB	Lebanon
LS	Lesotho
LR	Liberia
LY	Libya
LI	Liechtenstein

Table A.8 (continued)

Code	Country
LT	Lithuania
LU	Luxembourg
MO	Macao
MK	North Macedonia
MG	Madagascar
MW	Malawi
MY	Malaysia
MV	Maldives
ML	Mali
MT	Malta
MH	Marshall Islands
MQ	Martinique
MR	Mauritania
MU	Mauritius
YT	Mayotte
MX	Mexico
FM	Micronesia
MD	Moldova
MC	Monaco
MN	Mongolia
ME	Montenegro
MS	Montserrat
MA	Morocco
MZ	Mozambique
MM	Myanmar
NA	Namibia
NR	Nauru
NP	Nepal
NL	Netherlands
NC	New Caledonia
NZ	New Zealand
NI	Nicaragua
NE	Niger
NG	Nigeria
NU	Niue
NF	Norfolk Island
MP	Northern Mariana Islands
NO	Norway
OM	Oman
PK	Pakistan
PW	Palau
PS	Palestine
PA	Panama

Table A.8 (continued)

Code	Country
PG	Papua New Guinea
PY	Paraguay
PE	Peru
PH	Philippines
PN	Pitcairn
PL	Poland
PT	Portugal
PR	Puerto Rico
QA	Qatar
RE	Réunion
RO	Romania
RU	Russian Federation
RW	Rwanda
BL	Saint Barthélemy
SH	Saint Helena
KN	Saint Kitts and Nevis
LC	Saint Lucia
MF	Saint Martin
PM	Saint Pierre and Miquelon
VC	Saint Vincent and the Grenadines
WS	Samoa
SM	San Marino
ST	Sao Tome and Principe
SA	Saudi Arabia
SN	Senegal
RS	Serbia
SC	Seychelles
SL	Sierra Leone
SG	Singapore
SX	Sint Maarten
SK	Slovakia
SI	Slovenia
SB	Solomon Islands
SO	Somalia
ZA	South Africa
GS	South Georgia
SS	South Sudan
ES	Spain
LK	Sri Lanka
SD	Sudan
SR	Suriname
SJ	Svalbard and Jan Mayen
SZ	Eswatini (Swaziland)

Table A.8 (continued)

Code	Country
SE	Sweden
CH	Switzerland
SY	Syria
TW	Taiwan
TJ	Tajikistan
TZ	Tanzania
TH	Thailand
TL	Timor-Leste
TG	Togo
TK	Tokelau
TO	Tonga
TT	Trinidad and Tobago
TN	Tunisia
TR	Turkey
TM	Turkmenistan
TC	Turks and Caicos Islands
TV	Tuvalu
UG	Uganda
UA	Ukraine
AE	United Arab Emirates
GB	United Kingdom
US	United States
UM	US Minor Outlying Islands
UY	Uruguay
UZ	Uzbekistan
VU	Vanuatu
VE	Venezuela
VN	Vietnam
VG	British Virgin Islands
VI	US Virgin Islands
WF	Wallis and Futuna
EH	Western Sahara
YE	Yemen
ZM	Zambia
ZW	Zimbabwe

A.7 Disposable Features

Table A.9 Disposable features and related disposal characteristics

Code	Description	Notes
1	biodegradable	Material biodegrades naturally
2	compostable	Material can be industrially composted
3	home_compostable	Suitable for home compost
4	recyclable	Material can be recycled
5	mechanically_recyclable	Recyclable through mechanical processes
6	chemically_recyclable	Recyclable through chemical depolymerization
7	not_recyclable	Cannot be recycled
8	reusable	Can be reused without transformation
9	upcyclable	Material suitable for upcycling
10	incinerable	Can be safely incinerated
11	hazardous_disposal	Requires special disposal

A.8 Address Type

Table A.10 Address type classification

AddressType
Headquarters
OperationalSite
SupplierAddress
ManufacturingSite
ProcessingFacility
AssemblySite
Warehouse
DistributionCenter
FulfillmentCenter
ShippingAddress
ReceivingAddress
CrossDockHub
RetailStore
Showroom
ReturnCenter
RepairCenter
TakeBackPoint
RecyclingFacility
BillingAddress
CustomsAddress

A.9 Substances of Concern

Table A.11 Controlled vocabulary for Substances of Concern

Substance Name	CAS Number	Substance of Concern		
		Category	Material Type	Process
Chromium VI	18540-29-9	CMR, SVHC	Metals	Metal finishing / plating
Nickel (release)	7440-02-0	Allergenic, SVHC	Metals	Plating / surface treatment
Lead	7439-92-1	Toxic, SVHC	Metals, pigments	Dyeing / metal finishing
Cadmium (Cd)	7440-43-9	Toxic, SVHC	Metals	Surface treatment
Formaldehyde	50-00-0	Sensitizer / carcinogenic	Textiles	Resin finishing
Disperse Orange 1 (azo dye)	2581-69-3	Carcinogenic	Textiles	Dyeing / printing
Disperse Orange 3 (azo dye)	730-40-5	Carcinogenic	Textiles	Dyeing / printing
Disperse Red 1 (azo dye)	2872-52-8	Carcinogenic	Textiles	Dyeing / printing
Disperse Yellow 3 (azo dye)	2832-40-8	Carcinogenic	Textiles	Dyeing / printing
DEHP (phthalate)	117-81-7	Reprotoxic	Plastics	Plasticizer / molding
DBP (phthalate)	84-74-2	Reprotoxic	Plastics	Plasticizer / molding
BBP (phthalate)	85-68-7	Reprotoxic	Plastics	Plasticizer / molding
DIBP (phthalate)	84-69-5	Reprotoxic	Plastics	Plasticizer / molding
PFOA (PFAS)	335-67-1	Persistent, SVHC	Textiles	Water repellent finishing
PFOS (PFAS)	1763-23-1	Persistent, SVHC	Textiles	Water repellent finishing
PFHxS (PFAS)	355-46-4	Persistent, SVHC	Textiles	Water repellent finishing
GenX (PFAS)	62037-80-3	Persistent	Textiles	Water repellent finishing
NPEO / NPEs	9016-45-9	Persistent / toxic	Chemicals	Washing, scouring, finishing
BPA	80-05-7	Endocrine disruptor	Plastics	Printing / molding
Tributyltin (TBT)	688-73-3	Toxic	Plastics / leather	Stabilizer / finishing
Dibutyltin (DBT)	1002-53-5	Toxic	Plastics / leather	Stabilizer / finishing
Monobutyltin (MBT)	78763-54-9	Toxic	Plastics / leather	Stabilizer / finishing
DMFu	624-49-7	Skin sensitizer	Leather / textiles	Anti-mold treatment

Table A.11 (continued)

Substance Name	CAS Number	Category	Material Type	Process
Methanol	67-56-1	Toxic	Solvents	Cleaning / pretreatment
Benzo[a]pyrene (PAH)	50-32-8	Carcinogenic	Rubber	Vulcanization
TCEP (flame retardant)	115-96-8	Reprotoxic	Foams	Chemical finishing
TCPP (flame retardant)	13674-84-5	Reprotoxic	Foams	Chemical finishing
TDCPP (flame retardant)	13674-87-8	Reprotoxic	Foams	Chemical finishing
Arsenic trioxide	1327-53-3	Toxic	Metals, pigments	Metal processing / dyeing
Sodium arsenate	7778-43-0	Toxic	Metals, pigments	Metal processing / dyeing
Toluene (VOC)	108-88-3	Toxic	Solvents / adhesives	Printing / lamination
Xylene (VOC)	1330-20-7	Toxic	Solvents / adhesives	Printing / lamination
Ethylbenzene (VOC)	100-41-4	Toxic	Solvents / adhesives	Printing / lamination

A.10 Fashion Certification

Table A.12 Controlled vocabulary for Fashion Certification and Compliance Documents

Certification / Document Name	Fashion Certification Type
GOTS	MaterialCertification
GRS	MaterialCertification
RCS	MaterialCertification
OCS	MaterialCertification
OEKO-TEX Standard 100	ChemicalCertification
OEKO-TEX Leather Standard	ChemicalCertification
OEKO-TEX STeP	EnvironmentalCertification
OEKO-TEX ECO Passport	ChemicalCertification
OEKO-TEX Made in Green	TraceabilityCertification + ChemicalCertification + MaterialCertification
Leather Working Group (LWG)	EnvironmentalCertification
Bluesign Approved	ChemicalCertification
Cradle to Cradle Certified	EnvironmentalCertification
Fairtrade Textile Standard	EthicalAudit
Fair Wear Foundation Certificate	EthicalAudit
Better Cotton Initiative (BCI)	EnvironmentalCertification
RDS (Responsible Down Standard)	AnimalWelfareCertification + MaterialCertification
RWS (Responsible Wool Standard)	AnimalWelfareCertification + MaterialCertification
RMS (Responsible Mohair Standard)	AnimalWelfareCertification + MaterialCertification
RAS (Responsible Alpaca Standard)	AnimalWelfareCertification + MaterialCertification
ZQ Merino	AnimalWelfareCertification + MaterialCertification
FSC Chain of Custody	TraceabilityCertification
PEFC Certification	TraceabilityCertification
EU Ecolabel	EnvironmentalCertification
Nordic Swan Ecolabel	EnvironmentalCertification
USDA BioPreferred	MaterialCertification
BSCI Audit	SocialAudit
SMETA (Sedex)	SocialAudit
SA8000	SocialAudit
WRAP Certification	SocialAudit
ISO 9001	ManagementSystemCertification
ISO 14001	ManagementSystemCertification
ISO 45001	ManagementSystemCertification
Higg FEM	EnvironmentalCertification
CE Declaration of Conformity	ComplianceDeclaration
UKCA Declaration	ComplianceDeclaration
Prop65 Compliance Letter	ComplianceDeclaration
REACH Compliance Declaration	ComplianceDeclaration
ZDHC MRS� Conformance	ChemicalCertification
EcoDesign DPP Compliance Statement	ComplianceDeclaration

A.11 Company Documentation

Table A.13 *Controlled vocabulary for Company Documentation and Compliance Records*

Certification / Document Name	Type
BSCI Audit Certificate	SocialAudit
SMETA (Sedex Audit)	SocialAudit
SA8000 Certification	SocialAudit + EthicalCertification
WRAP Certification	SocialAudit
Fair Wear Foundation Certification	SocialAudit + EthicalCertification
Fairtrade Textile Standard (company-level)	EthicalCertification
Better Work Programme (ILO/IFC)	SocialAudit + EthicalCertification
ISO 45001 (Occupational Health & Safety Management System)	SafetyAudit + ManagementSystemCertification
ISO 9001 (Quality Management System)	ManagementSystemCertification
ISO 14001 (Environmental Management System)	EnvironmentalManagement + ManagementSystemCertification
ISO 26000 (Guidance on Social Responsibility)	EthicalCertification
Higg FSLM (Facility Social & Labour Module)	SocialAudit + DueDiligenceDocumentation
Higg FEM (Facility Environmental Module)	EnvironmentalManagement
Human Rights Policy (UN Guiding Principles aligned)	DueDiligenceDocumentation
Human Rights Due Diligence Report (HRDD)	DueDiligenceDocumentation
Supplier Code of Conduct	DueDiligenceDocumentation + ComplianceDeclaration
Modern Slavery / Forced Labour Statement	DueDiligenceDocumentation + ComplianceDeclaration
CSDDD (EU Corporate Sustainability Due Diligence) Compliance Statement	DueDiligenceDocumentation + ComplianceDeclaration
Conflict Minerals / 3TG (CMRT) Due Diligence Report	DueDiligenceDocumentation + ComplianceDeclaration
GRI Sustainability Report (GRI Standards)	ESGReportingFramework + DueDiligenceDocumentation
CSRD Sustainability Report	ESGReportingFramework + DueDiligenceDocumentation
Higg Brand & Retail Module	ESGReportingFramework + DueDiligenceDocumentation

Appendix B

B.1 Data Ownership Attribute Mapping (In-house vs Outsourced Manufacturing)

Table B.1 Data ownership attribute mapping across supply-chain tiers

Tier 0—Brand (Lead company) **Tier 0**—Brand (Lead company), Finished product manufa
Tier 1—Finished product manufacturer **Tier 1**—Material manufacturer
Tier 2—Material manufacturer **Tier 2**—Intermediate material supplier
Tier 3—Intermediate material supplier **Tier 3**—Raw material producer
Tier 4—Raw material producer

Product Generic Data	Outsourced product	In-house manufactured product
GenericID	Tier 0	Tier 0
ProductType	Tier 0	Tier 0
ProductCategory	Tier 0	Tier 0
ProductSubCategory	Tier 0	Tier 0
ProductName	Tier 0	Tier 0
ProductModel	Tier 0	Tier 0
Season	Tier 0	Tier 0
Year	Tier 0	Tier 0
KeyFeatures	Tier 0	Tier 0
CE Marking Information	Tier 0	Tier 0
hasSize()	Tier 0	Tier 0

Product Identification Data	Outsourced product	In-house manufactured product
ProductID	Tier 0	Tier 0
GTIN	Tier 0	Tier 0
ColorName	Tier 0	Tier 0
ColorCode	Tier 0	Tier 0
ProductWeight	Tier 1	Tier 0
ProductWeightUnit	Tier 1	Tier 0

Size Data	Outsourced product	In-house manufactured product
SizeDataID	Tier 0	Tier 0
Gender	Tier 0	Tier 0
GarmentType	Tier 0	Tier 0
SizeStandard	Tier 0	Tier 0
SizeValue	Tier 0	Tier 0

Bill of Material	Outsourced product	In-house manufactured product
BOMItemID	Tier 1	Tier 0
ComponentName	Tier 1	Tier 0
CompositionPercentageofProduct	Tier 1	Tier 0
QuantityUsed	Tier 1	Tier 0
QuantityUOM	Tier 1	Tier 0
BOMItemWeight	Tier 1	Tier 0
BOMItemWeightUnit	Tier 1	Tier 0

Table B.1 (continued)

Material Fiber Breakdown	Outsourced product	In-house manufactured product
BOMItemID	Tier 2	Tier 1
MaterialID	Tier 3	Tier 2
ComponentName	Tier 2	Tier 1
FiberName	Tier 3	Tier 2
PercentageOfMaterial	Tier 3	Tier 2
MaterialWeight	Tier 3	Tier 2

Material	Outsourced product	In-house manufactured product
MaterialID	Tier 3	Tier 2
MaterialName	Tier 3	Tier 2
MaterialFamily	Tier 3	Tier 2
RawMaterialOrigin	Tier 4	Tier 3
SupplierCountry	Tier 3	Tier 2
CatalogueWeightValue	Tier 3	Tier 2
CatalogueWeightUOM	Tier 3	Tier 2
CatalogueQtyForWeight	Tier 3	Tier 2
CatalogueQtyUOM	Tier 3	Tier 2
UnitWeightValue	Tier 3	Tier 2
RecycledContentPercentage	Tier 4	Tier 3
VirginMaterialPercentage	Tier 4	Tier 3
RenewableContentPercentage	Tier 4	Tier 3
hasAnimalOrigin	Tier 4	Tier 3
isSubstanceOfConcernPresent	Tier 3	Tier 2

DisposableFeature	Outsourced product	In-house manufactured product
DisposableFeatureID	Tier 3	Tier 2
MaterialID	Tier 3	Tier 2
Code	Tier 3	Tier 2
Description	Tier 3	Tier 2

Animal-Origin Presence	Outsourced product	In-house manufactured product
AnimalOriginPresenceID	Tier 4	Tier 3
MaterialID	Tier 3	Tier 2
AnimalSpecies	Tier 4	Tier 3

Substance of ConcernPresence	Outsourced product	In-house manufactured product
SubstanceOfConcernPresenceID	Tier 3	Tier 2
MaterialID	Tier 3	Tier 2
SubstanceName	Tier 3	Tier 2
CASNumber	Tier 3	Tier 2
Category	Tier 3	Tier 2
MaterialType	Tier 3	Tier 2
Process	Tier 3	Tier 2
Concentration	Tier 3	Tier 2

Table B.1 (continued)

MaterialDocumentation	Outsourced product	In-house manufactured product
MaterialDocumentID	Tier 3	Tier 2
MaterialID	Tier 3	Tier 2
DocumentationType	Tier 3	Tier 2
Name	Tier 3	Tier 2
IssuingOrganization	Tier 3	Tier 2
ValidFrom	Tier 3	Tier 2
ValidUntil	Tier 3	Tier 2
Status	Tier 3	Tier 2

Supply Chain Traceability	Outsourced product	In-house manufactured product
SupplyChainTraceabilityID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
CompanyID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
TierLevel	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
ManufacturingProcess	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3

Transportation	Outsourced product	In-house manufactured product
TransportationID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
TransportMode	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
Distance	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3

Company	Outsourced product	In-house manufactured product
CompanyID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
CompanyName	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
CompanyRegistrationNumber	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
EmailAddress	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
EmployeeCount	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
PercentageOfWomen	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
PercentageOfMen	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
PercentageOfNotSpecified	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3

CompanyDocumentation	Outsourced product	In-house manufactured product
CompanyDocumentID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
CompanyID	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
DocumentationType	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
Name	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
IssuingOrganization	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
ValidFrom	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
ValidUntil	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3
Status	Tier 1 / 2 / 3 / 4	Tier 1 / 2 / 3

Table B.1 (continued)

Address	Outsourced product	In-house manufactured product
AddressID	Tier 1/2/3/4	Tier 1/2/3
CompanyID	Tier 1/2/3/4	Tier 1/2/3
AddressType	Tier 1/2/3/4	Tier 1/2/3
StreetName	Tier 1/2/3/4	Tier 1/2/3
StreetNumber	Tier 1/2/3/4	Tier 1/2/3
City	Tier 1/2/3/4	Tier 1/2/3
PostalCode	Tier 1/2/3/4	Tier 1/2/3
Country	Tier 1/2/3/4	Tier 1/2/3
Latitude	Tier 1/2/3/4	Tier 1/2/3
Longitude	Tier 1/2/3/4	Tier 1/2/3

Environmental Impact	Outsourced product	In-house manufactured product
EnvironmentalImpactID	Tier 1	Tier 0
ProductID	Tier 0	Tier 0
Cradle-to-gateCO2eEmissions	Tier 1	Tier 0
BreakdownByLCStage	Tier 1	Tier 0
CalculationMethodology	Tier 1	Tier 0

Care Instructions	Outsourced product	In-house manufactured product
CareInstructionsID	Tier 1	Tier 0
ProductID	Tier 0	Tier 0
WashingMethod	Tier 1	Tier 0
MaxWashingTemperature	Tier 1	Tier 0
DryingMethod	Tier 1	Tier 0
IroningAllowed	Tier 1	Tier 0
MaxIroningTemperature	Tier 1	Tier 0
BleachAllowed	Tier 1	Tier 0
CareDescription	Tier 1	Tier 0
RepairOptionsDescription	Tier 1	Tier 0
EndOfLifeGuidanceDescription	Tier 1	Tier 0
TakeBackProgramAvailable	Tier 1	Tier 0
TakeBackProgramDetails	Tier 1	Tier 0