Vaasan yliopisto
UNIVERSITY OF VAASA

Vilma Hjelt

Digital product passport for SME in textile industry

Data requirements and solution

School of Technology and innovations
Master's thesis
Industrial management

Vaasa 2025

UNIVERSITY OF VAASA
School of Technology and innovations

Author:	Vilma Hjelt
Title of the thesis:	Digital product passport for SME in textile industry: Data requirements and solution
Degree:	Master of science in Economics and business administration
Discipline:	Industrial management
Supervisor:	Petri Helo
Year:	2025 **Pages:** 87

ABSTRACT:

The digital product passport is a solution proposed by the European Union to unify environmental and sustainability statements of consumer products. The purpose of this study is to map the information requirements of digital product passports and explore the solutions for data retrieval. Secondly, the study aims to analyze what these software and data requirements would mean in practice for small and medium-sized enterprises. Digital product passports will be implemented to the textile industry first due to the large size of the market and the industry's significant environmental impacts. The European textile industry consists largely of small and medium-sized enterprises, so the digital product passport has raised concerns about its economic viability and the adequacy of resources in small and medium-sized enterprises. EU working groups are still preparing the final information requirements for the digital product passport and the software solution is still not clarified.

The information requirements for the digital product passport as presented in the study are based on the European Union proposal documents, and previous research and legislation related to the requirements. Based on previous literature the literature review also includes my interpretations of a possible software solution. In addition, the literature review discusses enterprise resource planning and product information management systems commonly used in companies.

The empirical section of the study is done using the research methodology of design science. The requirements for digital product passport publishing are determined based on the literature review and the information already available in the case company is examined. In the case company also the automatic traceability of product information in the systems and the systems that process product related information are studied. Finally, the study proposes a way to create, update and publish digital product passport information from one centralized software, taking into account the company's resources. The result of the study suggests that in preparation for a digital product passport companies should begin to build data for a few products. This way the workload can be distributed more widely over time while the information requirements are not yet clarified and when the final requirements are published companies will be more prepared. Thus, the study also suggests an iterative and adaptive way of working, as well as active stakeholder engagement.

The research results show that concerns about the adequacy of resources in small and medium-sized enterprises are justified, but by utilizing an agile approach and available software solutions, a digital product passport can be implemented. However, when considering the financial sustainability and feasibility of the digital product passport the level of detail for calculating the product environmental footprint must be considered. With a digital product passport, the workload associated with publishing new products will increase in any case.

ABSTRACT IN FINNISH:

Digitaalinen tuotepassi on Euroopan unionin ehdottama ratkaisu yhdenmukaistaa ympäristö- ja kestävyyslupaukset kuluttajatuotteissa. Tämän tutkielman tarkoituksena on selvittää, millaisia tietovaatimuksia digitaalinen tuotepassi tulisi tämänhetkisen tiedon mukaan sisältämään ja mitä näiden järjestelmä- ja tietovaatimusten toteuttaminen käytännössä tarkoittaisi pienissä ja keskisuurissa yrityksissä. Vaatimus digitaalisesta tuotepassista on tulossa ensimmäisenä muun muassa tekstiiliteollisuuden tuotteille, markkinan suuren koon ja merkittävien ympäristövaikutusten vuoksi. Unionin työryhmät valmistelevat yhä digitaalisen tuotepassin lopullisia tietovaatimuksia, sekä ohjelmistoratkaisua. Eurooppalainen tekstiiliteollisuus koostuu suurilta osin pienistä ja keskisuurista yrityksistä, joten digitaalinen tuotepassi on herättänyt huolta sen taloudellisesta kannattavuudesta ja resurssien riittävyydestä pienissä ja keskisuurissa yrityksissä.

Tutkielmassa esitetyt digitaalisen tuotepassin tietovaatimukset perustuvat erilaisiin Euroopan unionilta saatavilla oleviin ehdotuksiin mahdollisista vaatimuksista sekä vaatimuksiin liittyvään aiempaan tutkimukseen ja lainsäädäntöön. Kirjallisuuskatsaus aiheesta sisältää myös aiempaan kirjallisuuteen pohjautuen näkemykseni mahdollisesta ohjelmistoratkaisusta. Lisäksi kirjallisuuskatsaus käsittelee yrityksissä yleisesti käytössä olevat toiminnanohjaus- ja tuotetiedonhallintajärjestelmät.

Tutkielman empiirinen osio hyödyntää suunnittelutieteen tutkimusmenetelmäoppia, jossa kirjallisuuskatsauksen pohjalta määritetään vaatimukset yritysten julkaisemille digitaalisille tuotepasseille ja tutustutaan kohdeyrityksessä valmiiksi saatavilla olevaan tietoon. Kohdeyrityksessä tutkitaan tuotetietoa käsittelevät järjestelmät ja tuotetiedon automaattinen jäljitettävyys niissä. Lopulta tutkielma ehdottaa yrityksen resurssit huomioiden yhtä tapaa luoda, päivittää ja julkaista digitaalisen tuotepassin tietoja keskitetysti. Tutkimus esittää, että digitaaliseen tuotepassiin valmistautuminen tulisi aloittaa muutaman tuotteen osalta niiltä osin, kun tietovaatimukset ovat jo selkeitä, jotta ajallisesti työkuormaa pystytään jakamaan laajemmalle. Täten tutkimus myös ehdottaa iteratiivista ja mukautuvaa työskentelytapaa, sekä sidosryhmien osallistamista.

Tutkimustulos osoittaa, että huoli resurssien riittävyydestä pienissä ja keskisuurissa yrityksissä on aiheellinen, mutta hyödyntämällä ketterää toimintatapaa ja saatavilla olevia ohjelmistoja digitaalinen tuotepassi on toteutettavissa. Ratkaisun taloudellisessa kestävyydessä täytyy ottaa huomioon kuitenkin erityisesti tuotteen ympäristöjalanjäljen laskemiselle asetettavat vaatimukset ja niiden toteutettavuus näissä yrityksissä. Digitaalisen tuotepassin myötä uusien tuotteiden julkaisemiseen liittyvä työmäärä tulisi joka tapauksessa kasvamaan.

KEYWORDS: digital product passports, textile industry, small and medium-sized enterprises, sustainable development, traceability KEYWORDS IN FINNISH: digitaaliset tuotepassit, tekstiiliteollisuus, pienet ja keskisuuret yritykset, kestävä kehitys, jäljitettävyys

Contents

Figures

Tables

Images

Abbreviations

API	Application programming interface
B2B	Business to business
B2C	Business to consumers
CAD	Computer aided design system
DPP	Digital product passport
DSRM	Design science research method
ERP	Enterprise resource planning system
ESPR	Eco design for sustainable products regulation
EU	European union
MES	Manufacturing execution system
PDM	Product data management
PIM	Product information management system
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SME	Small and medium sized enterprise
EUSSCT	Strategy for sustainable and circular textiles

1 Introduction

The complexities of textile industry are reflected to consumers with hard to read value promises and cryptic product information on sustainability matters. The textile industry is known for its global, low value and hard to track supply chain that produces a significant share of commercial products with short lived life cycles. For this reason, the European union (EU) has introduced digital product passports as their solution. Digital product passport (DPP) was presented in 2022, in the publication of EU's Strategy for Sustainable and Circular textiles (EUSSCT) and is included in the Eco design for Sustainable product regulation (ESPR) proposal.

Digital product passport aims to support the environmental and social sustainability by providing transparency to the supply chain, but the economical sustainability of the solution has sparked concerns. Although the EU textile strategy especially highlights the significant share of small and medium sized enterprises (SMEs) in European textile industry and their financial struggles caused both by the COVID-19 pandemic and recent energy price fluctuations, there have been concerns if the SMEs have sufficient resources to comply with the requirements. Especially on the level of resources available in SMEs for providing the data required for digital product passport.

This study aims to research the data requirements and readiness for required actions to provide the data in one case company.

1.1 The purpose of this study

The purpose of this thesis is to map the requirements and solution for data retrieval of digital product passport data for the purpose of creating digital product passport. The requirements of digital product passport span the whole product life cycle, and the first purpose of this study is to define the data required from textile manufacturing SME. Secondly the study aims to suggest a way of retrieving this data from the systems currently used in the case company and prepare the data for integration with digital product passport, or website in the absence of industry level solution for DPP.

1.2 Structure

The literature review of peer reviewed articles from Science direct, Google scholar, Finna databases and additional grey literature from European union and Associations such as Finnish textile and fashion association as well as Alliance for European Flax-Linen & Hemp. The literature review includes selected articles covering recent research on digital product passport, decoupling and circular economy in textile industry as well as traceability in manufacturing industries, studies on the use of LCA for product environmental footprint and textile lifetime.

Literature review covers the digital product passport, the current state of sustainability issues in textile industry as well as the information requirements and technical solution set for DPP. As digital product passport is aiming to utilize the tracking and tracing data available in currently available manufacturing systems, the last section focuses on traceability in manufacturing systems. It covers research on utilizing the systems used by the case company such as enterprise resource planning and manufacturing execution systems.

Based on the literature review a study is conducted on the retrieval of digital product passport data from the available systems in the case company that is a SME textile manufacturer in Finland. The study is conducted using design science research method (DSRM). The order of the five steps of DSRM has been adjusted to suit the needs of the research. Firstly, the definition of the objectives for the solution (1), elaborates the data required for DPP. In problem definition and motivation (2) the focus is on identifying the gaps in the currently used system in terms of the data required for DPP. At the design and development (3) a suggestion is presented on a way of using the current systems to retrieve data for DPP, with examples from both wool and linen products. If additional systems are needed this stage will require research on the available commercial solutions. Demonstration and the comments and evaluation (4) are summarized, and the results are evaluated against the objectives (5).

1.3 Case company and its product

The case company is SME home textile manufacturer located in Finland. The family-owned company, established in 1973, has a long history of designing and weaving jacquard textiles. With the family roots in textile dating back to 1917, the company strategy is focused on keeping the heritage of Finnish textile industry and craftmanship alive, while simultaneously creating innovative modern-day textiles, with state-of-art practices.

During the latest decades the company has made big investments. They have increasingly invested in finishing and wet finishing machinery lately building their own wet finishing facility in Finland. Together with the wet finishing facility partly aimed at increasing the wool finishing capabilities, they have started a process of using Finnish sheep wool, which was earlier mostly discarded from industrial use. They have also invested in new logistics terminal as well as overall digitalization of the manufacturing line.

The company produces home textiles for kitchen, living, sauna and bath, made from materials of natural origin. In 2023 the materials used in all products sold were wool (40%), wool blend (3%), linen (26%), linen-cotton (18%) and Tencel-linen-cotton (14%). 11% of the products contained local Finnish sheep wool.

Today the inhouse product life cycle stages of the company and its subordinates include activities such as yarn purchasing, purchasing dyeing, product design, warping, weaving, quality inspection, sewing, finishing and wet finishing. For a small part of their product portfolio including the products made from the Finnish sheep wool, they are also responsible for purchasing fibre, purchasing washing for the fibre and purchasing spinning and dyeing for the fibre. For this reason, the company can be seen to represent a wide range of product life cycle stages and therefore being in an important role when submitting data for digital product passports.

Throughout its history the company has done some subcontracting but most of the products produced in its manufacturing facilities have been sold under its own name both through stockists (B2B) and directly to consumers (B2C). B2B sales include own stores in Finland and Japan as well as an online store. B2C sales include exporting to stockists in thirty countries with the biggest export countries being, Germany, Switzerland and Japan. Today both B2B and B2C sales are handled increasingly through its online store. Therefore, the research aims at representing the DPP information on the company website, as industrial solution for digital product passport is not yet existing.

In the case study the traceability level currently available in the company as well as the integrations and processes required to effectively share data for digital product passport will be evaluated considering two different products, washed linen towel and a Finnish sheep wool blanket as these two products cover the many of the different production variations inside the company.

Washed linen towels used as an example in this research are made from 100% linen yarn certified by Alliance for European Flax-Linen & Hemp, meaning that all the production stages from fibre cultivation to ready-made products are done in Europe. Structurally the linen towel in question is a 48x70cm towel made from double weave fabric woven into shape in the company’s own weaving mill. The product is yarn-dyed so no dyeing of the product happens after weaving, due to the double weave structure each side of the product displays single colour different to the other side of the fabric. In the companies wet finishing facility, the product is wet finished in narrow foulard finishing. In the sewing facility the short ends of the towel are sewn and the hanging loop made from linen and the label including washing instructions to woven in the factory is sewn to one end. The product is ironed, wrapped and packed with one filament and a product card made of cardboard.

The Finnish sheep wool blanket used as an example is 100% wool blanked made from a mixture of wool purchased as washed fibre and Finnish sheep wool purchased directly from the farms. The fibre purchasing is made by the case company. For Finnish sheep wool the mechanical cleaning of the fibre is done in the case company after which the washing, spinning and dyeing of the wool are purchased from separate suppliers. The wool is yarn-dyed with natural colours. After this the yarns are woven into blankets in the company weaving mill. The product is then finished in the company's wet finishing facility. The edges of the blanket are stitched and a label and washing instructions are woven into it. Lastly, the product is wrapped and packed with linen ribbon, a product card made of cardboard and packed into a plastic bag.

2 Theoretical background

The theoretical background of this research begins with a general view on sustainability risks in textile industry based on previous research. These risks are examined to create understanding of the current state issues in the industry. The risks are analysed in a global context even though the company operates in EU and the research is focused on the EU Digital product passport, as the supply chains in textile industry are typically very complex and global.

After overview on textile industry sustainability risks, the research presents the European digital product passport which has been proposed as the solution to create transparency and coherency into the sustainability of products sold in EU. This in turn should serve as a tool for consumers for better decision making and for companies as a motivator to improve product sustainability. In DPP textile products have been proposed as one example of the products that should be implemented in an early phase.

As digital product passport is still a very new subject that has not been implemented earlier, the third theoretical background chapter covers the data requirements proposed for the digital product passport. Based on earlier research it will propose the underlying information and research requirements for generating the data needed for digital product passport.

In terms of the actual system solution for digital product passports the theoretical background covers the technical solutions proposed for digital product passports in academic research, industry publications and documents provided by European commission. Based on these two commonly proposed technical solutions are presented.

Lastly, the theoretical background of this research covers the software and systems used to provide traceability in manufacturing companies. This chapter covers earlier traceability solutions using commonly available software's such as enterprise resource planning, manufacturing execution and product information and product lifecycle management systems and their integrations. This part of the theoretical background aims to support solution proposal for data retrieval for DPP in the results section.

2.1 Sustainability risks in textile industry

Textile industry is a multi-step process with different sustainability risks related to each step (Muñoz-Torres et al., 2021; Shen et al., 2017). Therefore, the sustainability risks related to each step should be examined separately. Sustainability risks in all production phases include both environmental and social concerns (Warasthe et al., 2022; Niinimäki et al., 2020). Sustainable supply chain management and sustainable product development have been growing trends due to the possible negative reputation impact of sustainability issues (Warasthe et al., 2022;Luján-Ornelas et al., 2020). To understand the purpose and data collection points of digital product passport it is important to understand the sustainability challenges and industry development behind it.

Generally, as explained by Patti et al. (2020), textile production can be divided to four steps which are fibre production, yarn production, fabric production and finishing. Fiber production refers to the production of the material from which the yarn is produced and can be further divided into natural materials (cultivated or protein based) and man-made materials (cellulose based or synthetic). As the case company only uses natural and cellulose based materials this research will not cover synthetic materials. Yarn production refers to spinning and dying of the yarn, fabric production refers to weaving or knitting of the fabric and finishing refers to sewing, printing and wet finishing (Patti et al., 2020).

In the fibre and yarn production water consumption is one of the main sustainability risks associated with cultivated natural materials and cotton cultivation requires the most water usage as hemp, linen and cellulose based materials only require six percent, and wool only one third of the water required for cotton (Niinimäki et al., 2020). There is also a social sustainability risk related to water consumption when material production happens in areas of water scarcity (Niinimäki et al., 2020). Other social risks such as forced, and child labour have also been related to cotton cultivation (Luján-Ornelas et al., 2020). These sustainability risks also create a geopolitical issue when material is sourced by developed countries from developing countries (Langley et al., 2023). Cellulose based fibres have been a key development area due to lower sustainability risks (Niinimäki et al., 2020). The processes used in the cellulose-based fibre and yarn production can also be used in textile waste recycling in the future (Niinimäki et al., 2020). There are also sustainability related fibre certificates such as organic cotton and mulesing free merino wool.

From sustainability point of view the risks related to sewing are like risks related to fabric production and therefore examined as one. Fabric production is highly mechanical and automated production phase where machinery and therefore energy consumption are in the main role regarding sustainability. Sewing is a more labour-intensive production phase, but it has also been partly automated in recent years. In both fabric production and sewing the social sustainability risks depend on the working conditions of the company. Especially sewing has been in the spotlight due to Bangladesh factory collapse in 2013 as well as general social risks related to this production phase (Luján-Ornelas et al., 2020). Pricing pressure and on the other hand sustainability risks related to social and environmental sustainability have affected the textile industry and therefore both outsourcing and insourcing are common practices in textile industry (Warasthe et al., 2022).

From the sustainability point of view the risks related to dying and wet finishing are similar and therefore examined as one. The environmental sustainability risks are related to it are the lack of wastewater treatment and water consumption. Palacios-Mateo et al. (2021) state that as much as twenty percent of natural water pollution comes from these two phases of textile manufacturing and there are significant differences globally regarding wastewater treatment legislation and practices. The REACH certification in the European union sets limitations to hazardous substances allowed in production of products imported into European union countries (European Commission, 2022b). In addition to minimizing the use of hazardous substances, the use of natural dyes and closed-loop water systems can be seen as more sustainable practices (Palacios-Mateo et al., 2021). The use of hazardous substances in dying and wet finishing phases of textile production has also been connected to social sustainability issues such as cancers and skin conditions if proper protective measures are not implemented (Palacios-Mateo et al., 2021).

Lifecycle approach and circular economy aspects should also be considered when examining textile industry sustainability for digital product passport point of view. In their research Niinimäki et al. (2020) conclude that one of the main aspects of textile circularity is limiting the amount of waste created by the industry. Waste is generated as a side stream throughout textile manufacturing process as excess fibre, yarn, and fabric (Niinimäki et al., 2020). However, Niinimäki et al. (2020)state that one mainstream of textile waste is coming from unused unsold textiles. Waste is generated also thorough short-lived product lifetime and textile recycling level is still very low (Niinimäki et al., 2020). This is partly because the economical sustainability of circularity strategies for businesses has not been widely proven, often resulting in a situation where companies adopting circular strategies have suffered from higher cost structure in comparison to competitors who have not adopted sustainable or circular practices (Langley et al., 2023).

For European SMEs many of the sustainability risks associated with the textile industry are already limited with the current legislation in EU and its member countries, concerning for example wastewater management (Palacios-Mateo ym., 2021) as well as labour and occupational health and safety. Therefore, some of the sustainability risks are mostly highlighted regarding their suppliers outside EU and the lifecycle of the products produced (Palacios-Mateo ym., 2021). As a continuation of this, the key development area for European textile manufacturers' sustainability is regarding the due diligence processes for their suppliers, as well as the lifecycle of their products.

2.2 Digital product passport

Digital product passport is a tool accompanying the European Commission's actions to promote decoupling development (Llorente-González & Vence, 2019; Pieroni et al., 2021; Walden et al., 2021) by enabling circular economy practices for all stakeholders of product life cycle (European Commission, 2022b; Voulgaridis et al., 2024). Digital product passport is accompanying other ESPR actions as well as other regulatory activities that are aiming to support circularity development in European Union (Nokelainen et al., 2022; Walden et al., 2021).

As a solution for scalable adoption of circular strategies, digital product passport for digitalizing product life cycles has been suggested (Walden et al., 2021). It is vital to understand that transparency provided by digital product passport solution is not leading to circularity on its own but works as an enabler for circularity practices (Langley et al., 2023).

In current research the equivalent for digital product passports are digital twins (Voulgaridis et al., 2024) with digital product passports especially being digital twin for tracking and tracing of circularity data (Pehlken et al., 2024). For the purpose of circularity key emphasis in digital product passport solution is material flows rather than energy consumption (Langley et al., 2023), although environmental impacts related to use of energy and other resources are also covered from product sustainability perspective.

Digital product passport is a unified form of presenting product related sustainability information from various sources, such as product and material manufacturers (Adisorn et al., 2021; Nokelainen et al., 2022) and it was first presented as a regulation proposal in 2022, in the publication of EU's Strategy for Sustainable and Circular textiles (EUSSCT). With additional details on the affecting regulation DPP is included in the Ecodesign for Sustainable product regulation (ESPR) proposal, which is a revision of Ecodesign directive based on Sustainable products initiative (Psarommatis & May, 2024). Digital product passports' intention is to work a traceability solution for the end customer and to present lifecycle information, such as information of the origin, manufacturing, repair and disposal of the product (Adisorn et al., 2021; European Commission, 2022b; Nokelainen et al., 2022). Digital product passport data would therefore cover all physical, chemical and other relevant information of the data, and this data would be provided by the manufacturer (Langley et al., 2023).

As suggested by the ESPR proposal the adaptation of eco-design measures including digital product passport is suggested to be adopted first on energy related products, textiles, furniture, high impact intermediary products as well as chemicals. The reason for textiles to be included in the range is that the textile product consumption in Europe is relevantly high (European Commission, 2022b) and on average textile consumption category is estimated to have top four negative impact both on climate change and water and land use globally (European Commission, 2022a).

Currently no EU level instrument exists to address product level sustainability. This results in significant potential for improvement. The ESPR proposal refers to public consultation in 2019, which found out that also found out that 72% of the respondents did not think EU had sufficient tools for informing customers on environmental impact of clothes and the 62% thought that current policies did not sufficiently cover sustainable design and production (European Commission, 2022b). This finding is also supported in academic research as Ospital et al. (2023) found in their research that out of 54 brands included in the research only 8 shared manufacturing country, only 3 shared raw material origin, and 5 shared some level of environmental impact on their website. However, communicating brand level social and environmental information was a common practice done by 98% of the brands included in the research.

Tackling the challenges that consumers face regarding information available at the point of purchase and the non-circular consumption patterns currently in place will not be only based on DPP (Nokelainen et al., 2022; Walden et al., 2021). Other upcoming circular economy regulations and actions development in EU include European Commissions

Circular Economy action plan (CEAP) and Green Deal (Psarommatis & May, 2024; Walden et al., 2021) as well as other actions in ESPR (European Commission, 2022b) and EUSSCT (Nokelainen et al., 2022). Many of these actions are linked to DPP development and will be required from the companies simultaneously with the DPP data input development (European Commission, 2022b).

Even as most of the textiles are imported to EU, the textile industry inside EU is significant in size and mostly consists of SMEs (European Commission, 2022a). The EUSSCT recognizes the need to secure and further develop European know-how on creating quality textile products. ESPR is set to ensure the sustainable development of European textile industry (European Commission, 2022b) as the availability of digital product passport would be set as a requirement for the product to enter EU market (Langley et al., 2023). However, all the regulatory activities will come with a cost to SMEs that will need to reach the regulatory compliance and handle the administrative cost raise created by EPSR (Walden et al., 2021).

2.3 Digital product passport information requirements

To be able to map the required data from digital systems used in the organization the data requirements for digital product passport must first be defined. Previous research has also stated that further research should focus on how to compile the data required for digital product passport (Adisorn et al., 2021). This is also the key element in the case study in this research which will be done based on the data requirements.

The scope of DPP information requirements varies between different research papers with some highlighting the end-of-life and use phase more than others, and there are also different interpretations on whether suppliers of manufacturing companies will be submitting the information by themselves or if it will be submitted by the manufacturing company (Jansen et al., 2023; Nokelainen et al., 2022; Psarommatis & May, 2024; Voulgaridis et al., 2024).

The information requirements presented in table 1 are based on the European commission accompanying document for ESPR proposal. The document focuses on ecodesign as whole as optional approaches on improving ecodesign in European union. This is the main document presenting DPP implementation and requirements and will therefore function as the backbone of presenting information requirements in this research.

Table 1. Information requirements in eco-design directive proposal (EUROPEAN COMMISSION, 2022)

<table>
<tr><td colspan="3">OP4 Sustainability information for consumers and B2B</td><td rowspan="2">OP3 Product sustainability requirement</td></tr>
<tr><td>Option a</td><td colspan="2">Enhanced information requirements</td></tr>
<tr><td>4a.1</td><td colspan="2">Technical lifetime (Attribute)</td><td>3a.1</td></tr>
<tr><td>4a.2</td><td colspan="2">Repairability score and repair manual (Attribute)</td><td>3a.2</td></tr>
<tr><td>4a.3</td><td colspan="2">Substances of concern (Attribute)</td><td>3a.3</td></tr>
<tr><td>4a.4</td><td colspan="2">Recycled content (Attribute)</td><td>3a.4</td></tr>
<tr><td>4a.5</td><td colspan="2">Ecological profile (Attribute)</td><td>3a.5</td></tr>
<tr><td>4a.6</td><td colspan="2">Sustainability performance class (Attribute)</td><td></td></tr>
<tr><td>4a.7</td><td colspan="2">Social indicators (Attribute)</td><td></td></tr>
<tr><td>Option b</td><td colspan="2">European Digital product passport</td><td></td></tr>
<tr><td rowspan="9">4b.1</td><td colspan="2">4a.1-7 and track & trace information is made available in digital product passport</td><td></td></tr>
<tr><td>1.1</td><td>Manufacturer (Track & trace)</td><td></td></tr>
<tr><td>1.2</td><td>Global location, GLN or other (Track & trace)</td><td></td></tr>
<tr><td>1.3</td><td>Origin of components (Track & trace)</td><td></td></tr>
<tr><td>1.4</td><td>Modes of transport (Track & trace)</td><td></td></tr>
<tr><td>1.5</td><td>Global trade item number (Track & trace)</td><td></td></tr>
<tr><td>1.6</td><td>TARIC Code (Track & trace)</td><td></td></tr>
<tr><td>1.7</td><td>Name of authorized representative (Track & trace)</td><td></td></tr>
<tr><td>1.8</td><td>Composition (Track & trace)</td><td></td></tr>
<tr><td>4b.2</td><td colspan="2">Waste Framework directive and REACH in addition to 4a.3</td><td></td></tr>
<tr><td>Option c</td><td colspan="2">Generalized European digital passport</td><td></td></tr>
<tr><td>4c.1</td><td colspan="2">Options a, b and product specific requirements</td><td></td></tr>
</table>

In the ESPR proposal OP3 presents the proposal for enhanced product sustainability requirements, and OP4 presents the requirements of making sustainability information available for customers including both consumers and business to business customers. Table 1 explains this relationship between OP3 enhanced sustainability requirements and OP4 information requirements. As this research focuses on a situation where a general European digital product passport would be required, all the requirements presented in OP4 Options a-c are considered. The overview on current research by Langley et al. (2023) on digital product passport enabling technologies suggest that with the use of different approaches the data could be required in SKU level.

2.3.1 Technical lifetime

Technical lifetime information requirement presented in the ESPR, is set to support the decision making at the point of purchase (European Commission, 2022b), as product lifetime is often cut short by users' decision to discard the product (Aakko & Niinimäki, 2022) lifetime communication is hoped to increase the perceived lifetime as well as enforce quality product development (European Commission, 2022b).

The technical lifetime information requirement is related to enhanced sustainability requirements also presented in the ESPR proposal. This enhanced product sustainability requirement (measure 3a.1) suggests that the minimum product lifetime, or technical lifetime, for textile products should be expressed in years of use with description of the preventive maintenance actions that lead to the presented technical lifetime. According to ERPS a use-meter related to durability, such as number of washing cycles or duration of use should also be presented. To simplify this could also be expressed in a form of durability index (European Commission, 2022b). The regulation proposal also states that when presented to the customer the commercial guarantee for durability must be expressed clearly.

In previous research that studied cotton bed sheets lifetime and end-of use decision made by the customer, the product characteristics that had the biggest impact on product lifetime, were the colour density, fabric finishing, fibre, and spinning (De Saxce et al., 2012).

It can be concluded that the estimated product lifetime is highly dependent on lifetime information provided by the yarn producer as well as the decisions made on the colours of the products. Furthermore, product lifetime is dependent on the use factors, such as duration of use, number of washing cycles and the method used for dying the fabric after wash (Klep et al., 2023a). As noted by Klep et al. (2023a), the lifetime is also highly dependent on user attributes, such as the quantity of product in users' possession to fill the functional unit. As a conclusion, technical lifetime factor has been combined in Figure 1. To determine the technical lifetime the standardized use of a product according to washing instructions and preventive maintenance actions must be determined. The durability of yarns, colours and different finishing methods should then be evaluated based on these.

Setting up a standardized durability testing process can be considered to be a big investment for SMEs as the durability measurement system set up cost estimation is between 10,000 and 20,000 euros per company (European Commission, 2022b). EPSR proposal suggests that industry standards for measuring durability should be set to ensure the reliability of technical lifetime calculations. When technical lifetime is presented to consumers it must be considered that it will then act as a sort of commercial guarantee of the products' durability. As technical lifetime would function as decision making factor at point of sale (European Commission, 2022b) the reliability factor of the value is of great importance.

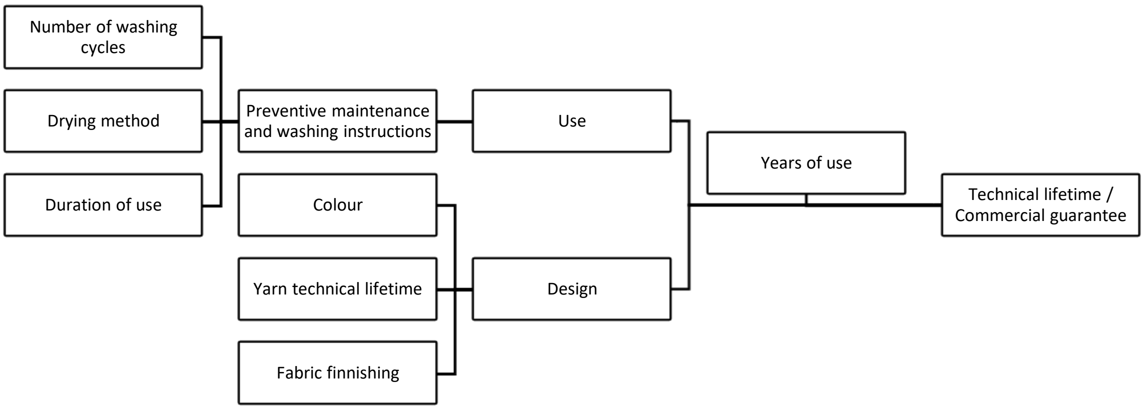


Figure 1. Factors contributing to technical lifetime

2.3.2 Repairability score

In the ESPR proposal the repairability score information requirements are set to communicate the repairability of a product to the consumers or other businesses. The sustainability requirement, measure 3a.2, in ESPR proposal is related to the information requirement and states that the minimum requirement for repairability should be based on the eco-design requirements already exiting for certain products (European Commission, 2022b). Requirements as presented in the ESPR measure 3a.2 when applicable for textile products could include ease of repair, maintenance and disassembly with commonly available tools and spare parts, availability of repair services, availability instructions for maintaining and repairing the product as well as *requirements on choice of materials and design in order to facilitate reuse, repair and adjustments* (European Commission, 2022b).

Based on these requirements a repairability score similar to French repairability index is set to be defined and the required information should be made available for the customer (European Commission, 2022b). French repair index is currently focused only on electronic product and has been quickly adopted in the industry, but has now been suggested to be replaced by Durability index (European Environment Agency, 2024;

Ministère du Partenariat avec les territoires et de la Décentralisation et al., 2024), highly suggesting overlap on durability and repairability information. The parameters for the repairability index are the availability of technical documentation, required tools and ease of disassembling, availability and delivery time of spare parts, ratio between repair and product price as well as product type specific parameters (Ministère du Partenariat avec les territoires et de la Décentralisation et al., 2024). The score based on these parameters is then displayed both in store and website.

As a conclusion repairability score should be presented on a scale from 1-5 or 1-3 should be based on the repair needs for the specific products (European Commission, 2022b). Therefore, the repair needs for a product must first be determined. Based on this, the repair instructions should be presented, and availability of required repair tools, materials and services needs to be evaluated. The factors influencing the repairability score are presented in Figure 2.

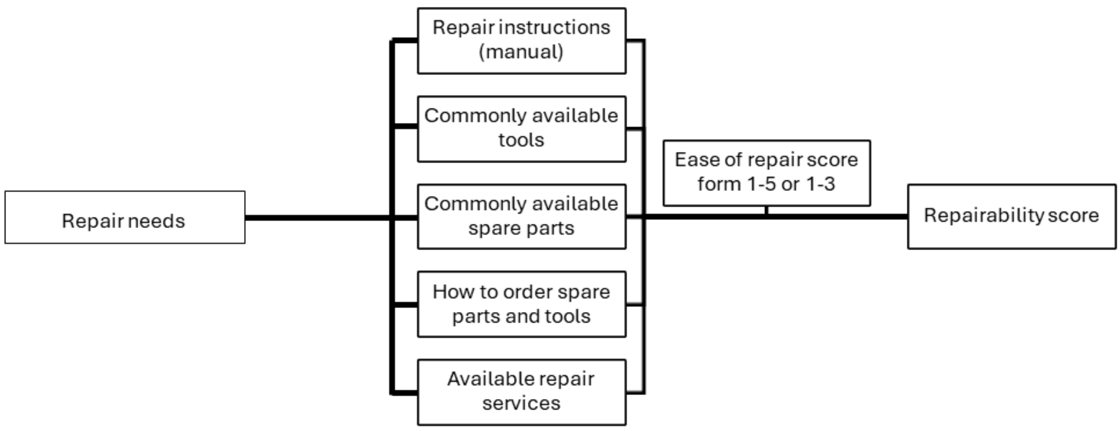


Figure 2. Repairability score factors

2.3.3 Substances of concern

The purpose of information requirements regarding substances of concern, as stated by the ESPR proposal, is to inform product lifecycle shareholders, such as recyclers of substances used in the product that could affect the recycling or remanufacturing process. It should also inform the consumer about substances of concern to ensure safe use of the product. For the information requirement regarding substances of concern the related sustainability requirement, measure 3a.3 in ESPR proposal, states that the main goal of this attribute would be restricting the presence of substances hindering circularity. Therefore, if there are none of these substances in the product the information requirement is only to state this.

The information requirement, 4a.3 in the ESPR proposal, for substances of concern then again states that the customer should be able to get the following information regarding substances of concern used in the product: name of the substance, location within the product, instructions on safe use, concentration levels of substances under REACH. Also, non-hazardous substances should be stated when they affect recycling, reuse or remanufacturing of the product.

Other eco-design requirements presented in the ESPR proposal include product design requirements to enable high quality recycling (3a.6), and minimum requirements for remanufacturability (3b.2). These are not mentioned as an information requirement for the digital product passport but should be considered in product design to maximise the recyclability of the products. According to ESPR proposal 3a.6. to ensure high quality recycling, use of plastic should be avoided in textile mixture as it limits the recyclability of yarns and fibres. As a conclusion the use of plastics in the textile mixture can also be seen as substance of concern that should be considered when collecting the information.

ESPR proposal suggests that the substances of concern would be more defined data requirement in terms of responsibility and range of tracked substances compared to Waste Framework directive and REACH.

2.3.4 Recycled content

For the information requirement regarding recycled content the related sustainability requirement, measure 3a.4 in ESPR proposal, states that a minimum requirement for recycled content on the product would be defined. The goal of this action would be to provide markets for recycling activities (European Commission, 2022b).

However, as noted in the qualitative feedback provided in the ESPR proposal the level of recycled material available in textile industry is still too low for this action. The qualitative feedback for ESPR also states that a level of trade-off between durability and use of recycled content exists in the textile industry.

In the information requirement 4a.4 in ESPR proposal, the feasibility of minimum requirements is noted, and it is stated that the information requirements may vary depending on this.

There are EU level actions, such as Circular economy action plan that aims to increase the collection and reuse of textiles. One action regarding this is included in EUSSCT which aims to ban the destruction of unsold and returned textiles (European Commission, 2022a). However, separate collection rate of textiles in 2020 was only 37% on average with clear differences between countries (Amicarelli & Bux, 2022). Furthermore, the study by Dukovska-Popovska et al. (2023) stated, that the current automated sorting capacity in the Nordic countries, mostly in Finland, could handle the minimum estimated volumes of recyclable textiles and that with additional future sorting capacity in Norway and Denmark the maximum estimated sorting capacity of recyclable textiles could be covered.

2.3.5 Ecological profile and sustainability performance class

The product life-cycle environmental profiling information requirement is a combination of the actions to reduce carbon emissions and environmental footprint of the products, as stated in ESPR proposal measure 3a.5 and the way of expressing this to the customer in form of Ecological profile. In ESPR proposal measure 4a.5 it is stated that a standardized approach to measurements and calculation methods will be set by European standardization organizations, and that sustainable product initiative framework will not predetermine this.

European Commission (2022b) suggest in their proposal that the ecological profile would be based on product environmental footprint method like using life cycle assessment approach and therefore product environmental footprint could be calculated by using this method. It has been suggested that environmental footprint calculations is likely to be required for all products sold in EU in the near future (Mordaschew & Tackenberg, 2024). Product environmental footprint (PEF) method will however be a separate standard to LCA calculations.

To create a life cycle assessment of a product, as presented in figure 3, bill of all materials, as well as validated data from the suppliers are required (Ellingsen & Vildåsen, 2022). After determining the ecological profile as a combination of PEF, product lifetime and end of life out-puts information requirement sustainability performance class could be determined and in the future sustainable performance class label could be required in products. (European Commission, 2022b).

When calculating the environmental impact of the product inputs such as emissions, waste and materials should be calculated from each production phase (Figure 3). However, as stated by Corona et al. (2019) the analysis of circularity is not the intended use case of LCA which focuses on waste generation as a detriment and is not able to consider the reuse, repurposing and recycled material strategies of circular economy.

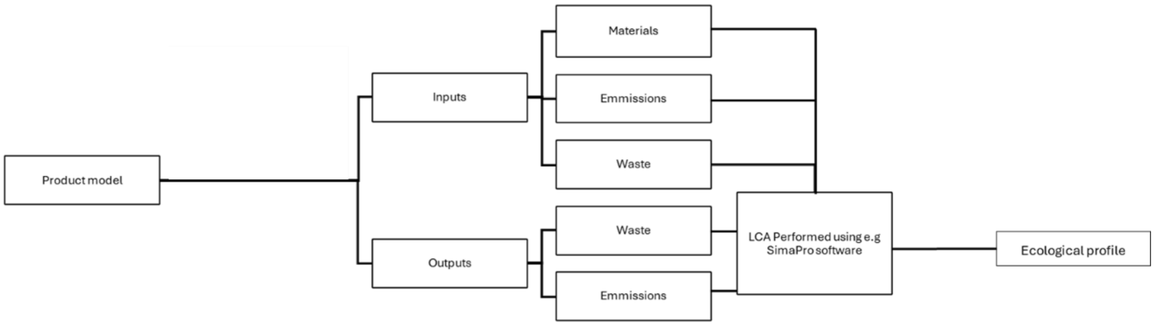


Figure 3. Product ecological profile factors

Klep et al. (2023) go as far as to state that this leads to the conclusion that product environmental footprint methods such as LCAs favour synthetic textiles and fast fashion. European Commission (2022) states that for a full ecological profile also product lifetime and emissions along it as well outputs such as waste generated should be considered. However, Klep et al. (2023a) note that the models also favour synthetic materials by neglecting environmental impacts of synthetic materials and failing to recognize the sustainable methods of land use. Klep et al. (2023a) continue to state that the models currently lack geographical coverage of data and are therefore not able to express global differences in environmental impact. Therefore, they conclude that the product environmental footprint measures are not aligned with EU strategy for textiles.

As of now European Alliance for flax is calculating the environmental impacts of yarn production and only fibre production data is available (Alliance for European Flax-Linen & Hemp, 2023). Therefore, calculating the environmental impact of the linen product made from European Flax TM will be possible in the future, thus partly solving the issues of global coverage of data as highlighted by Klep et al. (2023). To be able to create accurate LCA calculations all product life cycle steps should be considered. To create a product environmental footprint also the upstream and downstream inputs and outputs should be considered. However, if in the future PEF id required from all products in the

European market, product made from raw materials originating from inside Europe PEF could be calculated with real values.

2.3.6 Social indicators

The purpose of social indicators information requirements as stated by ESPR proposal is to inform the consumers at point of sale about social risks related to production. The purpose of the requirement is also to promote the use of practices reducing the social risks related to products life cycle (European Commission, 2022b).

As stated by European Commission (2022b) this information requirement would be based on social assessment that would identify hotspots for positive or negative impact in the value chain. According to European Commission, this could be done either on company level, or sector level. The ESPR proposal also notes that some social indicators are currently often presented in textile industry as a voluntary practice.

A related enhanced sustainability requirement presented by European Commission, (2022b), would be the requirement of due diligence in the supply chain of the product as stated in the ESPR proposal measure 3b.3. In the proposal due diligence is defined as a duty to set a process inside a company to identify, prevent and mitigate risks related to human rights as well as environmental impacts. The process should identify, prevent, and mitigate risks in both own operations, subsidiaries and in supply chain. It should also include tracking the effectiveness of the measures as well as include communication and complaint processes.

Currently common practices in textile industry include the use of code of conduct, where it is commonly stated that practices of health and safety, labour, and human rights as well as company policies need to follow certain social indicators (Ospital et al., 2023).

2.3.7 Track & trace information

In addition to the attributes presented above track and trace information is another main set of information requirements for digital product passport, as explained by the (European Commission, 2022b). ESPR proposal states that track and trace information could be required either on individual product level or model level.

The tracking and tracing information could according to the proposal include information such as manufacturer name, global location (GLN or other), origin of components, modes of transport, global trade item number, TARIC Code, name of authorized representative, composition (European Commission, 2022b). As stated in the ESPR proposal much of this information is already provided in some systems and therefore development needs regarding this information focus in ensuring that the data would sync between official systems. On the company side the easy submission of the information should be ensured.

2.4 Technical solution of digital product passport

While the information requirements and the administrative burden related to DPP greatly determine how the SMEs will need to approach circularity in the future, the technical solution regarding digital product passport will be important for them especially in the requirements it creates for the companies' data management. This chapter will cover the technical solution concerning SME's. However, regarding the technical solution for digital product passport, only few studies have been conducted to suggest technical solutions for providing the data and the final technical requirements are yet to be clarified (Nokelainen et al., 2022; Voulgaridis et al., 2024).

A study on Digital Product Passport, that was commissioned in co-operation by Finnish textile & Fashion association and association of Technology industries in Finland, an written by Solita and Gaia Consulting companies, Nokelainen et al. (2022), described a bottom-up solution that would consider the emerging regulation described in the previous chapters, as well as the economic, trade secret and technical feasibility factors. Their solution is mostly supported by other DPP literature, and it can be seen as the local industry guideline the technical solution presented here relies heavily on it.

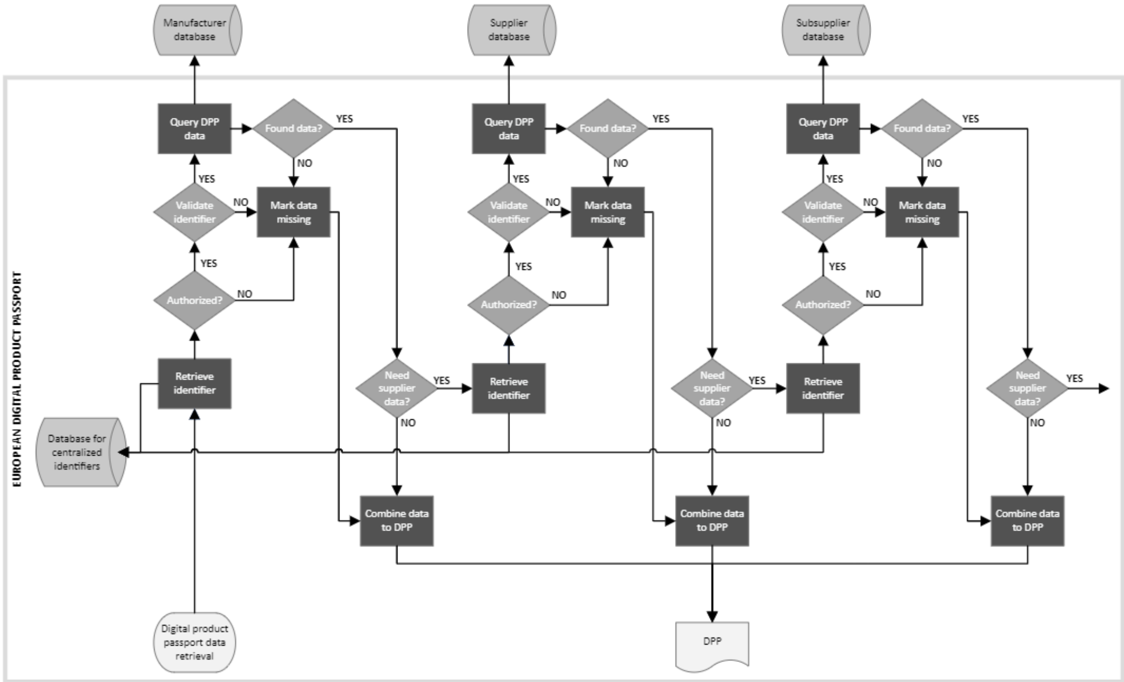


Figure 4. Simplified flow chart of using API calls in decentralized database to retrieve DPP data

The combination of the registry of product data identifiers and a decentralized system for storing the data is the solution for DPP supported in current literature and ESPR regulation (European Commission, 2022b; Jansen et al., 2023; King et al., 2023; Nokelainen et al., 2022). This technological solution is presented in figure 4.

In the solution presented in figure 4, product data available in the digital product passport would be appointed a decentralized identifier (Berg et al., 2022; Nokelainen et al., 2022). King et al. (2023) state in their research that system and information requirements from the side DPP requires the information of product breakdown structure, as well as product identification, product type identification, enterprise identification and access, verification and longevity related requirements. On the other end of the process information would be accesses by consumers and other parties using QR codes (Nokelainen et al., 2022; Voulgaridis et al., 2024). However, Gligoric et al. (2019) note that there is a limitation in the number of QR codes that can be generated.

This update would most likely be reflected in textile labeling requirements, currently covering composition as the only necessary information to be included and translated (European Union, 2024). As noted also in the ESPR proposal translations to the customers language will increase the administrative burden for SME's (European Commission, 2022b). Presenting DPP information online will support effective translations of the information when done with APIs to database supporting efficient management of translations.

The use of a decentralized system and integration to an enterprise system would however require for the enterprise system used to include all the necessary data. To do this the company needs to have a centralized database, that can then be integrated with EU DPP system (Voulgaridis et al., 2024). Nokelainen et al. (2022) suggest that the system used for this could be e.g. enterprise resource management system (ERP), or product information management system (PIM).

Nokelainen et al. (2022), deduce that enterprise systems should be integrated to European DPP service using application programming interfaces (APIs) as presented in Figure 4. However, they also note that not all actors in the value chain have the resources for integration and therefore manual data input interface should be available. Data submission efficiency should however be considered here, as it must be highlighted that DPP benefits for circular economy are dependent on how efficiently and well the technological solution for it is designed and implemented (Langley et al., 2023).

Data update frequency is dependent on the level of automaticity and high amount of data submission manually is not seen economically sustainable (Psarommatis & May, 2024). Automatic or semi-automatic data updates allow higher amounts of data to be updated (Psarommatis & May, 2024). The use API calls (Nokelainen et al., 2022) would support either automatic or semi-automatic updates depending on the process implemented. The agile updating and validating process supporting information accuracy can be seen as the core data management process of DPP from to industry side (Langley et al., 2023).

Many researchers have suggested cloud-based database to enable greater access to data (Nokelainen et al., 2022; Psarommatis & May, 2024; Voulgaridis et al., 2024). Langley et al. (2023) further suggest that cloud computing is the key technology enabling DPP systems by supporting agile, processing and storing of data by offering resources for computing on-demand.

Voulgaridis et al. (2024) underline the importance of data curation processes for effective management of the digital product passport data. They suggest approaches such as data cleansing and digital threads which would enable focus and curation tracking on meaningful data in terms of DPP data curation. In their suggestion preprocessed business data complying with full digital product passport requirements would be submitted for digital product passport and circularity data would be then sorted and presented separately.

Product use phase and circularity data, when done by other operators than the manufacturing company falls outside of the scope for this research. However, data leverage will be later an important aspect of utilizing digital product passport solutions to their full potential. (Voulgaridis et al., 2024). In addition to DPP development, the current research also highlights ongoing actions for developing an open-source industry standard for circularity data with global coverage, called product circularity data sheet, PCDS (Voulgaridis et al., 2024).

Noble technologies that will support the implementation of digital product passport to its full potential are internet of things, artificial intelligence and blockchain technologies

(Voulgaridis et al., 2024). Even though use of blockchain technology is evidently beneficial for DPP purposes (Voulgaridis et al., 2024), this research where the SME case company has significant share of the information is available in-house due to being responsible for a lot of production stages. Therefore, this research will not cover the use of blockchain technologies in depth.

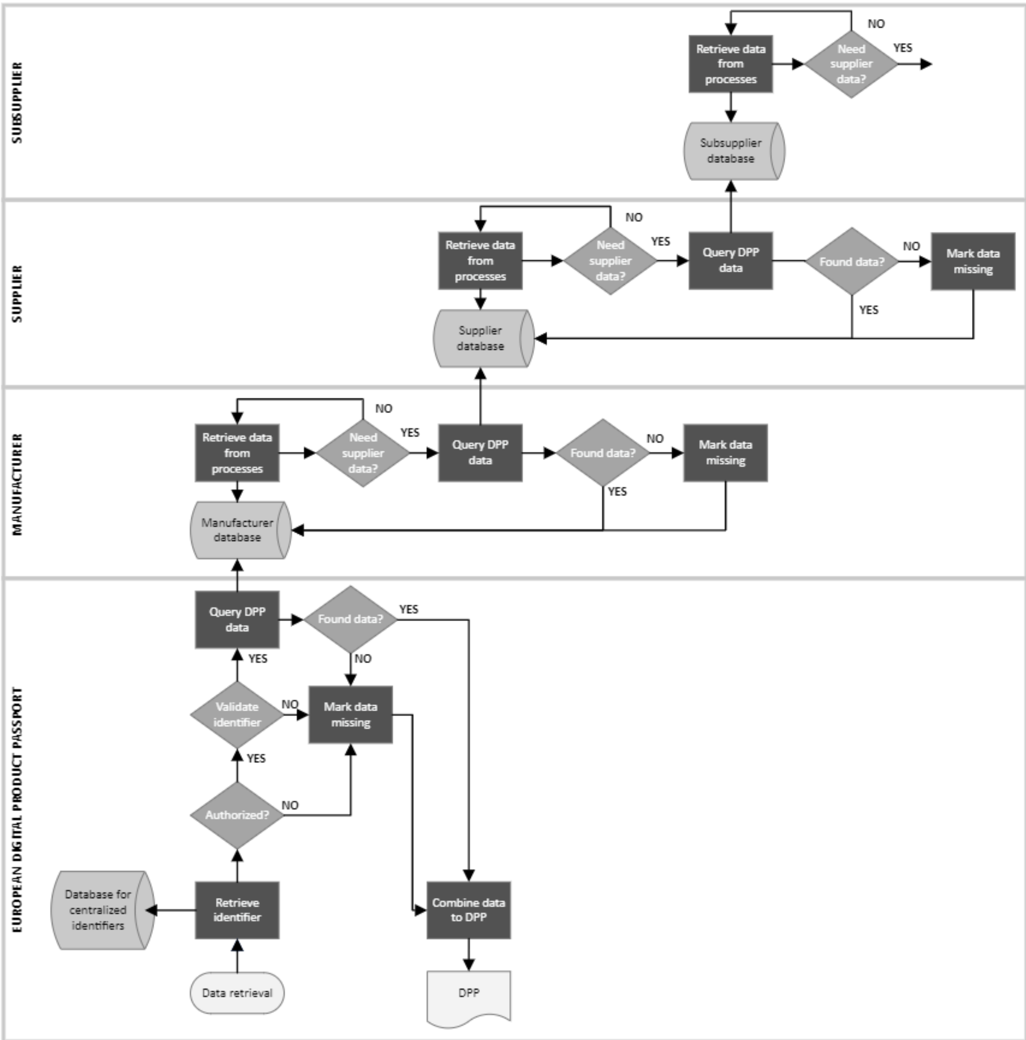


Figure 5. Flow chart of simplified DPP data retrieval process if done solely from manufacturer database

In another model presented by (Voulgaridis et al., 2024) the manufacturing company would be responsible submitting also the supplier data (Figure 5). However, this can be debated. It must be noted that the functional demand for digital product passport rises from the need for the decoupling development and need to reach the circular economy targets set inside European union by providing transparency to the products, their materials and production (Jansen et al., 2023). Therefore, this is also the initial goal for the technological solution, and it is supposed to be reached by improving the tracking of supply chain. To reach this target, Jansen et al. (2023) argue, that it is necessary for each supplier in the supply chain to submit the data of their own processes.

Figure 5 presents the retrieval process if the data submission responsibility would rely solely on the manufacturing company. The noticeable difference is the central role of the manufacturing company in comparison to technical solution presented in Figure 4 which sees all supply chain parties equally responsible for data submission.

ESPR proposal states that for a product to enter EU market a digital product passport would be required (European Commission, 2022b). The solution regarding data submission responsibility, as presented in figures 4 and 5, is therefore dependent on the scope of products considered as textile products, as well as the point in the supply chain in which the product enters the EU market. In the case where yarns would be considered a textile product, a product made from yarns produced in the EU, and a fabric woven in EU would most likely follow an information flow like one presented in Figure 4. Then again if the product enters the EU market as a final product, the information flow will likely be like the one presented in Figure 5. Therefore, a both of these two figures can be argued to be the solution in the future. However, as King et al. (2023), state in their research, even as the actors in the industry see this change affecting their business the clarity on the solution for DPP remains unanswered and the academic research is only suggesting solutions.

2.5 Traceability in manufacturing systems

The core element of digital product passport is the traceability data, labeled “track & trace” data in the ESPR proposal (European Commission, 2022b). Based on the proposal traceability data could be provided in batch or model level, depending on the requirements defined. To provide this data, traceability in manufacturing systems is required. This refers to verifiability events undertaken in the process of production of a product, commonly tracked using integration of several different manufacturing systems such as enterprise resource planning systems (ERP), manufacturing execution systems (MES), CAD, warehouse management systems, financial management systems and others (Cheng & Simmons, 1994).

When it comes to product lifecycle there are two separate topics that are fall under the scope of this research. There is the product entities lifecycle from the manufacturing companies' point of view, where the lifecycle begins from the product design and end when the company either ends the production of the product or in the circularity related processes planned for the product. However, in terms of digital product passport this product entities life cycle concerning the internal, external, upstream and downstream operations of the product is juxtaposed with the lifecycle of a single unit of the product owned by an end user. The characteristics of these two product life cycle perspectives are very different and therefore some level of loss of reality is to be expected when the data about the product life cycle is retrieved from the product entity's or even from a patch of product entity's point of view. Even from the product entities point of view Cheng & Simmons (1994) also state that some level of loss of reality of the events has to be acknowledged when the events are traced through manufacturing execution systems.

According to Ben Khedher et al. (2011) data regarding the product entities lifecycle in product in manufacturing systems consists of the following steps. Design phase information systems relate to the need for the bill of materials (BOM), product configuration and model. This information is provided for production planning and manufacturing on which information regarding manufacturing process and manufacturing bill of materials as well as work instruction and machine set-ups are covered. Lastly data relating to making the product available for market is covered. Usually there is also a process for the disposal of the product at the end of certain product entities life cycle.

In comparison to the data requirements for digital product passport it can be concluded that the bill of materials, manufacturing bill of materials, and the data related to making the product available in the market are in key role in DPP information. For the purpose of creating the ecological profile of the product, production information is also valuable.

However, Langley et al. (2023) highlight that the product information should be specific to component level. This sets granularity requirements also for the identifiers used for the products, as the same product could for example in different patches have the same components from different suppliers. Therefore, depending on the required information granularity identifiers further from SKU level might be required. The current-state identifier granularity is highly dependent on industry in question. According to Langley et al. (2023) novel technologies supporting the identification would be internet of things and smart tags. However, Aung & Chang (2014) note that food industry today is using granular tracking of products. This could be used as an example in other process industries (Kuhn & Franke, 2021).

The information of product entities lifecycle stages is traditionally managed through various information systems. Ben Khedher et al. (2011) state that the coverage of these stages in the most common systems such as, PLM, ERP and MES systems is also limited, and many stages are handled either manually or with tools for that specific purpose. For the purpose of data retrieval for digital product passport it is important to understand the original data source.

ERP system has been the traditional approach on managing data related to all companies' activities (Ben Khedher et al., 2011) and it can be seen as an environment supporting multilevel granular data with very traditional data processing logics (Helo et al., 2014). As track and trace data required for digital product passport is partly data already previously required for different purposes (European Commission, 2022b) the data is likely stored in a commonly used system such as ERP. The use of ERP systems enables integration possibilities between systems inside and outside of the organization.

Manufacturing execution system (MES) is traditionally used for production tracking, performance analysis and production control (Ben Khedher et al., 2011) and it has been adopted in many manufacturing companies to support where ERP solutions fall short (Helo et al., 2014).

Integration between MES and ERP has been standardized by ISA 95 and IEC 62264. According to this approach exchange between ERP and MES should work as follows: bill of materials should be in ERP and work instructions should be in MES, planning and scheduling should be based on product related data stored in ERP. However, in practice the same data is often stored in several different systems simultaneously often causing lack of coverage of on-time data on production activities. (Ben Khedher et al., 2011) This gap can be covered by PDM, PLM or PIM software depending on the requirements for product data. Therefore, integration between PLM software and MES software is suggested by Ben Khedher et al. (2011).

Ben Khedher et al. (2011) propose that bill of materials, work instructions and production routing information should be in PLM software and communicated from there to the MES system, even as in the case company production is production to stock and production to order, and therefore interaction between MES and PLM software is less frequent than in other production models.

PLM software definition. PDM software definition. Product information management (PIM) software is commonly used in companies to manage data required by online store and other similar internal and external platforms focusing on the ease of data management. PIM software was proposed as the solution for central information repository solution for digital product passport data submissions by Nokelainen et al. (2022). However, if high level of granularity in the data in terms of product patches or data layers of supplier data is required most commercial solutions for PIM are not adequately equipped for this.

In addition to information gathered from the company's internal manufacturing systems the data required from other supply chain operators must be considered. In the case of digital passport data this means considering both upstream and downstream traceability. This value chain is where product life cycle management and supply chain management (SCM) align. In research supply chain management is referred to when processes in distributed manufacturing chains are integrated for additional value (Helo et al., 2014). However, as each manufacturing facility comes with its own set of system architecture, the challenge regarding upstream and downstream traceability is to gather the information into one platform (Helo et al., 2014). As the technical solution for digital product passport is still open (European Commission, 2022b), it remains an open question if DPP will function as the solution for gathering the upstream and downstream data or if this will be left on the responsibility of the manufacturer selling the product into EU market.

Even as the textile industry is known for its complex supply chain, in the case company the complexities of textile industry are mostly reflected on its material supply chain. Therefore, if upstream and downstream data is required from the case company, the complexity as well as the low value of the upstream supply chain must be considered. Due to the formable nature of the products in material supply chain the use of tags for traceability is not considered a viable option for traceability and therefore Kuhn & Franke (2021) conclude that links between the objects should be managed as properties of the data, allowing the creation of inherent data to allow traceability. However, any proposed solutions are still very novel and therefore industrial utilization of these in the textile industry can be seen to happen in near future. More mature solutions for traceability of the supply can be applied with the example set on food supply chain. However, the research on these solutions falls outside the scope of this paper.

3 Methodology

This research follows the design science research method (DSRM) to propose a solution for gathering the data and pushing it forward to the company's website or digital product passport when a solution for it is eventually published. DSRM framework steps combine theoretical research and solutions to practical IS and IT problems (Peffers et al., 2007). The activities as presented by Peffers et al. (2007), and followed in this research are: problem identification and motivation, defining objectives and the solution, design and development, demonstration, evaluation, communication, reflection. The process based on this methodology is presented in figure 6.

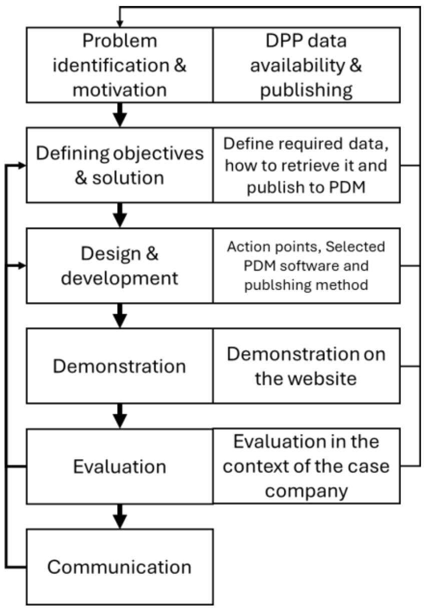


Figure 6. Methodology used in the research

As previously stated, the initial purpose of digital product passport is to enhance circularity practices in textile industry. On the other hand, the challenge for European textile manufacturing SMEs is proposed to be the availability of resources for the implementation. These aspects are considered throughout the process at each step.

Beginning from problem identification and motivation (1), the problem is defined based on literature review on previous research as well as the business problem defined. It is concluded that the key problem is to create clarity in the digital product passport information requirements and availability and to create a technical solution that supports pushing this information efficiently from company database to external systems. Peffers et al. state that in the problem identification and motivation phase the key element is to define the research topic in the IS research field.

Based on problem identification objective and solution are further defined (2), also for this phase the support comes from the literature review of previous research as well as EU documents regarding ESPR, but also from the research on company IT-systems. This step is considered as the phase that creates the separation between the existing research and solutions and the objective of the research in question (Peffers et al., 2007). DSRM methodology states that these objectives can be either quantitative or qualitative, the first considering metrics or terms for predicted solution, and the last considering the description for what is needed from the solution (Peffers et al., 2007). In this research it is concluded that separation between existing research is highly focused on the processes and software capabilities as well as the needed improvements for those inside a case company, therefore focusing on qualitative objectives.

Design and development (3) phase dives deep into the case company systems to locate and retrieve the data based on the objectives defined in phase two. Data flow inside the company's systems is mapped, required actions for creating the required data are identified, publishing method is detailed, and the responsibilities are defined based on the research done inside the case company.

In the design and development phase, two products are used as an example and a solution for pushing DPP data for these products into online store is presented as the process that utilizes API calls is mostly identical to pushing the data into official EU DPP. The example products are a double woven linen tea towel and a Finnish sheep wool blanket. These have been chosen as they represent well all the different production pipelines inside the company. To develop a model for retrieving all the required data for these two products, company employees responsible for the data in different phases of the manufacturing process have been interviewed. Additionally, hands on use of the different company software's for tracking and tracing was used to further define the locations of the required data. Also, participation in meetings regarding the implementation of a new online store was used as an opportunity to learn about the integration possibilities of ERP, online store and a proposed PIM system. This information is utilized in the development of the solution.

According to DSRM framework the design and development activity consists of first and foremost determining and creating the design artifact. In IS research field the artifact can refer to either model, construct, method, or initiation as the solution (Peffers et al., 2007). In this research the scope will be limited to the initiation as the solution. Demonstration of the solution (4) covers the solution in a scope relevant for research purposes. Also, according to Peffers et al. (2007), the demonstration activity is important in demonstrating the artifact as the solution to one or more research problem. In this research the solution is demonstrated using visuals to demonstrate the process of creating and publishing the data as well as an example of how the users can access the data.

The solution is evaluated against objectives (5). Peffers et al. (2007) state that in support of the evaluation, reflection through observation of the solution is the best practice in defining how well the suggested artifact responses the need stated in the problem identification phase.

Lastly, Reflection (6) is covered in the research paper section discussion and further research. Peffers et al. (2007) conclude that communication and reflection are the most important steps in terms of sharing the research with other professionals. According to Peffers et al. (2007), communication consists of the research problem and significance as well as the utility of the artifact, the rigor of the research. Communication of the research can follow the DSRM process to support discipline as one method of demonstrating rigor of research, which is vital for any scholarly publications.

To comply with best practices, process iteration and nominal process sequence will be utilized. The iterations in the process, as well as the consideration and reasoning for the activities and their contents is important in considering the rigor and validity and communication of the research.

4 Results

The purpose of this thesis was to map the requirements and solution for data retrieval of digital product passport data and suggest a way of retrieving this data as well as suggest a solution for publishing it. To do this the results section represents the interpretation of the data requirements from currently available literature as well as the availability of the data in the systems currently. In the solution design action points to create the data based on the requirements is listed and the software solution for publishing the information is suggested. The solution design also considers leading the project with iterative cycles to support adaptation to changes in the scope that are likely to arise and a stakeholder and project organisation breakdown structure to support workload management and communication of the project.

4.1 Problem identification for DPP creation

The research problem focuses on ESPR proposal presented by EU and the requirements it sets for SMEs in European textile industry. The aim of this study is to define the underlying requirements for retrieving all the information required in ESPR proposal and furthermore digital product passport. These underlying requirements include the data required for creating the information required as well as the readiness to provide this data. The requirements also include the actions required to be able to automatically provide the data into DPP systems.

The presumption is that the data required for sustainability attributes as well as track and trace data is currently stored in several different manufacturing systems, as presented in the literature revies section traceability in manufacturing systems. Much of the data required for different attributes in a current state is also not in a form usable for submissions to digital product passport or does not exist at all. To collect this data into a centralized database integrations and new data gathering process or systems are to be proposed.

At each stage the results need to be reflected with the initial purpose of the ESPR proposal and digital product passport, which is the aim to promote circular economy activities through standardized way of presenting sustainability data throughout the product life cycle. The results are also reflected in the resources available in SMEs and possible solutions with excessive resource use must therefore be discarded.

As presented in literature review section about technical solution for digital product passport, currently a solution for DPP does not exist and the structure of the final solution has not been clarified. Therefore, the demonstration of the solution will be done using a solution presenting the DPP data on the company website. This demonstration method also supports presenting the data in European digital product passport when the technological solution for it is made available.

4.2 Definition of requirements and objectives for the solution

The technical solution will be used to publish and generate the data required for digital product passport. Therefore, the database used to store the final information needs to support API calls for pushing DPP data in structured data format. Additionally, a system is process is needed to statistically process production data especially regarding environmental aspects.

The data requirements presented in the ESPR proposal and required in the full scope of digital product passport can be divided into two categories, attributes and track and trace data. Attributes are larger concepts promoting circular economy strategies and therefore requirements for them include both new processes and data requirements.

Attributes include concepts of technical lifetime, repairability score, substances of concern, recycled content, ecological profile and class as well as social indicators. Some of these, such as recycled content, or substances of concern, are more straightforward.

However, creating an ecological profile for a product is a process on its own and therefore is only covered here to the level of data requirements it creates. The objective for the solution is therefore to make the available data presentable and in cases where an update to process is required for creating the data, suggest the way of updating the processes. The solution includes process for maintaining the data. The following chapters will cover the requirements for each attribute in detail.

4.2.1 Technical lifetime

Technical lifetime is as defined in the literature review is a standardized way of expressing the lifetime of product. As the literature review suggests, technical lifetime could also be seen as the commercial guarantee. Therefore, technical lifetime when demanded as a regulatory object will have a significant change in the business perception of product lifecycle. Then again if introduced in a business before being required through regulations, it is a strategic decision implying lifecycle thinking in product development.

Based on the literature review technical lifetime can be based on two different methods, a standardized test of the product durability or estimated calculation based on user data and product design data. As the ESPR proposal states standards for the testing will be created in the future if this will be required.

As the standard for testing remains unclear, this research would suggest calculating the estimated technical lifetime for the products. However, for wool blanket where pilling is the most typical lifetime factor and standardized tests for fabric pilling exists. Therefore, in the case of wool blankets the existing standardized tests, for example EN ISO 12945-2, should be utilized. However, currently the company products have not been tested for pilling. Therefore, next step in the case company would be to categorize company wool product based on the material and techniques used and then send the products for testing.

For other products where the use of the product is key factor in the product technical lifetime estimation considering user data should be used for now, as a standard for lifetime testing does not exist. To make data-based evaluation of technical lifetime the required data can be grouped into two categories, user data and product design data.

User data should be the basis of determining the standardized use of the product. Important user data variables include the number of washing cycles, the drying methods used, as well as the duration of use. The washing methods can be concluded from the washing instructions. If the lifetime is expressed in the future according to industry standards, the standardized use will be presented in the standard. However, in the absence of industry standards, standardized use of a product can be based for example on data collected in user survey. Relevant questions for user survey are suggested in appendix 1. If the data collected in user survey is sufficient, one-time survey is enough to provide the needed data. With products that have extensive lifecycle the user surveys could be directed to restaurant and spas that have wash their products daily.

Based on user data the design data should be created based on the number of years of use a yarn or colour lasts in use. The design data should also consider the effect of finishing method used. Technical lifetime could then be expressed for example in format 10(30) years, where the first number refers to the technical lifetime of the product and the second number to the number of washing cycles used as a base for the calculation.

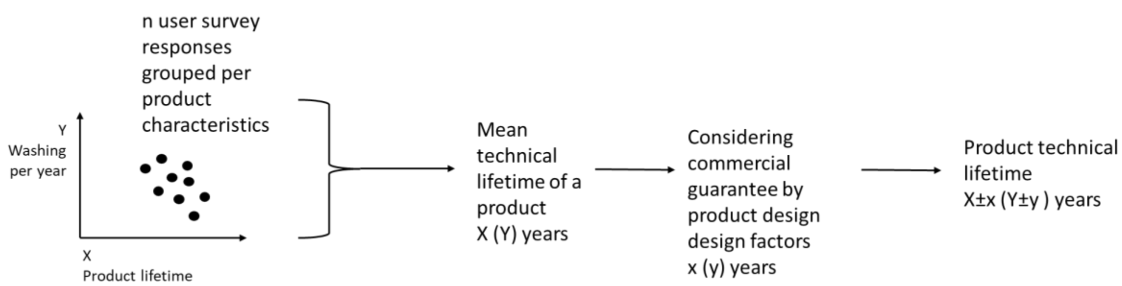


Figure 7. Creating product technical lifetime when standardized testing is not available

Suggestion as presented in figure 7, is to create a technical lifetime for different product categories based on combination of washing instructions, user survey of product lifetime and consumer usage habits, as well as the information of yarn durability and averages of colour durability information available. The base for product lifecycle estimate should be the user survey results and those can be modified based on the information the company has regarding the yarn, colour and finishing method affects to product lifetime. The information should be stored in company software that is able to push the data with APIs into company website and DPP. As sales function has the closest relationship with the customers collecting the data using a user survey would be on their responsibility. The calculations would be done with the product design team, and the information would be added to PDM software together with other product data. It should be noted that this estimation would be valid only until a standardized way for testing the product technical lifetime based on durability testing would be determined.

4.2.2 Repairability score

Based on the literature review on repair need as stated in ESPR and French repairability index it can be concluded that repairability score of a product could be created based on the following information. Repairability score should be based on availability of repair instructions, tools, spare parts, ease of ordering spare parts and tools as well as ease of ordering repair services. The criteria for the score should also be made available on the website. Repairability score for textiles should also state that the repairs do not fix the textile if washing instructions are not followed as failure to comply with washing orders often leads to irreparable damage.

To comply with these information requirements, it is recommended to generate repair instructions based on the feedback from product reclamations, offer product repair services and/or tools, if not commonly available, and spare parts (yarn or ribbon), for product repairs. To ensure ease of access, these should be made available on the website directly at the point where repairability score is presented. The information and its parameters should be stored in company software that is able to push the data with APIs into company website and DPP.

4.2.3 Material data

Substances of concern are not seen relevant for the case company as their products composition does contain substances of concern considering Waste framework directive and REACH. However, it is relevant to state that the products are produced from ÖEKO-TEX certified materials, meaning that the materials are tested for harmful substances. If the range of substances considered here would change for the final requirements of DPP this would need to be reassessed.

Regarding the recycled content used in the manufacturing of the product, the mapping of currently available data in company databases showed that the company ERP system contains information on the percentage of recycled material used in the yarns in the inventory. However, the percentage of recycled material used is not tracked for specific product even though that information is available by combining the information available in ERP and in the manufacturing execution system. Currently this information is not tracked after the manufacturing process has been finished. The company could consider making product specific directions on the use of yarns including certain percent of recycled material. Otherwise, considering the resources available in SME's the recycled content could be expressed as an average of all products produced from the same material. However, then it would need to be stated that this is an average of the whole production.

The same applies to giving information on the origin of the components as part of the track & trace information, although it has not been defined on what level of detail the origin of components should be expressed. The company mostly has information on the origin of the raw materials supplied to them in terms of where the fibre has been produced, where it has been spanned and where it has been dyed and what is the global location of the company that has sold it. However, currently the information is available by combining the data available in ERP and different files and other forms of information received from the supplier. Even if the level of information needed to publish the data remains unclear, the data will be required to be able to create LCA calculations. For these reasons, considering the resources available in SME's solution could be to present a list of the countries of origins with percentages of their supply of that specific material. If current data analysis tools are not sufficient to do this, business intelligence software could be utilized.

4.2.4 Ecological profile

The requirement for DPP states that Ecological profile should be expressed per product not per manufacturing facility. As concluded in the review of existing research the recommended approach for creating the product ecological profile would be to create LCA calculations for products grouped by their production process and other relevant characteristics. Another way of expressing product ecological profile would be to present the productions' water and energy usage, emissions and waste generated. To make sustainability easy to evaluate for consumers a sustainability performance class based on these factors could be used.

Regarding ecological footprint of the materials, as stated in the review of existing research enough LCA data from the global location of the supply chain in question would have to be available. With the lack of available LCA data, for example from European linen yarn production trustworthy LCA calculations cannot be made. Therefore, one key aspect of creating the product ecological profile would have to be to ensure the data availability from suppliers. The lifecycle steps of the product and its raw material are presented in figure 8. The information required from the suppliers on each step of this lifecycle would include energy usage, water usage, emissions, waste and transportation methods used to the next lifecycle stage. Additionally, the results for product lifetime and end of life survey (Appendix 1) can be used to determine the years of use and end of life of the product.

Fibre production	Yarn production	Fabric production	Finnishing	Use	End of life
Linen → Cultivation → Retting Wool → Farming → Cutting	Linen → Scutching → Hackling → Spinning → Dyeing Wool → Mechanical cleaning → Washing → Spinning → Dyeing	→ Warping → Weaving	→ Sewing → Wet finnishing → Heat → Inspection → Packaging	• Years of use • Extraction of substances of concern	• Waste • Emissions • Recycled material

Figure 8. General lifecycle of the textiles produced in case company.

As also stated in the section of DPP technological solution supplying the information of resource use in product manufacturing could in fact be required in the future also from the yarn manufacturers in Europe therefore making this data available. However, this research failed to determine whether retrieving this information will be the manufacturing companies or yarn suppliers' responsibility.

What comes to the material data required for the ecological profile the same presumptions apply as stated in the material data chapter. The material data should be expressed as an average of each material supplied to the company or else the tracking of the data would require extensive changes to processing of information.

In terms of in-house operations, the company is currently only tracking resource use in the whole manufacturing facility. To create a product specific Ecological profile, the products should be grouped in terms of the manufacturing process and product qualities affecting resource use. The calculations on energy and water usage should then be done.

All the data required for the LCA calculations should be stored in a system supporting the retrieval of the information for the purpose of creating LCA calculations. For creating an environmental performance class, the product should be placed on an environmental performance scale in terms of the environmental performance in LCA or the variables affecting this. However, as stated in the literature review, LCA calculations fail to recognize the technical lifetime and the circularity of the product so to present a full ecological performance the effect of these should be noted.

Table 2. LCA data fields

ECOLOGICAL PROFILE = SUSTAINABILITY PERFORMANCE CLASS	**DATA REQUIRED FROM SUPPLIERS AT DIFFERENT LIFECYCLE STAGES**
	Water usage
	Energy usage
	Transportation
	Waste
	Emissions
	DATA REQUIRED FROM THE COMPANYS OWN MANUFACTURING PROCESS
	Water usage
	Energy usage
	Transportation
	Waste
	Emissions
	Bill of materials
	Unit weight
	Number of products produced
	DATA REQUIRED FROM USE PHASE AND END OF LIFE
	Water usage of washing
	Energy usage of washing
	Years of use
	% of products recycled as raw material
	% of products turned into waste
	Emissions from disposal

4.2.5 Social indicators

It is still unclear whether the social conditions information requirement will be done at company level or sector level. This decision will highly affect the data required from the company. As the standard way of expressing the social indicators remains unclear the information covered in code of conduct as well as due diligence processes in place should be used as the social indicators for the production. The code of conduct should consider the critical the sustainability risks associated with textile industry covered in the literature review. For the case company this type of code of conduct exists and has been signed by all 1st tier suppliers.

4.2.6 Sales data

The information requirements stated in the track and trace category are mostly information already requirement from the company for different sales purposes. Therefore, this data has been categorized as sales data. It is information that is mostly stored in ERP and therefore submitting this data to any application can be done efficiently using APIs. Only the data about the name of the authorized representative in a country would require the knowledge of the global location of the reader, this requirement would have to be set for the DPP platform or the website where the information is presented.

Table 3. Track and trace data required

Track and trace data	Manufacturer	The case company
	Global location, GLN or other	Needs to be created
	Origin of components	ERP
	Global trade item number	ERP
	TARIC Code	ERP
	Name of authorized representative	Depending on the readers location
	Composition	ERP

4.3 Solution design

Adaptive and iterative approaches should be implemented to ensure ease of change as there is still high level of uncertainty, and the requirements will most likely change on some level before the final requirements are published. The need to develop a solution early on before having the final requirements rises from the early mover market advantage. However, the organizational capability of transforming from the commonly used predictive development projects to slightly more agile way of working must be considered.

To do this in the solution design phase the initial list of requirements has been collected into an action point list for the data requirements. Furthermore, to comply with these requirements the current IT-infrastructure has been mapped regarding the required data and a software supporting adaptive and iterative DPP development in the company is suggested. To present the solution in action an example of DPP layout in the website and project organization breakdown and stakeholders are presented.

4.3.1 Action points for providing the data required for DPP

Based on the review of the information requirements set of underlying data requirements were identified. Together with the review of the availability of the data in company systems, list of 14 action points was defined. Table 4 presents the required data based on the previous chapters on both digital product passport attributes and track and trace data and the required action points for creating the data needed for DPP.

Table 4. Actions breakdown for creating required DPP data

Information requirement	***Required data***		***Required action points (AP)***	
Technical lifetime	**Other products**	**Wool**	**Other products**	**Wool**
	Color durability Yarn durability Fabric finishing effect Standardized use / user survey data: Number of washing cycles, duration of use and product lifetime	Durability test results	AP1: Create a lifetime evaluation based on AP7.5 (User survey) and product characteristics. Save results in PIM(DPP).	AP2: Group products and do pilling test. Save data in PIM(DPP).
Repairability	Repair needs		AP3: Create repair manual and offer repair service for most	

		required repairs. Publish manual in website, link in PIM(DPP).
	Repair tools required Spare parts required	AP4: Ensure the availability of tools and spare parts
Substances of concern	Bill of materials Fabric finishing Dyeing	AP5: Add statement regarding the use of ÖEKO-TEX certificate and substances of concern to PIM(DPP).
Recycled content	Bill of materials	AP6: Create products that use solely yarns made from certain % of recycled material or create statistical analysis of recycled material used for certain yarns.
Ecological profile	Suppliers: Water usage	**AP7: Create LCA calculation and save the results in PIM(DPP).**
	Suppliers: Energy usage Suppliers: Waste Suppliers: Indirect resource use Suppliers: Transportation	AP7.1: Collect data directly from suppliers or use data available in LCA softwares. For this the information of the suppliers and their yarns used for specific products is required (AP12). Consider using geographically accurate data.
	Manufacturing: Water usage Manufacturing: Energy usage Manufacturing: Waste Manufacturing: Indirect resource use	AP7.2: Group products and calculate water usage, energy usage and waste created
	Manufacturing: Transportation	AP7.3: Calculate transportation methods and kilometers during manufacturing for each product
	Manufacturing: Bill of materials Manufacturing: Unit weight	AP7.4: Retrieve data from ERP
	User survey: Washing cycles, years of use, disposal methods	AP7.5: Create user survey
Sustainability performance class	Ecological profile	AP8: Assign each product a sustainability performance class in PIM(DPP) based on LCA results
Social indicators	Code of conduct and due diligence processes	AP9: Link code of conduct and a statement of due diligence process on PIM(DPP).
Track and trace data	Manufacturer	AP10: Save this information in PIM(DPP)

	Global location, GLN or other	AP11: Generate required GLNs for the company, save in PIM(DPP).
	Origin of components	AP12: System integration between MES and ERP to provide, in one place, data required for tracking on the origin of components for certain products. Alternatively update general level information to PIM(DPP).
	Global trade item number TARIC Code Composition	AP13: Retrieve data from ERP to PIM(DPP)
	Name of authorized representative	AP14: Create a solution for website to recognize which country the user is from and provide authorized representative information based on this if needed

4.3.2 Enhanced material data retrieval from MES and ERP

Depending on the requirements that will be finally defined for textile products in EU DPP enhancements to the material data retrieval capabilities in the manufacturing systems might be required. As case company is doing most of its manufacturing operations in-house, this information is mostly needed for creating the ecological profile of the DPP data requirements. However, there might be some raw material information such as the supplier of the yarn patch used in the production.

These enhancements should be considered if origin of components needs to be expressed from all steps from cultivation to dyeing, if it the origin of components needs to be expressed on patch level as a country of origin rather than just EU, and if the origin of components needs to be expressed on patch level these and enhancements might be required. For the purpose of LCA calculations statistical averages on the origin of components should be sufficient.

4.3.2.1 Yarn information of yarn purchased from suppliers

Currently the ERP is lacking information about yarn suppliers and their products. If the decision is made to store this information in the ERP the information data fields should be updated with the information on the country of origin of each step in the yarn manufacturing process: cultivation, spinning and dyeing. Otherwise, this information could be retrieved using collaborative traceability platform introduced by EU or textile industry organizations such as Alliance for European Flax-Linen & Hemp in case of linen products.


Varastoluettelo
[redacted]
Kaikki ryhmät
Sis. konsignaatiovarasto
Saapumishetken valuuttakurssit

Standard ERP, Tulostus pvm: 21.10.2024 12:37
Tuotevalinta LI200N110
Kaikki tuoteluokittelut
Kaikki liikekump. luokat
Tapa: Oletus

Koodi	Nimi	Yks.	Saldo	Yksikköhinta	Arvo
LI200N110	Linen 20/1 Nm esivalkaistu, prebleachedLMD color 110 V4		[redacted]	KG	0,00
				0,00	0,00
Sarjanumero	[redacted]35SL4DAAC7S0 14 [redacted] 2059901-8 2099905-7RS 22119909-6RD			[redacted]	
Tuotteiden lkm:	1		[redacted]		0,00

Image 1. ERP inventory information about yarn patch numbers

For the Finnish sheep wool traceability, the system differs on some level from the linen products as each stage of the yarn manufacturing process in purchased separately by the case company. Currently the information is available but cannot be traced back to its origin automatically. The information trace runs as following. The information on the cultivation is stored in ERP in the supplier data, then the inventory of supplied wool is stored in ERP inventory (Image 1). The production stage of mechanical cleaning has not been digitalized, and the information is stored in Excel after which the inventory information in ERP is updated. Purchase order for washing is then created in ERP after which the inventory information is again updated in ERP. Then the purchase order is done for spinning and dyeing and again the inventory information in ERP is updated. As the purpose of ERP is not to work as a traceability platform tracing the materials from ERP only would mean expressing the origin in percentages. More advanced origin information would require updates to the system or use of additional traceability platform.

4.3.2.2 Traceability of the material data of a production patch

For ERP to be able to provide data about the origin of components of a production patch it should have the manufacturing process linked to the level of a yarn patch used in the production. However, currently tracking the yarn patch requires manual retrieval of weaving information from MES. This is because the process for the data flow in the production currently is as follows. The whole process of information flow is also described in figure 8.

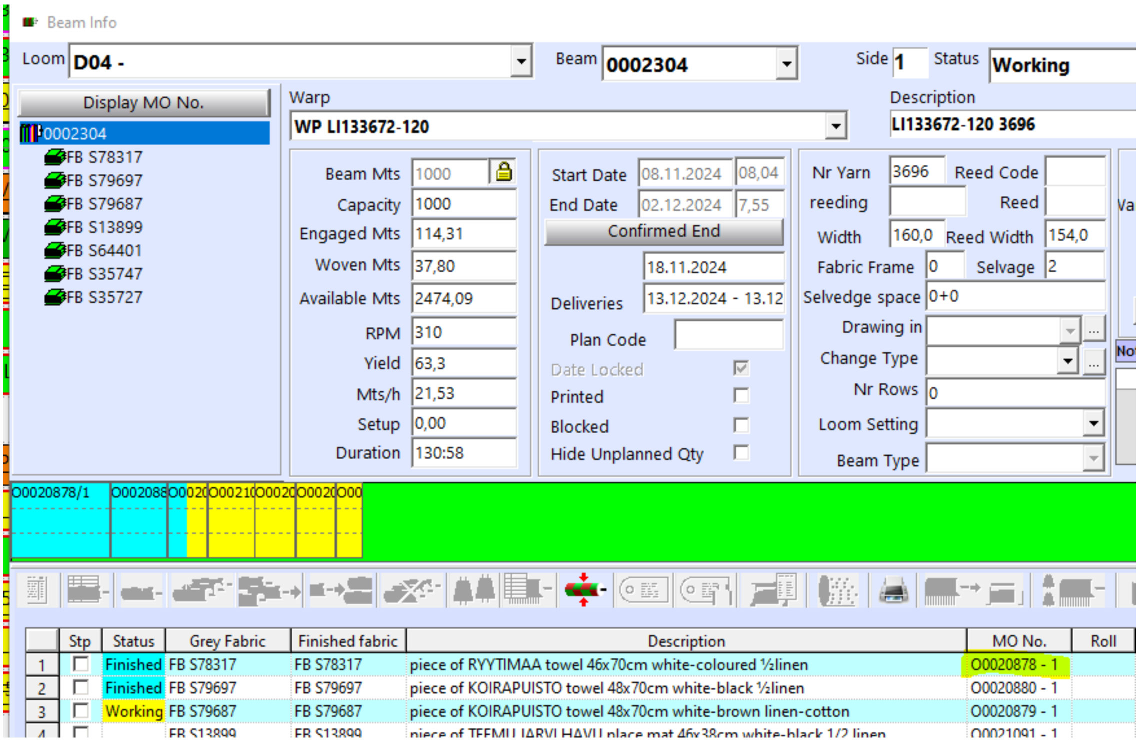
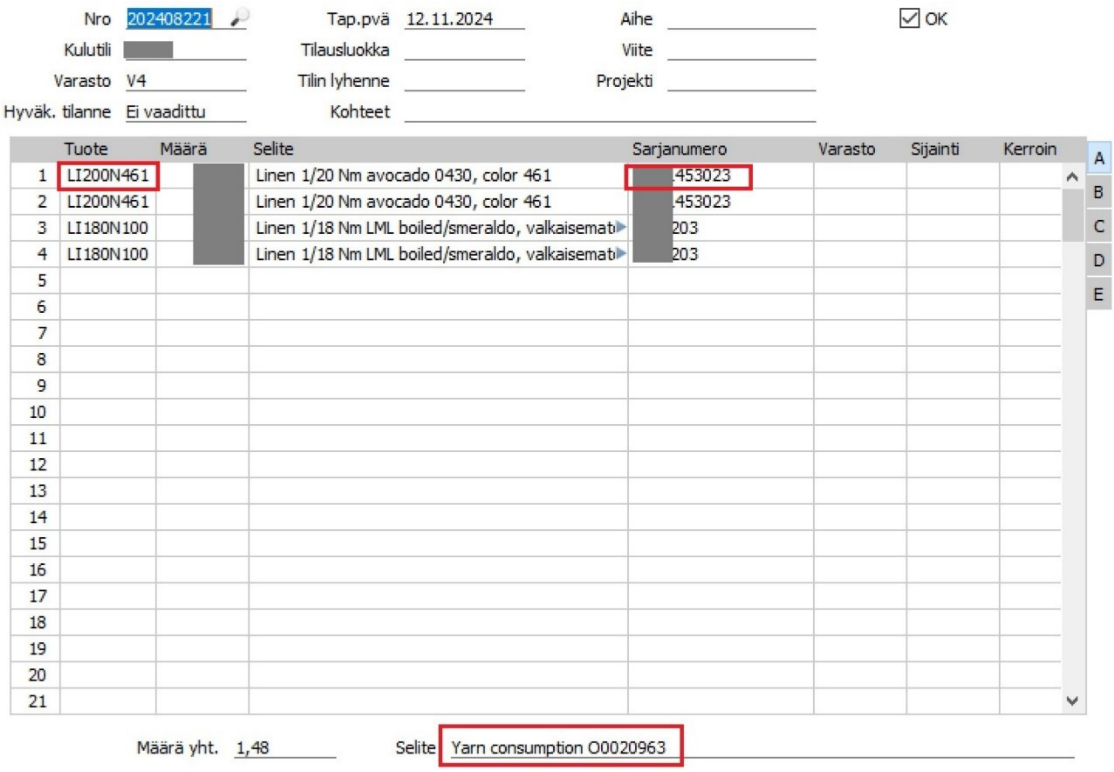


Image 2. MES Order referred to in the inventory yarn consumption information.

When a production order for weaving is created in MES, the system creates MO No. in format OXXXXXXX-X, this is shown in image 2. In the weaving there is an HMI where the patch number of the yarns used in the production are inserted. This creates an inventory change in ERP where the system also posts the MO No. in the definition field with the description, for example "yarn consumption OXXXXXXX-X". An example of this is shown in image 3. It needs to be noted that the current field used for this information in ERP is not supported by the search function of the system.


Nro 202408221 Tap.pvä 12.11.2024 Aihe OK
Kulutili [redacted] Tilausluokka Viite
Varasto V4 Tilin lyhenne Projekti
Hyväk. tilanne Ei vaadittu Kohteet

	Tuote	Määrä	Selite	Sarjanumero	Varasto	Sijainti	Kerroin
1	LI200N461	[redacted]	Linen 1/20 Nm avocado 0430, color 461	[redacted]453023			
2	LI200N461	[redacted]	Linen 1/20 Nm avocado 0430, color 461	[redacted]453023			
3	LI180N100	[redacted]	Linen 1/18 Nm LML boiled/smeraldo, valkaisemati	[redacted]203			
4	LI180N100	[redacted]	Linen 1/18 Nm LML boiled/smeraldo, valkaisemati	[redacted]203			
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							

A B C D E

Määrä yht. 1,48 Selite Yarn consumption O0020963

Image 3. ERP inventory information about the consumption of yarns and yarn patches in weaving.

For each roll of fabric weaved, MES generates an item number in the form of PXXXXXXX as presented in image 4. This number is used for production patch identification in all the later stages of production. It must be noted that depending on the product one weaving machine can produce several rolls of fabric concurrently and therefore one OXXXXXXX-X number can have multiple related PXXXXXXX numbers as shown in image 4.

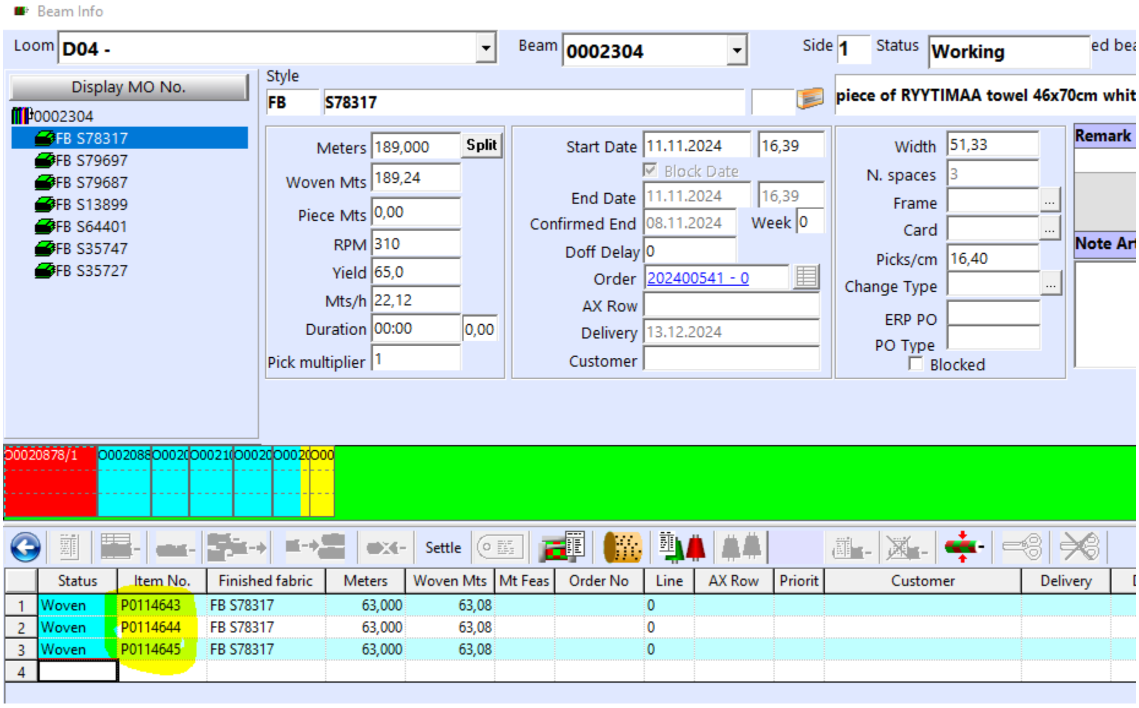
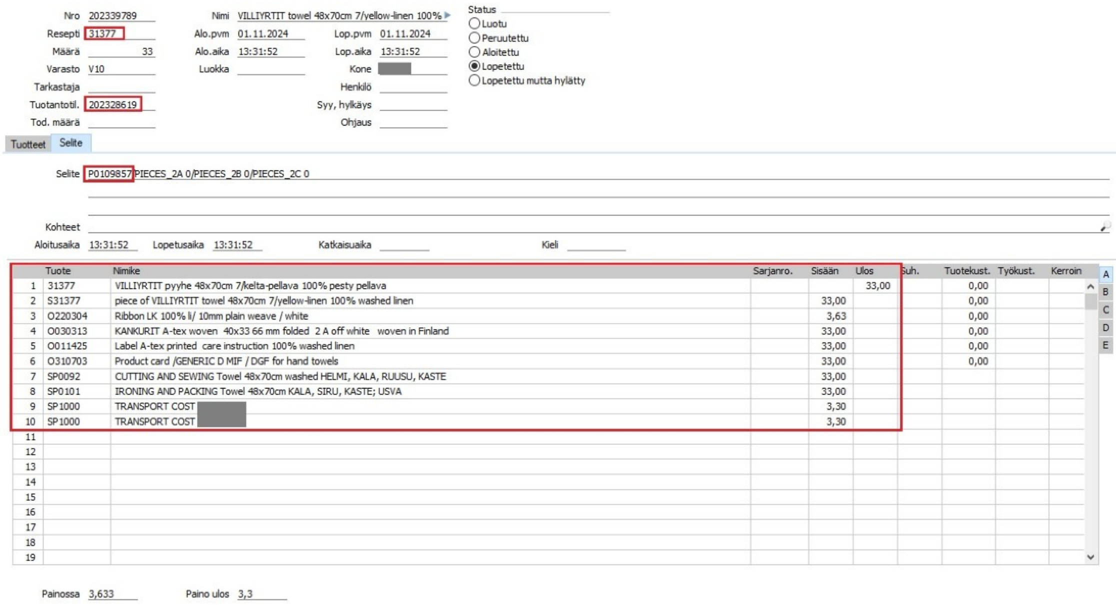


Image 4. MES production with MES Order number and product patch numbers.

When a weaving machine finishes weaving a roll of product it also automatically adds the product to ERP inventory as "piece of product" and pushes also the corresponding PXXXXXXX number into description field of ERP production order as seen in the image 5. Similarly, inspection pushes information about the inspected defects into ERP production history. This production history involving different production patches is linked to the ready-made products in the inventory and the information in ERP is linked.



Nro 202339789
Resepti 31377
Määrä 33
Varasto V10
Tarkastaja
Tuotantotil. 202328619
Tod. määrä

Nimi VILLIYRTIT towel 48x70cm 7/yellow-linen 100%
Alo.pvm 01.11.2024
Alo.aika 13:31:52
Luokka

Lop.pvm 01.11.2024
Lop.aika 13:31:52
Kone [redacted]
Henkilö
Syy, hylkäys
Ohjaus

Status
- ○ Luotu
- ○ Peruutettu
- ○ Aloitettu
- ◉ Lopetettu
- ○ Lopetettu mutta hylätty

Tuotteet | Selite

Selite P0109857 PIECES_2A 0/PIECES_2B 0/PIECES_2C 0

Kohteet

Aloitusaika 13:31:52 Lopetusaika 13:31:52 Katkaisuaika Kieli

	Tuote	Nimike	Sarjanro.	Sisään	Ulos	Suh.	Tuotekust.	Työkust.	Kerroin
1	31377	VILLIYRTIT pyyhe 48x70cm 7/kelta-pellava 100% pesty pellava			33,00		0,00		
2	S31377	piece of VILLIYRTIT towel 48x70cm 7/yellow-linen 100% washed linen		33,00			0,00		
3	O220304	Ribbon LK 100% li/ 10mm plain weave / white		3,63			0,00		
4	O030313	KANKURIT A-tex woven 40x33 66 mm folded 2 A off white woven in Finland		33,00			0,00		
5	O011425	Label A-tex printed care instruction 100% washed linen		33,00			0,00		
6	O310703	Product card /GENERIC D MIF / DGF for hand towels		33,00			0,00		
7	SP0092	CUTTING AND SEWING Towel 48x70cm washed HELMI, KALA, RUUSU, KASTE		33,00					
8	SP0101	IRONING AND PACKING Towel 48x70cm KALA, SIRU, KASTE; USVA		33,00					
9	SP1000	TRANSPORT COST [redacted]		3,30					
10	SP1000	TRANSPORT COST [redacted]		3,30					
11									
12									
13									
14									
15									
16									
17									
18									
19									

Painossa 3,633 Paino ulos 3,3

Image 5. ERP inventory information about the materials and processes intake per production of a patch of products.

Based on these findings in the traceability in the manufacturing system the break in information flow has been identified to be in the point where PXXXXXXX related to certain OXXXXXXX-X number is generated in the production, but the related OXXXXXXX-X number is not transferred into the ERP systems information about the piece of product. This gap in the information flow is presented in Figure 9.

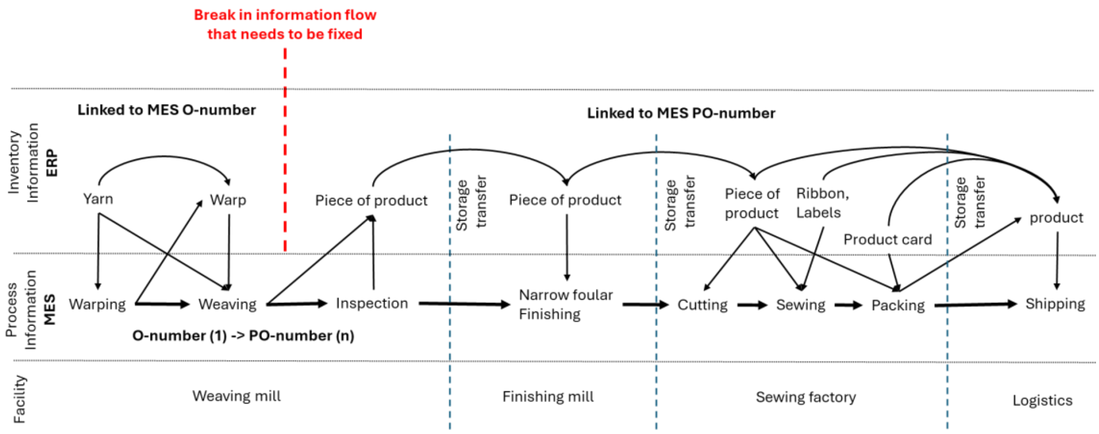


Figure 9. Information flow of the production process of a tea towel

To enhance the automatic traceability of material data in the production process searchability of the fields where PXXXXXXX and OXXXXXXX-X numbers are pushed would need to be ensured and the related OXXXXXXX-X number should be pushed to ERP together with the PXXXXXXX number.

As most of the digital passport data required from the manufacturer in question is not product patch specific but rather product specific, implementation of digital product passport is considered on in the first phase on product level and then a second phase implementation is suggested for path specific implementation. On key reasoning for this is considering the resources available in an SME company.

4.3.3 PIM database for DPP data publishing and maintenance

Based on the suggestions raised in the literature review requirement for some product data management software was identified. As the company had also other business needs raised from the market that supported choosing product information management system for this purpose, PIM software was selected. However, based on the scope that will be later defined in the requirements for textile products traceability and environmental calculations in relation to eco-design policy, need for the use of PLM software or other lifecycle calculations based should be considered.

PIM software will support central publishing of all DPP related information in software, however action listed in table 4 mostly need to be performed outside PIM software and only the results should be updated in PIM. From the 14 action points listed only 3 can be performed directly by just updating the information to PIM.

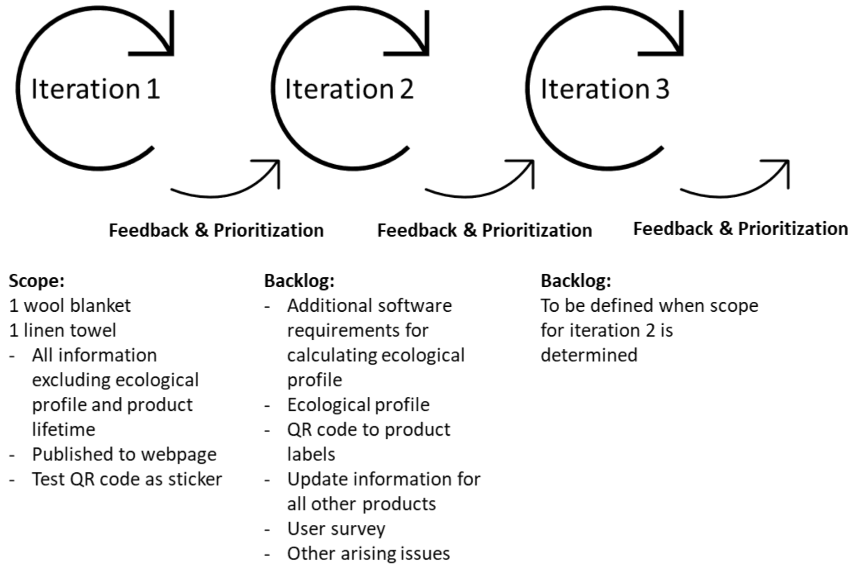


Figure 10. Iterative cycles for DPP implementation

However, in an industry with relatively short cycles for creation of new designs, PIM supports easy updating of the information in one central location that is then used to automatically publish the information elsewhere. It also supports updating information for several products simultaneously, as products can be filtered and updated based on multitude of product characteristics at once. This supports the adaptive and iterative adaptation of DPP as shown in figure 10. This is also a clear benefit in comparison to ERP system which does not offer as wide functionalities for searching and updating information. PIM software supports also creating translations of the information to different sales locations so that any requirements of the availability of DPP information in local language can be met (image 8).

The information fields for DPP related information in PIM software could be for example as presented in image 6. Ecological profile fields have been excluded from this for now as the scope is yet to be defined but for example the Ecological profile could be expressed as the example in image 7 shows.

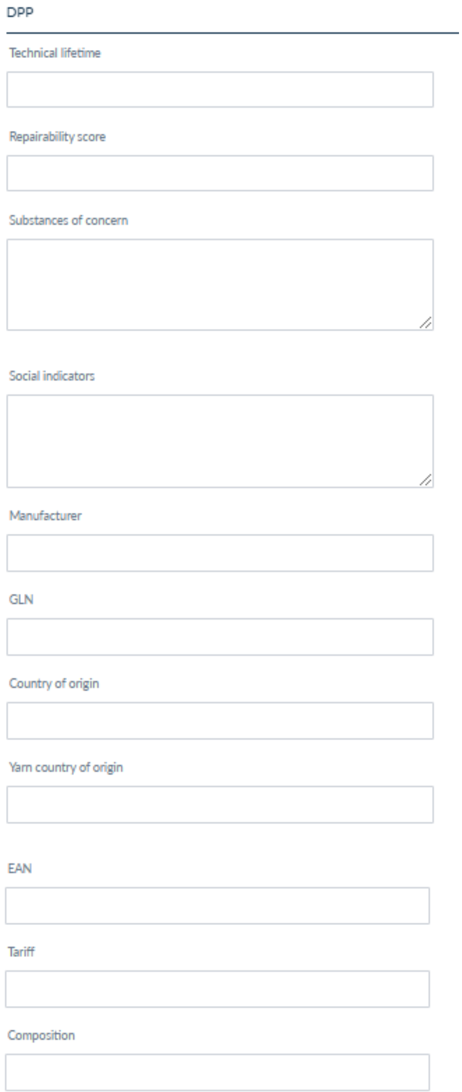


Image 6. Example digital product passport public data fields in PIM without ecological profile fields

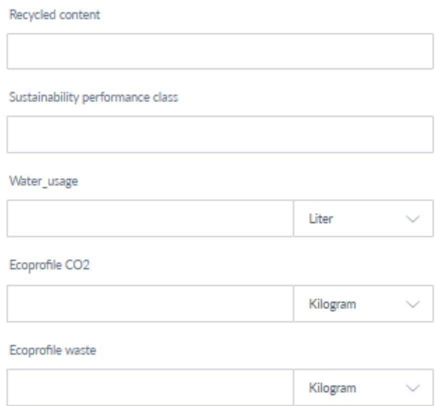


Image 7. Example ecological profile fields in PIM

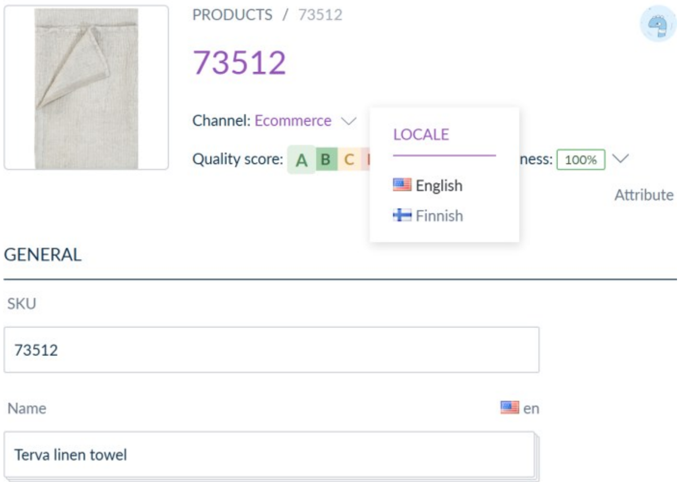


Image 8. Managing translations in PIM

4.3.4 Demonstration of the DPP on the website

As industry level solution for digital product passport is still not existing, the solution is demonstrated on the soon to be published company website where appropriate locations for publishing DPP data are created and an API connection is mapped out to be used for publishing the information. It is concluded that as the data is provided from PIM in structured format, the same approach would be sufficient for providing information to any official DPP platform or other publishing formats on the website.

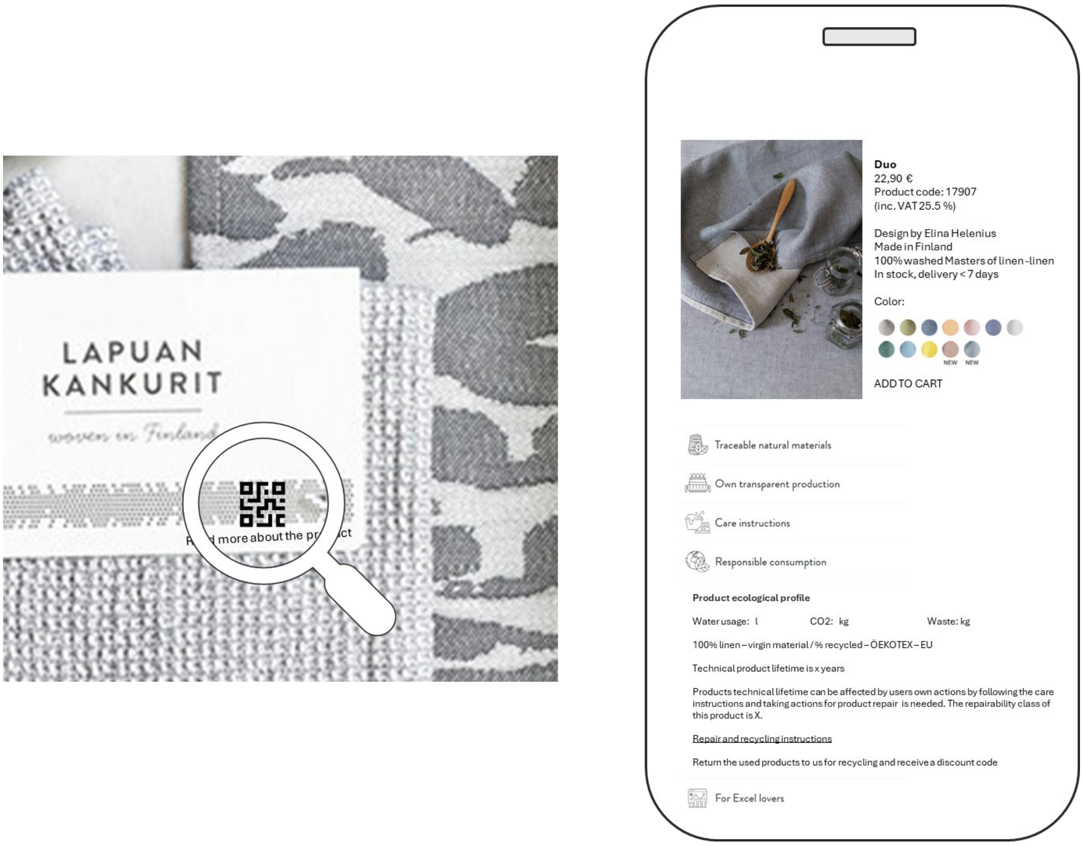


Image 9. Accessing DPP information published on the website information categories.

Table 5. Information categories for DPP information fields on the website

Information requirement	***Category***
Technical lifetime	Responsible consumption
Repairability	Responsible consumption
Substances of concern	Traceable natural material
Recycled content	Traceable natural material
Ecological profile	Responsible consumption
Sustainability performance class	Responsible consumption
Social indicators	Traceable natural materials and own transparent production
Track and trace data	For excel lovers (composition and origin of components included in traceable natural materials field)

The case company has held a workshop and decided that before the publication of DPP requirements the term DPP should not be used in the company website and that the information would be distributed into categories shown in Image 19. These categories would also contain additional longer texts regarding the product or its production. A suggestion on the distribution of the information to these categories is presented in table 5. Example of DPP is presented in Appendix 2.

4.3.5 Organizational responsibility areas

The actions regarding the process for creating DPP in the SME focus on the allocation of resources for creation and maintenance of the data. Additionally, allocating resources to the implementation phase of any software changes like the ones presented in figure 9, needs to be considered. Regarding the workload it needs to be noted that creating the required data is a significant amount of work that would take place always when publishing new products.

The responsibilities would be shared as shown in figure 11. Production would be responsible for running tests on resource use for the product ecological footprint, and the final phase of production would have to add the QR code to the product at the same time as other labels. The design and material handling would be responsible for reporting all product related information required and the calculations would be done in finance. The responsibility in sales would focus on the publishing of the data and creating a user survey if needed. To see more precise task breakdown structure of the actions needed to create DPP data see table 4.

However, with limited resources available in the SME this would mean that one single person is responsible for resource use tests, one for all reporting, one for all calculations and one for publishing, with maybe some support from the team.

Considering that the employees are most likely to currently work at full to near full capacity, either a long enough time-defined schedule with workload estimates or additional resources would be needed to assign for successful implementation of the DPP.

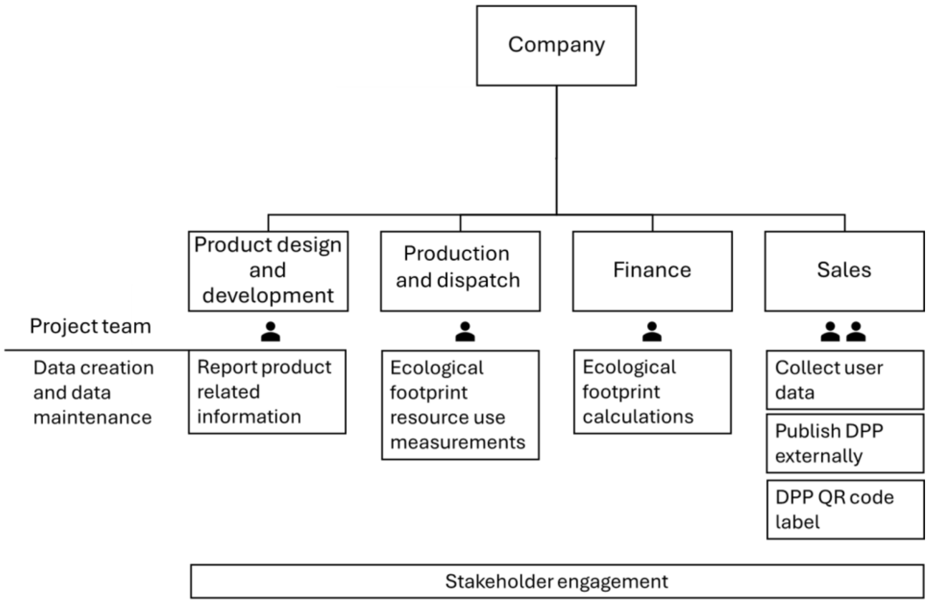


Figure 11. Responsibility breakdown structure

The importance of stakeholder engagement to reach organization level satisfaction of the project should not be neglected. The project stakeholders can be divided into two levels regarding their relationship with the project as shown in figure 12.

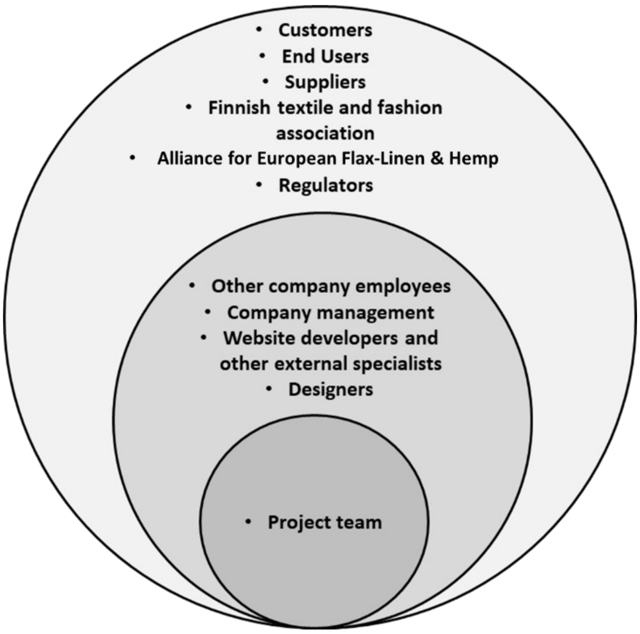


Figure 12. Stakeholders

In the first tier there are the people who have personal relationship with the project such as other company employees who's daily work might be affected by the tasks in this project, there is the company management who lead the decisions in the company where it might be valuable to consider this project and its requirements and effects. In the first tier there are also external people such as website and software developers who need to consider the requirements of this project as well as designers who are designing products that the DPP will be done for.

In the second tier there are stakeholders that are having a relationship with the product or its components rather than the actual project and project team regarding DPP. These include the customers and end users that the DPP is providing information for, the suppliers, who the information is required from, Finnish textile and fashion association and Alliance for European Flax-Linen & Hemp who are the spokespeople of these products towards the EU as well as regulators requiring the DPP information.

Table 6. Stakeholder engagement plan

Stakeholder group	**Stakeholder engagement plan**
First tier stakeholders	• Briefing on iterative and adaptive method and initial project goals • Demo session after each iterative cycle to report on progress • Openly discussing the project during daily conversations
Internals	Timing: Engagement on regular session after/before each iteration cycle
Externals	Timing: Engagement regarding the project when working with the externals
Second tier stakeholders	• Communication through emails and a document explaining the project status and business case (upstream) and newsletters and social media (downstream) • Briefing the associations and regulators of the project goals and progress

Upstream	Timing: When information is required from the up-stream parties, or when otherwise communicating with the on the topic beforehand
Downstream	Timing: After the project results are published in ac-ceptable level
Associations and regulators	Timing: When working with associations and regulators concerning this topic or something similar

For the stakeholders in the first tier there needs to be a plan of regular stakeholder engagement to be able to do effective expectation management and then report the results of the project as it goes. At the end of each iterative cycle a demo session could be held to show progress done. These stakeholders need to be briefed of the adaptive and iterative methods used in the development to be able to gain shared understanding of the project goals. The communication with the second tier stakeholders is mainly email based and tied to specific steps of the project. Details of the stakeholder engagement plan are explained in table 6.

5 Conclusions

The Background for this research was in the Eco design for Sustainable products regulation (ESPR) proposal and EU's Strategy for Sustainable and Circular textiles (EUSSCT) that introduced Digital product passport (DPP) as the solution for communicating product sustainability related attributes to all product life cycle parties in a unified form. The literature review on the topic showed that the regulative actions regarding the unified requirements and the technological solution for the passport are still under development. In 2024 when the literature review was conducted a preparatory study on textile products requirements was under work.

Even as the technological solution and final requirements for the attributes required from textile products were yet to be defined, some conclusions could be made on what the requirements for the SMEs will be. It was concluded that track and trace information is mostly preexisting information from ERP. Therefore, most of the actions required from SMEs to provide the data are related to attributes waiting for industry level requirements such as durability, repairability, maintenance of the product, as well as expressing the percentage of recycled materials used and calculating products ecological footprint. Even though all of these are still waiting for standardized requirements but there are still several actions that can be taken to ensure swift operations ones the requirements are clarified.

Regarding the technological solution it can be concluded that there are two parallel approaches to the technological solution of digital product passport. These are presented in figures 4 and 5. The approach chosen will also affect the level of the data required from the SMEs. However in the case company research it was noted that there are industry level actions in EU linen organization to cover at least some attributes such as product ecological footprint with approach similar to one presented in figure 4 and therefore it was concluded that eventually both technological solutions, the one presented in figure 4 and the one presented in figure 5 could be used parallelly for different attributes. On the company level the technological solution in any case means that a

PDM software that can push data efficiently to external systems using API or other method is required. For the end user of the DPP the data will be provided most likely using QR code from the product label.

In the case company the requirements can be grouped into three categories. Software requirements, data requirements and process requirements.

The software requirements the key element is introducing software for product data management, such as PIM software suggested in the literature review and used as an example in this research. PIM software should also be capable of managing the QR codes related to products. In this research the data is published on the website and therefore the online store is required to generate QR codes and maintain the pages after the products are sold out. However, in the final use case the QR code will lead to DPP software and the QR code should then be updated to PIM accordingly. Depending on the final requirements set for textile industry software requirements can also include fixing the gaps in the traceability data flow between ERP and MES to automatically sync all the required traceability data.

As stated earlier, the final requirements for data are yet to be defined but there are some actions that can be taken as preparatory steps. Regarding products durability for woollen blankets that are non-complex, final textile products with limited factors affecting durability, this research suggests that preexisting standardized pilling tests could be utilized to determine the product durability. For linen products the industry standard determined will be a key element for providing any information, but a lifetime estimate could be done based on user survey and design of the product.

The repairability data requirements suggest that publishing product repair and maintenance instructions and checking the availability of tools and materials needed for common repairs would be beneficial for achieving higher index scores. For the recycled content the company should either set tracking on the percentage of recycled materials used in the production of different product types per time periods or determine a percentage of recycled materials to be used in the production of certain products. For the social indicators the code of conduct regarding the due diligence process should be linked to each product for now.

Regarding the product environmental footprint, calculations per product type in the own manufacturing facility should be started. This means calculating inputs and outputs such as material use, energy use, water usage, transport, and waste generation. This information can then be utilized when the final method for calculating product environmental footprint is published and the next steps for generating product environmental footprint can be taken. For enhanced understanding of the product life cycles use and end of life faces a user survey with questions suggested in the appendix could be done to generate end of life data. Both the calculations and track and trace information also set a requirement for global location number such as GLN, so this would need to be defined.

This research considered two different products: linen towel and wool blanket. For these products the main difference comes from the extent of calculations that need to be done per product to create product environmental footprint as different number of lifecycle stages is handled within the organization. This also affects the needs for enhancements of data flow between different software used in the company. For other attributes the difference comes from the level of existing standards, like for the durability, but will mostly follow the same process.

The research results suggest an iterative and adaptive process for implementing DPP in the SME as there is still more clarity required on some attributes but as stated before some actions can already be taken. The iterative process has been suggested in figure 10 to start this process with the two example products and publish the information that can be made available at this point, then this process suggests creating QR-code stickers for these products labels to test the process. In the backlog are left then data that requires still more clarification of the requirements as well as creating the DPP for other product and printing the QR-code to the label. Organizational responsibilities of the project as well as a plan of ensuring stakeholder engagement are presented in figures 10 and 11 and table 6. It is important to note that creating the data for the whole product portfolio is considerable amount of work. There is only one person responsible for these tasks in each function of the organization, and we should expect that already before these tasks these persons are working to full or near to full capacity and therefore a long enough timespan or additional resources should be made available to ensure project success. As a result of this research, it must be noted that the economical sustainability of DPP on its full extent, can be a difficult task for SMEs, but depending on the requirements for product environmental footprint, it can be achieved.

Therefore, the managerial implications for the DPP can be concluded to be as follows:

- Define a responsible person to lead the DPP process and to track the legislative advancements regarding it.
- Share knowledge on the upcoming sustainability requirements to relevant parties inside the organization and consider these in any upcoming development projects.
- Allocate resources for the PDM software implementation.
- Prioritize the data creation actions.
- Define responsibilities for data creation, reporting, calculations and publishing and maintenance.
- Ensure the availability of resources for required actions.
- Ensure stakeholder engagement
- Take actions to share the process and challenges with stakeholders such as Alliance for European Flax-Linen

The topic of this research is really time sensitive as the requirements have still not been published but the companies are expected to offer some level of information in close future. Therefore, the SMEs with limited resources should be cautious to start preparative activities as soon as possible to ensure staying on track when the final requirements are published by EU. Considering these circumstances the research managed to suggest one way of preparing for this. However, as DPP implementation covers various topics for product sustainability calculation to SME IT-infrastructure and product data traceability separate research on each topic could be done to support deeper understanding of each of these areas.

Therefore, this research also identified several topics relevant for future research. Ones the standardized method for calculating product environmental footprint for DPP is defined research on creating this should be conducted. Additionally on industry level future research on the standardized method for expressing product durability should be defined. For better understanding of the economical sustainability of the solutions industry research on the expenses used and the additional value gained with DPP should be studied.

References

Aakko, M., & Niinimäki, K. (2022). Quality matters: reviewing the connections between perceived quality and clothing use time. In *Journal of Fashion Marketing and Management* (Vol. 26, Issue 1, pp. 107–125). Emerald Group Holdings Ltd. https://doi.org/10.1108/JFMM-09-2020-0192

Adisorn, T., Tholen, L., & Götz, T. (2021). Towards a Digital Product Passport Fit for Contributing to a Circular Economy. *Energies*, *14*(8), 2289. https://doi.org/10.3390/en14082289

Ahmed, W. A. H., & Maccarthy, B. L. (2021). Blockchain-enabled supply chain traceability in the textile and apparel supply chain: A case study of the fiber producer, lenzing. *Sustainability (Switzerland)*, *13*(19). https://doi.org/10.3390/su131910496

Alliance for European Flax-Linen & Hemp. (2023, December 8) European Flax-Linen fibre Life Cycle data are now integrated into the version 3.10 ecoinvent database. Retrieved 11-01-2024 from https://allianceflaxlinenhemp.eu/en/european-flax-linen-hemp-news/news-archive/european-flax-linen-fibre-life-cycle-data-are-now-integrated-into-the-version-3-10-ecoinvent-database

Alves, L., Sá, M., Cruz, E. F., Alves, T., Alves, M., Oliveira, J., Santos, M., & Rosado da Cruz, A. M. (2023). A Traceability Platform for Monitoring Environmental and Social Sustainability in the Textile and Clothing Value Chain: Towards a Digital Passport for Textiles and Clothing. *Sustainability*, *16*(1), 82. https://doi.org/10.3390/su16010082

Amicarelli, V., & Bux, C. (2022). Quantifying textile streams and recycling prospects in Europe by material flow analysis. *Environmental Impact Assessment Review*, *97*, 106878. https://doi.org/10.1016/j.eiar.2022.106878

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007

Ben Khedher, A., Henry, S., & Bouras, A. (2011). Integration between MES and Product Lifecycle Management. *ETFA2011*, 1–8. https://doi.org/10.1109/ETFA.2011.6058993

Berg, H., Kulinna, R., Stöcker, C., Guth-Orlowski, S., Thiermann, R., & Porepp, N. (2022). *Overcoming Information Asymmetry in the Plastics Value Chain with Digital Product Passports How decentralised identifiers and verifiable credentials can enable a circular economy for plastics*. www.wupperinst.org

Berger, K., Rusch, M., Pohlmann, A., Popowicz, M., Geiger, B. C., Gursch, H., Schöggl, J.-P., & Baumgartner, R. J. (2023). Confidentiality-preserving data exchange to enable sustainable product management via digital product passports - a conceptualization. *Procedia CIRP*, *116*, 354–359. https://doi.org/10.1016/j.procir.2023.02.060

Cheng, M. J., & Simmons, J. E. L. (1994). Traceability in Manufacturing Systems. *International Journal of Operations & Production Management*, *14*(10), 4–16. https://doi.org/10.1108/01443579410067199

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., & Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. In *Resources, Conservation and Recycling* (Vol. 151). Elsevier B.V. https://doi.org/10.1016/j.resconrec.2019.104498

De Saxce, M., Pesnel, S., & Perwuelz, A. (2012). LCA of bed sheets – some relevant parameters for lifetime assessment. *Journal of Cleaner Production*, *37*, 221–228. https://doi.org/10.1016/j.jclepro.2012.07.012

Ducuing, C., & Reich, R. H. (2023). Data governance: Digital product passports as a case study. *Competition and Regulation in Network Industries*, *24*(1), 3–23. https://doi.org/10.1177/17835917231152799

Dukovska-Popovska, I., Kjellsdotter Ivert, L., Jónsdóttir, H., Carin Dreyer, H., & Kaipia, R. (2023). The supply and demand balance of recyclable textiles in the Nordic countries. *Waste Management*, *159*, 154–162. https://doi.org/10.1016/j.wasman.2023.01.020

Ellingsen, O., & Vildåsen, S. S. (2022). Developing circular business models: LCA and strategic choice. *Procedia CIRP*, *109*, 437–442. https://doi.org/10.1016/j.procir.2022.05.275

European Commission. (2022a). *COMMITTEE AND THE COMMITTEE OF THE REGIONS EU Strategy for Sustainable and Circular Textiles*. https://eur-lex.europa.eu/resource.html?uri=cellar:9d2e47d1-b0f3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF

European Commission. (2022b). *Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC: Accompanying the document. Part 4/4*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A52022SC0082

European Environment Agency. (2024). *Data on products evaluated against the French repairability Index*. Data on products evaluated against the French repairability Index

European Union. (2024, March 15). *Textile Label*. Your Europe. https://europa.eu/youreurope/business/product-requirements/labels-markings/textile-label/index_en.htm

Gligoric, N., Krco, S., Hakola, L., Vehmas, K., De, S., Moessner, K., Jansson, K., Polenz, I., & van Kranenburg, R. (2019). SmartTags: IoT Product Passport for Circular Economy Based on Printed Sensors and Unique Item-Level Identifiers. *Sensors*, *19*(3), 586. https://doi.org/10.3390/s19030586

Hatzfeld, T., Backes, J. G., Guenther, E., & Traverso, M. (2022). Modeling circularity as Functionality Over Use-Time to reflect on circularity indicator challenges and identify new indicators for the circular economy. *Journal of Cleaner Production*, *379*. https://doi.org/10.1016/j.jclepro.2022.134797

Helo, P., Suorsa, M., Hao, Y., & Anussornnitisarn, P. (2014). Toward a cloud-based manufacturing execution system for distributed manufacturing. *Computers in Industry*, *65*(4), 646–656. https://doi.org/10.1016/j.compind.2014.01.015

Jansen, M., Meisen, T., Plociennik, C., Berg, H., Pomp, A., & Windholz, W. (2023). Stop Guessing in the Dark: Identified Requirements for Digital Product Passport Systems. *Systems*, *11*(3), 123. https://doi.org/10.3390/systems11030123

King, M. R. N., Timms, P. D., & Mountney, S. (2023). A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns. *Journal of Cleaner Production*, *384*, 135538. https://doi.org/10.1016/j.jclepro.2022.135538

Kirchherr, J., Yang, N.-H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. *Resources, Conservation and Recycling*, *194*, 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Klep, I. G., Laitala, K., Berg, L. L., Tobiasson, T. S., Måge, J., & Hvass, K. K. (2023a). *CRITICAL REVIEW OF PRODUCT ENVIRONMENTAL FOOTPRINT (PEF) WHY PEF CURRENTLY FAVORS SYNTHETIC TEXTILES (PLASTICS) AND THEREFORE ALSO FAST FASHION*.

Klep, I. G., Laitala, K., Berg, L. L., Tobiasson, T. S., Måge, J., & Hvass, K. K. (2023b). *CRITICAL REVIEW OF PRODUCT ENVIRONMENTAL FOOTPRINT (PEF) WHY PEF CURRENTLY FAVORS SYNTHETIC TEXTILES (PLASTICS) AND THEREFORE ALSO FAST FASHION*.

Kuhn, M., & Franke, J. (2021). Data continuity and traceability in complex manufacturing systems: a graph-based modeling approach. *International Journal of Computer Integrated Manufacturing*, *34*(5), 549–566. https://doi.org/10.1080/0951192X.2021.1901320

Langley, D. J., Rosca, E., Angelopoulos, M., Kamminga, O., & Hooijer, C. (2023). Orchestrating a smart circular economy: Guiding principles for digital product passports. *Journal of Business Research*, *169*, 114259. https://doi.org/10.1016/j.jbusres.2023.114259

Leng, J., Ruan, G., Jiang, P., Xu, K., Liu, Q., Zhou, X., & Liu, C. (2020). Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey. *Renewable and Sustainable Energy Reviews*, *132*, 110112. https://doi.org/10.1016/j.rser.2020.110112

Lim, K. Y. H., Zheng, P., & Chen, C.-H. (2020). A state-of-the-art survey of Digital Twin: techniques, engineering product lifecycle management and business innovation perspectives. *Journal of Intelligent Manufacturing*, *31*(6), 1313–1337. https://doi.org/10.1007/s10845-019-01512-w

Llorente-González, L. J., & Vence, X. (2019). Decoupling or 'Decaffing'? The Underlying Conceptualization of Circular Economy in the European Union Monitoring Framework. *Sustainability*, *11*(18), 4898. https://doi.org/10.3390/su11184898

Luján-Ornelas, C., Güereca, L. P., Franco-García, M.-L., & Heldeweg, M. (2020). A Life Cycle Thinking Approach to Analyse Sustainability in the Textile Industry: A Literature Review. *Sustainability*, *12*(23), 10193. https://doi.org/10.3390/su122310193

Milios, L., & Dalhammer, C. (2023). Consumer Perceptions of Product Lifetimes and Labelling: Implications for Introducing a Durability Label. *Circular Economy*, *1*(1). https://doi.org/10.55845/AHFR5526

Ministère du Partenariat avec les territoires et de la Décentralisation, Ministère de la Transition écologique, de l'Énergie, du C. et de la P. des risques, & Ministère du Logement et de la Rénovation urbaine. (2024, July 18). *Indice de réparabilité*. https://www.ecologie.gouv.fr/politiques-publiques/indice-reparabilite

Mordaschew, V., & Tackenberg, S. (2024). The Product Environmental Footprint – A Critical Review. *Procedia Computer Science*, *232*, 493–503. https://doi.org/10.1016/j.procs.2024.01.049

Mulhall, D., Ayed, A.-C., Schroeder, J., Hansen, K., & Wautelet, T. (2022). The Product Circularity Data Sheet—A Standardized Digital Fingerprint for Circular Economy Data about Products. *Energies*, *15*(9), 3397. https://doi.org/10.3390/en15093397

Muñoz-Torres, M. J., Fernández-Izquierdo, M. Á., Rivera-Lirio, J. M., Ferrero-Ferrero, I., & Escrig-Olmedo, E. (2021). Sustainable supply chain management in a global context: a consistency analysis in the textile industry between environmental management practices at company level and sectoral and global environmental challenges. *Environment, Development and Sustainability*, *23*(3), 3883–3916. https://doi.org/10.1007/s10668-020-00748-4

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. In *Nature Reviews Earth and Environment* (Vol. 1, Issue 4, pp. 189–200). Springer Nature. https://doi.org/10.1038/s43017-020-0039-9

Nokelainen, M., Tikkanen, S., Köykkä, S., Kieksi, L., Pulkkinen, A., Roschier, S., Markkula, A., Luoma, P., Jyrälä, M., & Bergman, L. (2022). *Digital Product Passport SOLITA*. https://www.stjm.fi/wp-content/uploads/2022/10/Digital-Product-Passport-A4-v010.pdf

Ospital, P., Masson, D., Beler, C., & Legardeur, J. (2023). Toward product transparency: communicating traceability information to consumers. *International Journal of Fashion Design, Technology and Education*, *16*(2), 186–197. https://doi.org/10.1080/17543266.2022.2142677

P. P. Pieroni, M., C. McAloone, T., & C. A. Pigosso, D. (2019). Configuring New Business Models for Circular Economy through Product–Service Systems. *Sustainability*, *11*(13), 3727. https://doi.org/10.3390/su11133727

Palacios-Mateo, C., van der Meer, Y., & Seide, G. (2021). Analysis of the polyester clothing value chain to identify key intervention points for sustainability. In *Environmental Sciences Europe* (Vol. 33, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s12302-020-00447-x

Panza, L., Bruno, G., & Lombardi, F. (2023). Integrating Absolute Sustainability and Social Sustainability in the Digital Product Passport to Promote Industry 5.0. *Sustainability*, *15*(16), 12552. https://doi.org/10.3390/su151612552

Paramatmuni, C., & Cogswell, D. (2023). Extending the capability of component digital threads using material passports. *Journal of Manufacturing Processes*, *87*, 245–259. https://doi.org/10.1016/j.jmapro.2023.01.032

Patti, A., Cicala, G., & Acierno, D. (2020). Eco-Sustainability of the Textile Production: Waste Recovery and Current Recycling in the Composites World. *Polymers*, *13*(1), 134. https://doi.org/10.3390/polym13010134

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Pehlken, A., R, M. F. D., Dawel, L., & Meyer, O. (2024). Digital Twins: Enhancing Circular Economy through Digital Tools. *Procedia CIRP*, *122*, 563–568. https://doi.org/10.1016/j.procir.2024.01.082

Pieroni, M. P. P., McAloone, T. C., Borgianni, Y., Maccioni, L., & Pigosso, D. C. A. (2021). An expert system for circular economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption. *Sustainable Production and Consumption*, *27*, 534–550. https://doi.org/10.1016/j.spc.2021.01.023

Psarommatis, F., & May, G. (2024). Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing. *Sustainability*, *16*(1), 396. https://doi.org/10.3390/su16010396

Rusch, M., Schöggl, J., & Baumgartner, R. J. (2023). Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*, *32*(3), 1159–1174. https://doi.org/10.1002/bse.3099

Shen, B., Li, Q., Dong, C., & Perry, P. (2017). Sustainability issues in textile and apparel supply chains. *Sustainability (Switzerland)*, *9*(9). https://doi.org/10.3390/su9091592

Stridsland, T., Biørnstad, W., Vigen, K., Østergaard, K. L., & Sanderson, H. (2023). No-one left behind: An open access approach to estimating the carbon footprint of a Danish clothing company. *Journal of Cleaner Production*, *426*, 139126. https://doi.org/10.1016/j.jclepro.2023.139126

Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., Boulogeorgos, A.-A. A., Argyriou, V., & Sarigiannidis, P. (2024). Digital product passports as enablers of digital circular economy: a framework based on technological perspective. *Telecommunication Systems*, *85*(4), 699–715. https://doi.org/10.1007/s11235-024-01104-x

Walden, J., Steinbrecher, A., & Marinkovic, M. (2021). Digital Product Passports as Enabler of the Circular Economy. *Chemie Ingenieur Technik*, *93*(11), 1717–1727. https://doi.org/10.1002/cite.202100121

Warasthe, R., Brandenburg, M., & Seuring, S. (2022). Sustainability, risk and performance in textile and apparel supply chains. *Cleaner Logistics and Supply Chain*, *5*, 100069. https://doi.org/10.1016/j.clscn.2022.100069

Appendices

Appendix 1. Product lifetime and end of life user survey

Question 1: Product family, Dropdown field, user needs to select one option

Dropdown options: Kitchen towel, hand towel, bath towel, sauna cover, loungewear and accessories

Question 2: Picture of the product, user needs to upload a picture of the product

Question 3: Year of purchase, user needs to write the year in format XXXX

Question 4: How many times a year is the product washed?

Question 5: How many days in a year is the product used?

Question 6: Drying method used, Dropdown field, user needs to select one option

Dropdown options: Tumble dyer, air drying

Question 6.1 (Only for sauna covers): has the product been air dried always after use? Yes/No

Question 7: Has the product been washed according to the washing instructions? *Washing instructions* Yes/No

Question 8: Evaluation of the products' condition as of today? Dropdown field, user needs to select one option, Dropdown options: Great, moderate, bad

Question 9: How likely are you to us the following methods after you yourself discard the product from use? On a scale from 1-5

Return to textile recycling

Dispose with household waste

Reuse or recycle inside the household

Resell as second-hand item

Possibility for everyone submitting the survey to give their email to receive some predefined compensation for filling the survey

Appendix 2. Example DPP

Traceable natural materials

Own transparent production

Care instructions

Responsible consumption

For Excel lovers

Traceable materials

100% linen – virgin material – EU (DPP composition, recycled content, origin of components)

We have used 100 % linen yarn for both the warp and weft, spun from fully traceable Masters of Linen –certified long staple flax. We love linen as a material, for it is a durable, comfortable and environmentally friendly fibre.

Our linen grows with the power of rainwater in the temperate climate of Normandy, France, needing no irrigation. The yarns have been spun and dyed in the EU area according to the REACH regulations, and they meet the requirements of the OEKO-TEX certificate.

Did you know that linen is an ecological choice also because the dirt comes off it even when washed at 40 degrees Celsius?

Supplier Code of conduct (DPP Social indicators)

Traceable natural materials

Own transparent production

Care instructions

Responsible consumption

For Excel lovers

Own transparent production

The most significant part of the production is done by the fourth generation of weavers in our own weaving mill in Lapua, Finland. We want to be responsible for the production of our products ourselves, starting from the yarn all the way to the finished product.

The product design, material purchases, loom programming and warping as well as the pre-work stages, weaving and fabric inspection are done in our own weaving mill in Lapua, Finland. The sewing is done in our subsidiary's own sewing department in Kaunas, Lithuania, or in our own sewing department in Lapua. The product finishing is done in our finishing plant in Lapua.

Thanks to owning our production, we are able to design our products and processes so that our ecological footprint stays as small as possible.

Lapuan Kankurit Code of conduct (DPP Social indicators)

- Traceable natural materials
- Own transparent production
- Care instructions
- Responsible consumption
- For Excel lovers

Own transparent production

The most significant part of the production is done by the fourth generation of weavers in our own weaving mill in Lapua, Finland. We want to be responsible for the production of our products ourselves, starting from the yarn all the way to the finished product.

The product design, material purchases, loom programming and warping as well as the pre-work stages, weaving and fabric inspection are done in our own weaving mill in Lapua, Finland. The sewing is done in our subsidiary's own sewing department in Kaunas, Lithuania, or in our own sewing department in Lapua. The product finishing is done in our finishing plant in Lapua.

Thanks to owning our production, we are able to design our products and processes so that our ecological footprint stays as small as possible.

Code of conduct (DPP Social indicators)

- Traceable natural materials
- Own transparent production
- Care instructions
- Responsible consumption
- For Excel lovers

Responsible consumption

Ecological profile of the product (DPP Ecological profile)

Sustainability performance class of this product is X.

The intake for product manufacturing process considers following factors from farm to ready-made product:
Water usage: x l CO2: x Kg Waste: x Kg

100% linen – virgin material /x% recycled – EU- The product does not contain any substances of concern

(DPP composition, recycled content, origin of components, substances of concern)

Technical product lifetime is x years when used xx (define standardized use) (DPP technical lifetime)

Products technical lifetime can be affected by users own actions by following the care instructions and taking actions for product r epair is needed. The repailability class of this product is X. (DPP Repair needs and instructions)

Few sentences of what can be fixed and what not . Link to repair manual .

Sorting package and waste, Product material recycling instructions (DPP waste)

Some text on how you can return the products to store to receive discount

- Traceable natural materials
- Own transparent production
- Care instructions
- Responsible consumption
- For Excel lovers

For excel lovers

Product code	64443
Colour	white-green
Size	95 x 150 cm
Material	100% washed linen, Masters of Linen (DPP Composition)
Designer	[redacted]
Serie	HOHTO
Manufacturer	[redacted] (DPP manuafacturer)
GLN code/Location	(DPP Global location)
Certificate	Key Flag
Authorized Representative	The system needs to detect the global location of the user to be able to show the representative in that country (DPP Name of authorized representative)
EAN code	6417695644435 (DPP GTIN)
Tariff code	63029910 (DPP Taric code)
Weight	0.4 kg
L x W x H (package)	6 x 25 x 19 cm