Promoting supply chain transparency and circularity with the EU Digital Product Passport

Master's thesis

Sustainability has emerged as a significant strategic factor for companies due to the continuously growing expectations and demands from supply chain stakeholders. Especially, the circular economy has gained traction among policymakers and industry stakeholders, driving it to the forefront of political and strategic agendas. Enhancing transparency across the entire supply chain is crucial for organizations aiming to improve the efficiency of production processes, the circularity of end-of-life materials and products and promote responsible consumption. However, this transition is currently hindered by inadequate visibility, transparency, and standardized data-sharing practices within supply chains. The European Commission's proposal for the Ecodesign for Sustainable Products Regulation (ESPR) introduces Digital Product Passports (DPPs) to offer concrete solutions to mitigate the barriers to adopting sustainable business practices. The DPPs are designed to facilitate the gathering and disclosing of information in supply chains aiming to further sustainable procurement, production, and recycling processes as well as more responsible purchasing decisions from consumers.

Despite the evident potential of the DPPs to improve supply chain transparency, challenges remain in collecting and sharing vast amounts of information about processes and product details in practice. This study investigates the key factors in successfully implementing a DPP as well as their role in improving supply chain transparency and promoting the adoption of circular business models. This study is conducted as qualitative research, where empirical data is collected from five expert interviews. The study also examines the benefits of proactivity towards the planning and implementation process of the DPPs and provides answers to the following research questions: (1) What are the critical success factors for implementing the Digital Product Passport to improve supply chain transparency and circularity? (2) How can companies benefit from preparing early for the implementation of DPPs?

The findings suggest that ensuring the necessary technology, enhancing collaboration, adopting unified DPP standards, and building motivation towards the adoption are the most critical success factors for implementing a DPP from a practical perspective. The inability to achieve these goals can act as a barrier to the successful implementation of the digital product passport, also making it impossible to fully realize the objectives of the concept. The implementation of the DPPs does not automatically lead to improved transparency; rather, the results showed that the credibility of the DPP's content, as well as the motivation to use it and achieve its goals, stemming from both businesses and consumers, are of key importance. The results clearly indicate that a proactive approach to the planning and implementation of DPPs provides companies with numerous benefits, including the minimization of financial and reputational risks, the creation of a competitive advantage, and the establishment of a stable technological foundation for the digital passport, which significantly facilitates its eventual implementation. Digital product passports are still scarcely studied and are an emerging concept, which inherently carries uncertainty and limits the broad generalizability of the findings, especially before further practical research and revision of the upcoming standards.

Vastuullisuudesta on tullut yrityksille merkittävä strateginen tekijä toimitusketjun sidosryhmien jatkuvasti kasvavien odotusten ja vaatimusten myötä. Erityisesti kiertotalous on saanut jalansijaa poliittisten päättäjien ja toimialojen eri sidosryhmien keskuudessa, mikä on lisännyt aiheen näkyvyyttä myös osana strategisia ja poliittisia agendoja. Läpinäkyvyyden parantaminen koko toimitusketjun laajuudella on keskeistä organisaatioille, jotka pyrkivät parantamaan tuotantoprosessiensa tehokkuutta, materiaalien ja tuotteiden kierrätystä niiden elinkaaren loppuvaiheessa sekä edistämään vastuullista kulutusta. Merkittävänä esteenä toimintamallien muuttamiselle on kuitenkin riittämätön näkyvyys ja läpinäkyvyys toimitusketjuissa sekä standardoitujen tiedonjakokäytäntöjen puute. Euroopan komission kestävien tuotteiden ekosuunnitteluasetus (ESPR) esittelee digitaalisen tuotepassin (DPP) konkreettisena ratkaisuna kestävämpien liiketoimintamallien implementoinnin tukemiseksi. Digitaalinen tuotepassi on suunniteltu helpottamaan tiedon keräämistä ja jakamista toimitusketjuissa ja sen tavoitteena on edistää kestäviä hankinta-, tuotanto- ja kierrätysprosesseja sekä vastuullisempia kulutuspäätöksiä.

Vaikka digitaalisten tuotepassien potentiaali toimitusketjun läpinäkyvyyden parantamisessa on merkittävä, käytännön haasteeksi nousee suuren datamäärän kerääminen, hallinnointi ja jakaminen tehokkaasti lukuisista eri lähteistä, kuten tuotantoprosesseista ja tuotetiedoista. Tämä tutkimus pyrkii selvittämään, mitkä ovat kriittiset menestystekijät digitaalisten tuotepassin onnistuneeseen implementointiin sekä mikä on digipassin rooli toimitusketjun läpinäkyvyyden parantamisessa ja kiertotalousmallien omaksumisessa. Tutkimus tarkastelee myös, miten yritykset voivat hyötyä digitaalisen tuotepassin aikaisesta suunnittelusta ja implementoinnista sekä vastaa seuraaviin tutkimuskysymyksiin: (1) Mitkä ovat kriittiset menestystekijät digitaalisen tuotepassin onnistuneeseen implementointiin, jotta toimitusketjun läpinäkyvyys ja kiertotalousmallit paranevat? (2) Miten yritykset voivat hyötyä valmistautumalla aikaisin ja ennakoivasti digitaalisen tuotepassin käyttöönottoon? Tutkimus on toteutettu laadullisena tutkimuksena, jossa empiirinen aineisto on kerätty viidestä asiantuntijahaastattelusta.

Tulokset osoittavat, että tarvittavan teknologian varmistaminen, yhteistyön lisääminen, yhtenäisten DPP-standardien omaksuminen ja motivaation rakentaminen ovat tärkeimmät tekijät digitaalisen tuotepassin toteuttamisessa käytännön implementoinnin näkökulmasta. Näiden kriittisten tekijöiden jääminen saavuttamatta voi estää digitaalisen tuotepassin onnistuneen implementoinnin ja estää myös konseptin perimmäisten tavoitteiden saavuttamisen. Digitaalisen tuotepassin käyttöönotto ei automaattisesti paranna läpinäkyvyyttä; sen sijaan tutkimustulokset osoittivat, että digitaalisen tuotepassin sisällön luotettavuus sekä yritysten ja kuluttajien motivaatio tuotepassin käyttämistä ja asetettujentavoitteiden saavuttamista kohtaan ovat avainasemassa. Tuloksista kävi myös selkeästi ilmi, että ennakoiva lähestymistapa digitaalisen tuotepassin suunnitteluun ja toteutukseen tarjoaa yrityksille lukuisia etuja, kuten taloudellisten ja maineeseen liittyvien riskien minimoinnin, kilpailuedun luomisen sekä vakaan teknologisen perustan rakentamisen digitaalista tuotepassia varten, mikä voi helpottaa merkittävästi sen lopullista käyttöönottoa. Digitaaliset tuotepassit ovat edelleen niukasti tutkittu aihe sekä nouseva teknologinen konsepti, mikä lisää tutkimukseen liittyvää epävarmuutta ja rajoittaa löydösten laajaa yleistettävyyttä, erityisesti ennen käytännön lisätutkimusta ja tulevien standardien tarkentumista.

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1.1   Background and research problem

Consumers and other supply chain stakeholders are progressively putting more pressure on companies to consider sustainability matters comprehensively in their business activities (Ashby et al. 2012). The circular economy is simultaneously capturing the attention of policymakers and industry stakeholders, which is reflected in circularity becoming a focal point of many political and strategic agendas (Walden et al. 2021). Contrary to the traditional linear economy, the circular economy provides reversed throughput flows, where materials are in cyclical use. The concept offers solutions to the ongoing climate crisis and enables new business opportunities for companies as value is not only embedded in resources once but multiple times. (Korhonen et al. 2018.) Enhancing transparency across the entire supply chain is essential for organizations to develop and adopt practices that foster the circular economy, thereby promoting responsible consumption (Adisorn et al. 2021). The inadequate transparency and standardized ways of data sharing are currently acting as barriers to the circular economy transition. At the same time, product compliance and sustainability regulations are tightening, causing more cost burden and pressure to react quickly to the changing requirements for data handling. (Walden et al. 2021.) This is explicitly indicated by the EU's proposal for the Ecodesign for Sustainable Products Regulation (ESPR), which introduces Digital Product Passports (DPPs) to accelerate the circular transition. The ESPR will obligate implementing a digital product passport for nearly all physical products put up for sale in the EU market (GS1 2023). The DPPs are expected to enable efficient sharing of relevant product information to stakeholders, which is considered essential regarding the sustainability and circularity of a product.

The complex nature of supply chain transparency adds to the challenges of collecting and sharing comprehensive information about processes and product details (Montecchi et al. 2021). The digital product passport (DPP) is defined as a digital tool for recording and sharing more specific and reliable information about the environmental impact of a product throughout its lifecycle, such as data on raw materials, safety, and recyclability (Jansen et al. 2023). The DPP not only aims to promote the green transition but also offers concrete solutions to challenges connected to a lack of information (Adisorn et al. 2021). The digital product passport is expected to be a crucial means to achieve the principles of

the circular economy through improved transparency in supply chains (Plociennik et al. 2022). The DPP aims to offer a solution to the sparse information currently available to consumers about the sustainability and lifecycle of products. The DPP is also expected to create new opportunities for information sharing in complex value chains that facilitate responsible purchasing decisions and create new business opportunities. The digital product passport does not come without challenges but its potential to provide accurate and more easily accessible information to various stakeholders is considerable. (Adisorn et al. 2021.)

Supply chain transparency has gained extensive interest in various research domains but the focus on how transparency contributes to the adoption of circular business models and how can organizations manage transparent supply chain information effectively and safely is still scarce (Montecchi et al. 2021). While the circular economy has also been widely discussed in academic studies, a gap remains between the practical implementation and the general concept of circularity. (Walden et al. 2021.) Recently researchers have focused on the utilization of different emerging technologies, such as the blockchain and RFID in collecting and sharing data to increase supply chain transparency (Bai & Sarkis 2020; Sunny et al. 2020). Digital product passports have also become a burning topic in the research field during the past few years, however, the challenges, opportunities, and implementation requirements call for further investigation for organizations to be better prepared in the future. The literature also lacks a clear and comprehensive overview of how companies can and should be prepared for the implementation of the DPPs and what kind of benefits being an early adopter has on companies. In most cases, implementing a DPP will require vast changes in supply chains as many global companies do not have efficient information on suppliers and their technological abilities beyond the first tier. (Chen et al. 2019.) This accentuates proactivity as a key competitive factor in the concept of digital product passports.

1.2 Research objectives and questions

This study examines the key factors in improving supply chain transparency and circularity with the upcoming EU Digital Product Passport. The focus of the study is on finding critical factors for a successful implementation of a DPP leading to increased transparency and eventually circular business model adoption in supply chains. There are many stumbling blocks for companies when it comes to planning and implementing a

DPP, especially due to the novelty of the concept and scarce academic research on the practicalities of DPPs. Therefore, the study also aims to research the expected benefits for companies if the planning and preparation process of a DPP is started proactively and well in advance. To meet the research objectives, the study will answer the following research questions:

- *RQ1: What are the critical success factors for implementing the Digital Product Passport to improve supply chain transparency and circularity?*

- *RQ2: How can companies benefit from preparing early for the implementation of DPPs?*

The thesis begins with two sections of the literature review, the first examines supply chain transparency and the second focuses on the concept of Digital Product Passports. Chapter 4 presents the theoretical framework for improving supply chain transparency and circularity with the DPP. Next in Chapter 5, the methodology behind the empirical part of the thesis is covered. The final two chapters of the study focus on analyzing the empirical findings, followed by discussion and concluding remarks.

2 Supply chain transparency

2.1 Definition and concept

Numerous organizations face the task of enhancing supply chain transparency not only to adhere to regulatory compliance but also to streamline operations, ensure output quality, and promote the sustainability of production processes (Montecchi et al. 2021). Transparency is seen as an essential requirement in contemporary organizations, and maybe even more importantly in their information systems, as it enables information to be more reliable and shared more effectively with multiple stakeholders (Hosseini et al. 2018). The ethics and originality of products are an increasing concern for end customers (New 2010), which increases the need for reliable product information, revealing the origin of materials and other relevant details about products and their production processes. Customers are seeking more and more product-related information to find commodities that meet their values (Ospital et al. 2023). Bhaduri and Ha-Brookshire (2011) noticed that consumers seemed to value transparent practices only when the company's transparency efforts were familiar to them and the information was easily available. However, even these scarce details are often not available, as information related to different supply chain actors and their operations is seldom shared with external stakeholders (Plociennik et al. 2022).

Supply chain transparency is the practice of creating readily accessible information for end customers and other supply chain stakeholders such as partner companies (Lamming 2001). According to Sunny et al. (2020), transparency refers to the degree of overall visibility in a supply chain, indicating how easily, for instance information about a particular inventory, process, or supplier is accessible. From a sustainability point of view, transparency is seen as a set of criteria that are crucial to implementing sustainability practices and standards. Transparency is used as a way of creating trust among stakeholders and thus enhancing the creditability of companies' sustainability efforts and strategies (Gardner et al. 2019). The relevance of transparency to external stakeholders is emphasized as detailed information is often only available to internal users (Egels-Zandén et al. 2015).

Effective supply chain transparency allows organizations to reduce risks and costs by having more visibility over suppliers' activities (Montecchi et al. 2019). Transparent

information about a product's origins, material properties, and end-of-life processing throughout the entire lifecycle is critical for realizing a global circular economy (Plociennik et al. 2022). Thus, supply chain transparency plays a key role in promoting environmental sustainability in general and serves as a means of corporate responsibility oversight. (Montecchi et al. 2019.)

In most cases, risks and challenges lie hidden within the intricacies of the value chain (Ebinger & Omondi 2020). Achieving transparency in the whole supply network is a key challenge for businesses as transparency requires active participation from all actors across the supply chain (Bai & Sarkis 2020). The complexity of global multi-tier supply chains has created many challenges in tracking and managing suppliers as companies often have limited or no information about suppliers beyond the first tier (Chen et al. 2019). Without adequate transparency in the supply chain, companies may struggle to understand the risks or effectively progress their sustainability initiatives. Stakeholders are however paying more and more attention to supply chain impacts due to the increasing focus on transparency. (Kashmanian 2017.)

Technology plays a key role in improving SC visibility and traceability and can aid in overcoming the major challenges of information sharing. Technological tools can make handling and transferring large amounts of data easier and most importantly safer (Ahl et al. 2020) as well as locate inefficient processes in supply chains more effectively (Sodhi & Tang 2019). The efficient exchange of information among different supply chain partners and building strong relationships dismantle the barriers to achieving transparency. Also, the support, engagement, and leadership from top management are identified as crucial means to achieve these strong supply chain relations through trust. (Brun et al. 2020.)

Transparency can be seen as voluntary or requirement-based for companies (Hosseini et al. 2018) depending on the willingness to do more beyond meeting regulatory compliance. Businesses are naturally required to follow laws and compliance regulations that order a certain transparency level on different processes or data flows. However, some organizations choose to voluntarily disclose, for example, supplier information to increase supply chain sustainability or gain competitive advantage (Chen et al. 2019). There is a risk that if a company does not voluntarily publish transparent information,

third parties may seek this information externally and release it, potentially causing harm, such as reputational damages, to the company (Sodhi & Tang 2019).

2.2 Components of transparency

Egels-Zandén et al. (2015) have created a framework that recognizes three dimensions of supply chain transparency from the point of view of corporate disclosure. First, companies must know the names of their suppliers involved in their goods' production processes. The transparency of supplier names allows the complete tracking of products from their materials to finished products for end customers. Organizations can also show commitment to supply chain transparency and sustainability and mitigate brand damage by disclosing the names and addresses of their suppliers to external stakeholders (Chen et al. 2019). Nevertheless, some companies only share their methods for verifying provenance but refrain from revealing any supplier names (Sodhi & Tang 2019). The second dimension of supply chain transparency is the disclosure of sustainability information such as the sustainability conditions at each supplier. Many sustainability-oriented companies are open about sustainability conditions in general but do not release their connections to the names of their suppliers. In such cases, a supply chain is not considered transparent in terms of the traceability of products and operations. The lack of complete information about the interconnections between the suppliers' names and sustainability conditions can lead to misleading transparency information. (Egels-Zandén et al. 2015.) However, companies are likely reluctant to share such detailed internal information as there is a risk of being exposed to public criticism and having reputational damages to suppliers and the company itself (Bartley 2007). Lastly, companies should publish their suppliers' purchasing practices to achieve true supply chain transparency. Disclosing purchasing practices, for example, the breakdown of production costs per product, indicates the level of sustainability conditions based on pricing. (Egels-Zandén et al. 2015.)

A key factor is that a company can achieve a high level of sustainability by disclosing each of the three transparency elements and choosing between a so-called *cooperation* or a *compliance* approach towards transparency. The compliance approach obliges supply chain partners to comply with a standard transparency policy developed by the company. (Egels-Zandén et al. 2015.) If a supplier is unable to meet the standards, there is a risk of terminating business relations (Gardner et al. 2019). The cooperation approach gives

more latitude for suppliers to adapt to transparency requirements as managers are trying to comprehend the current transparency processes of suppliers and how they can be improved. This approach can have the power to reduce supply chain conflicts and improve collaboration. However, as strong collaboration may lead to customized transparency policies for different suppliers, there is a risk that the transparency information disclosed by a company is viewed as an attempt to engage in greenwashing. (Egels-Zandén et al. 2015.)

Gardner et al. (2019) used the supply chain transparency framework by Egels-Zandén et al. (2015) as a base for creating a more holistic and information-centric definition of transparency in the supply chain context. Improving supply chain sustainability requires assessment and intervention, which consists of the following elements of information:

1. *Traceability*: provides transparency by reporting on the various actors in supply chains, their connections, locations, and roles.

2. *Transactions*: includes information on purchasing practices and investment decisions of supply chain stakeholders also outside the primary supply chain. Clarifying the main beneficiaries of each supply chain helps to identifying the responsible actor in case of sustainability concerns.

3. *Impact*: reporting social and environmental impacts as well as production-, transportation-, and other process-related risks in supply chains. Impact information is considered crucial in improving the transparency of supply chain nodes, enabling performance assessments between different parties.

4. *Policies and commitment*: consist of sustainability commitments and other policies of different supply chain actors. The goal is to attain increased sustainability in different stakeholders' operations and processes due to the enhanced transparency level and strength of the practices adopted.

5. *Activity*: policies and commitments set frames for the activities supply chain actors must take to achieve transparency and change their course of action. The new activities adopted can be connected to production processes, sales, procurement, or investment decisions.

6. *Effectiveness*: effectiveness information highlights the intervention perspective of providing transparency in supply chains. The element assesses how well a particular intervention addresses and mitigates negative environmental and social impacts within a supply chain or in a particular process or location of a supply chain actor. It then qualifies the progress made by an actor in achieving set targets.

Breaking down the concept of transparency aids in clarifying uncertainties and avoiding confusion regarding the collection and use of information for supporting change processes. Defining the term transparency is also key in helping to unveil biases and discrepancies in the types and amount of information accessible to supply chain actors (Gardner et al. 2019). There are many terms connected to the topic of transparency that touch one another on many elements but have their unique characteristics. For example, traceability and transparency are closely linked to one another but are often wrongly used as synonyms in the supply chain management context despite their different definitions (Ospital et al. 2023). Pagell and Wu (2009) differentiate the two terms by describing their features relative to information sharing. Traceability is the process of sharing supply chain information internally to improve performance and reduce risks on a noneconomic basis. Transparency refers to information sharing with external stakeholders aiming to optimize financial performance along the supply chain. Hence, disclosing traceability information to external stakeholders is seen as transparency. Increased traceability improves transparency, which can provide deeper insights into the product's environmental impact (Götz et al. 2022; Psarommatis & May 2024).

Roy (2021) presents four views of supply chain traceability: technology-dominant, supply-chain dominant, traceability and product recalls, and traceability used for improving supply chain performance. The technology-centric view focuses on exploring how technology can be utilized within supply chain logistics to attain traceability. The view considers the weaknesses and strengths of different technological solutions and focuses on how traceability can facilitate the virtual management of complex supply chain processes. The supply chain-dominant view highlights the logistical needs and focal points of a supply chain, emphasizing how traceability can be aligned with the practical intricacies of the value chain. The goal is to streamline supply chain operations through technology to mitigate errors and achieve operational efficiency. Traceability has a key role in managing product recalls effectively as it enables the quick verifying of a product's provenance. Lastly, traceability for improving supply chain performance highlights the

role of traceability in achieving maximized economic performance through cost reductions, improved quality, etc.

In contrast, visibility is a term for collecting information about upstream and downstream operations inside a company or a supply network. To achieve transparency, companies need to have visibility over their supply chain. (Sodhi & Tang 2019.) Barrat and Barrat (2011) describe visibility as the extent of relevant and timely operations-related information provided to supply chain actors. The definition resembles Sunny et al.'s (2020) definition of supply chain transparency a great deal, which indicates the overlap of terms related to the subject. Traceability is described as a provenance of information making it an essential part of visibility (Sodhi & Tang 2019). Roy (2021) distinguishes traceability and visibility by stating that visibility is the unification of technology-based transparency and provenance facilitated through traceability. Enhanced traceability within a supply chain is essential for achieving superior visibility, which in turn acts as a prerequisite for the competitive advantage gained by complex modern supply chains.

2.3 Opportunities and risks of increased transparency

Historically, companies have kept supply chain information rather confidential to maintain their competitive edge in various operational areas such as product innovation, manufacturing, and delivery efficiency. The increased information available on the internet, together with the legal obligation of detailed reporting on supply chain activities has however made safeguarding supply chain information harder than before. (Sodhi & Tang 2019.) Regulation and the pressure of stakeholders drive companies to release more product-related information to provide transparency and to create trust with customers while reducing reputational risks (Mollenkopf et al. 2022; Sodhi & Tang 2019). Increased transparency can therefore create opportunities but also pose risks to companies, depending on how well they can meet compliance, gain trust, and prevent possible publicity issues.

Building trust and credibility in supply chains can positively affect product demand and create financial advantages (Egels-Zandén & Hansson 2016; Sodhi & Tang 2019). For example, a brand owner can gain marketing and operational benefits by disclosing the origins of all product components (New 2010). Disclosing information on transparency also eases the linking of a specific supplier to a company, which is increasingly in the public's interest. In case of negative allegations toward a supplier, transparency

naturally adds to the reputational risks. However, while transparency increases public scrutiny and adds pressure on the brand's supply chain, it also enables the brand to harness public attention to tackle suppliers' sustainability issues. This, in turn, helps the buyer to enhance supply chain sustainability and mitigate potential damage to the brand. (Chen et al. 2019.)

Egels-Zandén and Hansson (2016) state that supply chain transparency is both a consumer and a corporate tool driving companies towards different objectives. Consumers put pressure on companies to increase transparency by disclosing information that enhances the sustainability conditions at different suppliers. From the corporate point of view, purchasing intentions can strengthen due to increased transparency and trust gained by consumers. If done successfully, transparency can simplify complex supply chains by facilitating the management and development of supply chain activities, while also helping actors to pinpoint risk areas and see where progress has been made. On top of this, improved transparency balances the highly asymmetrical access of information between supply chain shareholders such as suppliers and consumers, and reduces their vulnerability caused by ignorance. (Gardner et al. 2019.)

Mol (2015) highlights six aspects of challenges related to supply chain transparency. First, transparency is generally expected to empower stakeholders in a vulnerable or weak state due to information asymmetries and lack of know-how in transparency and sustainability-related matters. Transparency can however do the opposite by empowering the already influential and dominant supply chain actors that have more capabilities such as money or bargaining power to fulfill requirements, thus creating even more inequality in value chains. Powerful supply chain actors can likely utilize transparency information better to serve their own needs and gain an advantage in the market (Gupta 2010) while simultaneously setting the level and nature of transparency requirements for other actors. Actors, especially in developing countries, often have a weaker position compared to large corporations in the field of environmental politics and may fail to meet compliance, leading to sanctions and restrictions on their operations. At worst, this setup may drive inequalities between supply chain actors further to the point where vulnerable suppliers are driven out of the market completely. (Gardner et al. 2019.)

Closely related to the first challenge, Mol (2015) states that transparency is meant to drive towards supply chain sustainability but can only be achieved when the following two

conditions are fulfilled. The quarters using the disclosed supply chain information should have access and the ability, i.e. literacy, to understand it. It is not enough for information to be disclosed to stakeholders but those who have poor sustainability performance must be responsive and exposed to the accusations to improve the level of sustainability. Incomplete or false information disclosed to stakeholders will not promote sustainability improvements (Egels-Zandén et al. 2015). Suppliers need to be open to improving their policies to cope with the changing nature of information sharing and competitive conditions to achieve transparency and therefore achieve better sustainability performance. Collaboration with suppliers is of key importance when enhancing efficiency and encouraging partners to be environmentally compliant (Sodhi & Tang 2019).

Third, the increased surveillance of consumers is raised as a concern related to transparency. Transparency is traditionally considered as the disclosure of information regarding environmental and social impacts from producers and other supply chain partners to external SC actors, such as consumers. There is a possibility that traceability will transfer to another dynamic, where increased surveillance will enable the disclosing of personal information on environmental practices, impacts, and resource utilization from end-users to producers. It is stated that the inverse information is not necessarily seen as problematic but raises questions on environmental politics as well as other surveillance questions. (Mol 2015.) Although the intention behind monitoring is to promote responsible practices and prevent environmentally irresponsible behavior, it raises a critical need to consider a good governance approach and where the line is drawn between governance and surveillance (Gupta et al. 2020).

Increased transparency can also create data overload, which is presented as the fourth challenge. It is increasingly difficult for stakeholders to know which information to trust and which one to identify as misinformation without strong institutions publicly distinguishing them. (Mol 2015.) Information overload can negatively affect decision-making and create unwanted delays (Gardner et al. 2019). Thus, excessive information can be counterproductive and may dissuade consumers from purchasing from the company (Sodhi & Tang 2019). The fifth point, which is closely connected to the second and fourth concerns, is the need for information to be legitimate and guarded to achieve the goals of transparency, including improving sustainable performance. Some parties will likely benefit from both misinformation and data overloads and therefore actively

promote their dissemination. (Mol 2015.) Building trust between supply chain actors has a critical role in ensuring the accuracy and security of information (Gardner et al. 2019).

A final topic concerns whether transparency has a positive effect on sustainability performance (Mol 2015). The subject has not been sufficiently studied and the question remains open whether transparency has real transformational potential and to what extent (Gupta et al. 2020). Many studies argue that supply chain transparency has a pivotal role in promoting environmental sustainability and it acts as a critical predecessor for the adoption of circular business models (Adisorn et al. 2021; Montecchi et al. 2019; Plociennik et al. 2022) Wu et al. (2019) discovered that increased transparency within firms amplified the impact of innovative knowledge assets on sustainable practices. However, the journey toward achieving impactful, transformative transparency is filled with challenges. Transparency is more likely to lead to sustainability initiatives if the focus is expanded from single products to changes on the ground level, assumptions that highly detailed information is always superior are avoided, collaboration is enhanced, and transparency is embedded in governance and publicly open to all (Garnder et al. 2019). Trust is a prerequisite for balancing greater cooperation, heightened compliance, and accountability, all of which are critical to driving change toward sustainability (Egels-Zandén et al. 2015).

In addition to the challenges stated above, companies must make highly discretionary decisions when disclosing supplier information to avoid speculations on missing information or questionable partners. With increased transparency and external disclosure, accessible and open information cannot be hidden or denied subsequently, which increases the risks of backlash in case of emerging sustainability issues. (Sodhi & Tang 2019.) Negative responses from stakeholders can also increase the risks of financial losses and diminish investor support. On top of this, the cost burden of collecting relevant information from multitier supply chains with low current visibility may also become extremely high. (Chen et al. 2019; Sodhi & Tang 2019.)

3 Digital Product Passport (DPP)

3.1 Background of the DPP and why is it needed

Digital solutions play a pivotal role in the transition to the circular economy (Götz et al. 2022). To enable the adoption of new materials, production processes, and technologies, businesses need increased transparency and traceability in supply chains to effectively manage large amounts of product-related data (Solita & Gaia Consulting 2022). The simultaneous transition towards digitalization and climate-neutral green solutions is referred to as the "Twin Transition", which requires seamless integration of both circularity and digitalization (Götz et al. 2022). However, as Sitra (2024) mentions, the digital and green transition are not self-evidently linked to one another, but it is necessary to ensure that the data economy is built to promote the green transition.

As stated before, the need for circularity is widely recognized, however, means to carry out circular solutions in practice have had slower progress due to the lack of transparency, standardized technologies, and unified data. Despite the vast business opportunities connected to circularity, only 9 % of the world is currently circular, which puts a great burden on the environment (Stepke-Müller et al. 2023). The digitalization and standardization of product and process information is a significant challenge as there aren't thoroughly developed and applicable solutions to such data collection and sharing (Walden et al. 2021). The Digital Product Passport (DPP) proposed by the European Commission strives for solutions connected to data integration and lack of transparency to meet the needs of circular practices. As a result of the DPP, sustainable business and circularity are expected to gain momentum as data can be better utilized and shared in supply chains throughout the entire product life cycle (Sitra 2024).

Product data is seldom shared among stakeholders, despite the increasing collection, recycling, and remanufacturing of end-of-life products (Plociennik et al. 2022). The lack of information is seen as a key barrier to closed-loop activities (e.g., recycling); however, the limited information also brings challenges to the production side, such as responsible sourcing and thus the ability to minimize the environmental footprint of products and processes. According to Götz et al. (2022), most of the information required for the adoption of a circular economy is lost in different stages along a linear supply network. Therefore, there is a clear need for more standardized information requirements that

would accelerate the transition to more sustainable products and better end-of-life handling of materials.

Providing standardized information throughout a product's life cycle is explicitly indicated by the European Commission's (EC) proposal for the Ecodesign for Sustainable Products Regulation (ESPR) published in March 2022. The regulation officially entered into force in July 2024. The proposal introduces Digital Product Passports to accelerate the green transition by enabling product-related data sharing to be more effective. The ESPR is a part of The European Green Deal that works as the base for striving towards being the first climate-neutral continent by 2050. The ESPR includes requirements for product design, labels, and reporting to simplify the process of producing more environmentally friendly products and to enhance the operations of the internal market. (Solita & Gaia Consulting 2022.) The European Commission pursues a mandatory implementation of the DPPs for all products except food supplies, feed, and pharmaceuticals. On a practical level, this means that products cannot be sold or utilized in the EU unless a DPP is implemented (Langley et al. 2023; Psarommatis & May 2024). The future timeline of the implementation of DPPs remains rather uncertain, however, the commission is hoping to carry out the implementation in the first product groups during 2026. (Stepke-Müller et al. 2023.)

The Digital Product Passport aims to gather data from the entire product life cycle from materials to manufacturing processes and logistics, as well as from the reuse, repurposing, and environmental impacts of the products (Psarommatis & May 2024). The DPP is defined as an electronic tool for recording more specific and reliable information about a product's environmental impact throughout its lifecycle. (Jansen et al. 2023). The DPP works as a mechanism for supply chain stakeholders allowing them to make more informed decisions and allocate resources better in supply chains (Psarommatis & May 2024). The DPPs have the power to extend product lifecycles, boost resource efficiency, and improve the repair and end-of-life handling of products remarkably. On a practical level, the information included in the DPP will be available to all actors by scanning for example a GTIN bar code, QR code, or other suitable data carrier (European Commission 2022g). The DPP is described as a complex system of systems (SoS), which is why studies suggest that it should be looked at as an ecosystem. The Digital Product Passport Ecosystem (DPPE) is a socio-technical system owned by stakeholders such as producers, end-users, and recyclers. Ecosystem thinking enables closer collaboration among

stakeholders in efforts toward circular economy models, leading to smoother information flow, shared operational practices, and mindset shifts. (King et al. 2023.)

Adisorn et al. (2021) state that relevant product information is already provided to stakeholders today, but the format of data-sharing varies, in other words, it is not standardized. The DPP has the power to make sustainability information of products transparent, traceable, and most of all, easily accessible to all supply chain actors. On top of that, the DPP can enable authorities to access and monitor product information more effectively and evaluate compliance levels better (Langley et al. 2023). The stakeholders connected to the DPPs can be categorized as data providers and data users. Data providers are those included in the manufacturing process of a product and are the generators of information. This group of stakeholders includes for example manufacturers, suppliers, importers, dispensers, and retailers. The data users may be public or professional actors who utilize the information, for example, to support decision-making or for preparation, collection or reusing purposes. (Wagner et al. 2023.)

3.2   General requirements for a DPP

The literature underscores the lack of a standardized framework for the DPPs, making it difficult to perceive the complex nature of a digital product passport's planning, development, and implementation process. The concept of the DPPs and their contribution to the circular economy initiatives are relatively distinct but a clear approach to how digital product passports are tangibly implemented and what they require from companies is still lacking (Adisorn et al. 2021). However, the ESPR has listed multiple general requirements for the DPPs, most notable being *durability, reliability, reusability and reparability, upgradability, and energy efficiency*. These requirements may not always lead to specific information requirements but act as general principles or goals in the digital product passport concept. According to a study by Meda et al. (2023), manufacturers perceived that logistics, waste, recyclability, and basic model-related data required lower-level effort to provide. In contrast, information pertaining to life-cycle costs, carbon footprint, emissions, composition, and acquisition costs was identified as significantly more challenging and uncomfortable to disclose.

Götz et al. (2022) mention multiple essential components that the DPP should contain on a general level. The DPPs must have a unique product identifier, i.e. a data carrier, compliance information, operating instructions, and manuals for the users, that include

safety information, details regarding the manufacturer, and information about the entity responsible for placing the product up for sale in the EU market. Furthermore, the type of data carrier will also be specified as the content may vary depending on whether the information collected to the DPP must be specific to a model, batch, or an individual item. As previously mentioned, necessary product information needs to be openly accessible to all relevant supply chain stakeholders, including consumers (Adisorn et al. 2021). Information access must be provided free of cost, and the data should be retained by the economic operator accountable for creating the information in the first place. Information contained in the digital product passport should also be available for the duration specified by the law. (Götz et al. 2022.)

To further the requirements of the DPP, also the following set of general conditions has been listed in the ESPR (2024/1781):

- A data carrier shall be used to connect the DPP to a unique product identifier

- The data carrier needs to be a physical part of a product, its packaging, or the instructions that come with it.

- The data carrier and unique identifier need to be compliant with the standard ('ISO/IEC') 15459:2015

- All details encompassed within the DPP must adhere to open standards, be in an interoperable format, be scannable, structured, and findable, and align with the fundamental requirements specified in the ESPR.

- The information contained in the DPP must be item, model, or batch-specific

- Regulations set out in the ESPR should be complied with when giving access to information included in the DPP and when identifying access rights at a product group level

According to Plociennik et al. (2022), the specifications for a DPP depend on various factors related to products, their materials, and lifecycles. First, the requirements may vary depending on the intricacy of the product and its lifecycle. Questions such as how a product's materials are mixed, how can the product be disassembled, how is the product used, and how complex its lifecycle, is should be considered. Product or fraction value also affects the information required in the DPP, meaning the monetary value of a product

or its residues. Many products can contain toxins or other hazardous substances, which is why the potential harm caused by the product is also seen as a criterion for the DPP requirements. However, it is yet to be decided whether the requirements for the DPP will vary depending on the specific product or a product group, etc.

It is suggested that unified open standards are essential to the deployment of the DPPs. (ESPR 2024/1781; Suomi et al. 2024). To avoid radical disruption, rapid shifts in the solutions and technologies currently in use should be minimized. Instead, the architectural strategy should align with established best practices, standards, and solutions that are already widely adopted and supported within organizations. (Suomi et al. 2024.) Deloitte (2022) conducted a study report commissioned by GS1 where three possible standard systems scenarios for DPPs were presented: global open decentralized standards, competing proprietary standards, and centrally managed institutional standards. Decentralized open standards are based on building the DPP on well-known and widely used global standards, such as ISO or GS1, which would accelerate the practical implementation of the DPPs and bring significant cost benefits due to high data interoperability and integration possibilities of the already vastly familiar system to stakeholders. Competing proprietary standards, on the contrary, are expected to be the most expensive standard model as it exponentially increases the DPP concept's complexity by requiring companies to adapt to multiple different data standards. Lastly, centrally managed institutional standards would mean creating EU-level standards that might pose a risk to international trade as data interoperability would be ensured only inside the European market. This scenario would also require vast initial investments and cost inputs for the implementation process and maintenance of data. The report concludes that utilizing existing global open data standards for supply chains would provide substantial value as a foundation for DPP implementation. Although the ESPR mandates that the digital passport must be based on open standards, it remains unclear what this means in practical terms. Suomi et al. (2024) state that the EU should avoid endorsing single DPP standards that restrict opportunities for value creation.

3.2.1 System architecture and data requirements

For now, it has not been regulated specifically at the EU level what data a digital product passport is required to contain. The practical implementation and information-related requirements of the DPPs have gotten limited attention also from scholars (Langley et al.

2023) likely due to the extremely complex nature of global production processes and thus data and system integration. The ESPR determines general requirements, including previously listed conditions, that the DPP is mandatory to fulfill, but specifying and standardizing the technical requirements is still in the making. The current general requirements have been said to be too scarce to use as the base of planning the technical architecture behind the passport completely (CIRPASS Consortium 2023b). However, some scholars have researched the key information-related aspects to identify and collect the necessary technical components of a digital product passport system (Jansen et al. 2023; Langley et al. 2023; Voulgaridis et al. 2024)

Solita and Gaia Consulting (2022) state that the implementation of a DPP should be carried out in phases, the first-phase architecture model being used as a version that companies can build now, utilizing their current systems and data from existing supply chains. Psarommatis and May (2024) share a similar thought and stress the importance of a phased implementation, starting, for example, with testing the development of a digital product passport for a single product line. This reduces operational disruptions and enables real-time adjustments to system issues before full-scale implementation is carried out. When the basic concept of a DPP is outlined, companies can then start evolving the system in stages by adding new functionalities from longer supply chains. King et al. (2023) also stress that the DPP should not be viewed as a new system but as an interface on top of organizations' existing systems. Utilizing systems already in place, the DPP can be used as a tool for enhancing operational efficiency and reducing system- and sustainability-related administrative load.

One description of a basic DPP model is that manufacturers, suppliers, or other raw material providers should send the information to the DPP in a unified format via a data interface such as API. The system also includes a digital passport interface, designed to enable the reading of product-related data. The most common user groups of the DPP interface are expected to be end-users such as consumers, service providers, and recyclers. (Solita & Gaia Consulting 2022.) Solita & Gaia Consulting (2022) have formed a possible high-level architecture of the DPP system, presented in Figure 1, which outlines the relationships between the main technical parts of the system and the core parties related to it.
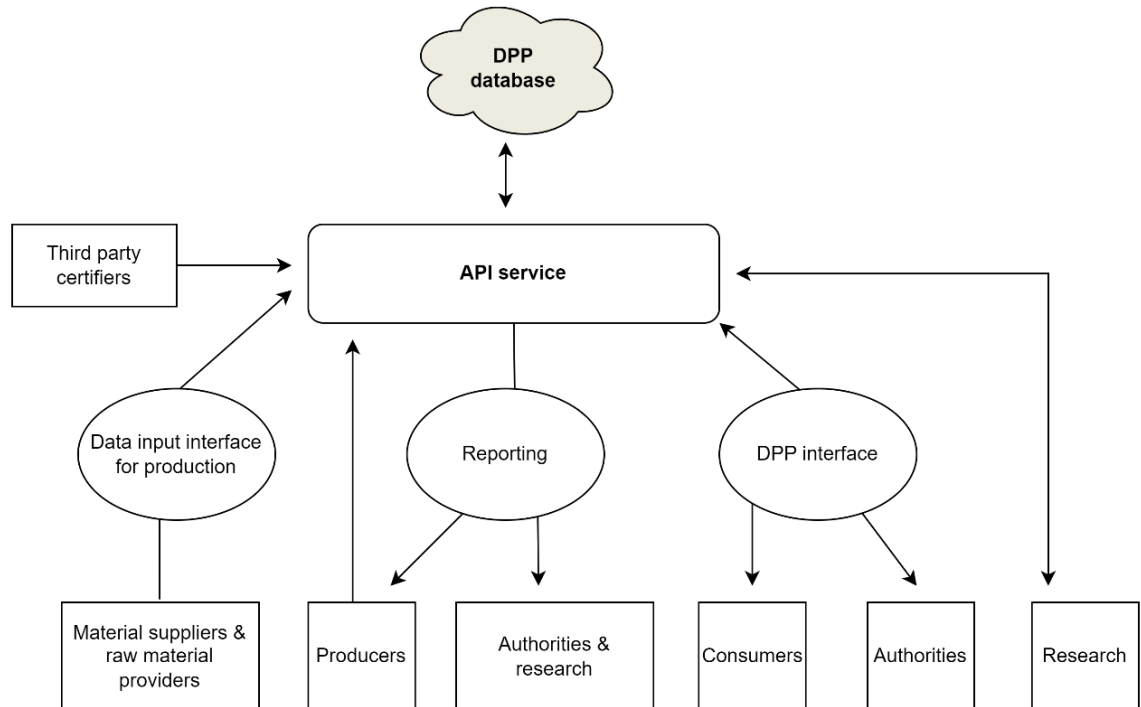
Figure 1 High-level architecture of a DPP (Solita & Gaia Consulting 2022)

As products may pass across different industries and applications throughout their lifecycle, the DPP must be interoperable with other systems to ensure seamless integration of information (Götz et al. 2022; Psarommatis & May 2024). King et al. (2023) also stress the importance of interoperable systems across different product life cycles, companies, and value chains to realize the benefits and common goals of the DPP. Jansen et al. (2023) describe *the DPP* itself as the information and data shared by the stakeholders interacting across the product's supply chain. On the contrary, *the DPP system* is the underlying IT architecture that consolidates the necessary data for the DPP. The DPP system supports the interactions among multiple data flows and stakeholders in the supply chain and acts as the link between the physical product and the DPP.

Making data requests overly complex or requiring unrealistic data or system criteria as mandatory can jeopardize achieving the DPP objectives (Meda et al. 2023). Based on findings from multiple academic journals and reports, Jansen et al. (2023) state that the DPP will likely include manufacturing, usage, end-of-life, and life-cycle data. Through this data derived from value chains, organizations can trace details and gain a deeper understanding of the product's composition, environmental impacts throughout production and utilization phases, and available recycling solutions at the end of its

lifecycle. Ultimately, the successful collection, handling, and utilization of this DPP data can lead to increased transparency, and consequently, circularity of materials and products.

Voulgaridis et al. (2024) suggest that the DPP infrastructure is divided into three data tiers: data collection, data curating and sharing, and lastly data leveraging. Integrating various technologies is seen as mandatory to meet the data requirements and create an efficient and prosperous DPP. The scholars, for instance discovered that IoT is commonly used in the collection phase, AI for curating data and blockchain is the preferred technology for leveraging and sharing intricate information.

3.2.2 Legal obligations, security, and confidentiality

Solita & Gaia Consulting (2022) divide the common legal obligations of the DPP into the following four categories:

- Chemical regulation

- Circular economy, sustainability, and waste-related regulation

- Safety and product responsibility-related laws

- Regulation related to reporting

The chemical regulation (e.g., REACH directive) aims to find alternatives for hazardous chemicals to protect the environment and individuals. Many harmful substances are used in the production of everyday products, and consumers are often not aware of what products they consume contain. The chemical regulation restricts and evaluates certain chemical substances' contents and their storage so that products are "safe by design" and substances are overseen. (Solita & Gaia Consulting 2022.)

The key legislation connected to the upcoming DPPs is the Proposal for the new Ecodesign for Sustainable Products Regulation (ESPR). As mentioned, the regulation obliges the implementation of a DPP for most products in the EU market by approximately 2030. The regulation contains an overview of the information requirements needed and gives generic views of a DPP's underlying system architecture. The ESPR also acts as the general legal framework of the digital product passport (Götz et al. 2022). The key focus when implementing a DPP should also be on processing

information safely according to data protection regulations. The General Data Protection Regulation (GDPR) is the most prominent regulation that considers data privacy and focuses on personal data and the safety of individuals. Data related to natural persons will also be present in the context of digital product passports, as the DPPs can include, for example, employee data in case of product repairs. (Jensen et al. 2023.) Therefore, GDPR will most likely offer new implications specifically for the use of DPPs to make data protection more efficient and safer.

Moreover, many directives and regulations such as the Eco-management and Audit Scheme and The Waste Directive 2008/98 oblige companies to gather information about waste, including the types of waste, as well as other waste-related data that needs to be verified and reported following the law. The product passport is also a possible tool to utilize in audit processes due to improved data management. Legislation about sustainability and circularity also includes certain standards for topics, such as product and repair information and sustainability markings. (Solita & Gaia Consulting 2022.)

Product safety falls under the General Product Safety Directive (GPSD) 2001/95/EC. According to the directive, a "safe product" does not pose any significant risks, or only presents minimal risks, that are seen as acceptable and in line with the standard of health and safety of individuals. The definition considers various factors such as product characteristics, demographics, and the potential impact of other products (Directive 2001/95 EC 2024.). Product safety is an essential part of the DPPs as legislation obliges businesses to provide relevant product-related information to customers that gives them the ability to assess the potential risks of use.

Lastly, the Corporate Sustainability Reporting Directive (CSRD) will strengthen the requirements for mandatory sustainability reporting. The directive aims to increase the reliability of environmental, social, and governmental (ESG) information disclosed by companies, and to ensure accessibility to information. The CSRD concerns all large and listed companies, apart from micro companies, that must ensure accessibility to required information. (Corporate sustainability reporting 2024.) The DPP can support the CSRD reporting and reduce overall costs as the DPP will already contain a great deal of sustainability and emission-related data at the required quality and accuracy level (Protokol 2024).

Some of the regulations connected to the digital product passport are only emerging (Jansen et al. 2023) and differences between product groups have made it more difficult to create clear regulations. Open access to product-related data will pose a considerable risk for companies when data is available to competitors or other unauthorized actors who may misuse the data for competitive purposes. Langley et al. (2023) suggest that organizations should develop a governance principle that includes clear rights and something at stake for each participant, thereby reducing the risks of commercial losses and power distribution to only one DPP owner.

3.3   Expected benefits, concerns, and barriers

Researchers have identified various benefits of adopting the digital product passport (see, for example, Adisorn et al. 2021; Panza et al. 2023; Plociennik et al. 2022; Stepke-Müller et al. 2023). Nevertheless, there is a consensus on the most prominent benefits the DPP can provide. Many scholars expect the DPPs to enhance data-sharing in supply chains, leading actors in a supply chain to gain better insight into product and process information. The standardized method of collecting data will facilitate the management of global supply networks where data storage, processing, and use are highly complex (Langley et al. 2023). The DPP will also allow the data to be in a comparable format, which eases the mandatory monitoring and reporting but also creates opportunities for automatically optimizing processes such as resource allocation (Stepke-Müller et al. 2023).

The expected opportunities of the DPP are often connected to the increased traceability and transparency in supply chains, which can lead to companies being better equipped to manage their supply chains sustainably. Various supply chain actors can make more informed choices due to the easily accessible source of product-related information. (Adisorn et al. 2021.) For instance, manufacturers have more knowledge and visibility to manage supply chains, which can improve decision-making and resource optimization. If manufacturers adopt the DPPs successfully and then produce more sustainable and desired products on the market, they are likely to gain a competitive advantage. (Psarommatis & May 2024.) Designers and engineers may utilize the information stored in a DPP throughout a product's lifecycle to create more durable, repairable, re-manufacturable, and energy-efficient products. The more information about the history

of products is stored in the DPPs the better manufacturers or other focal stakeholders can use it for warranty-related purposes or to provide better repair or maintenance services.

The digital product passport will inevitably bring parties closer together due to increased collaboration and can therefore create even closer relationships in global value chains. The DPP enables retailers to customize their product range to be sustainable and to meet customers' needs. End-users are thus able to get necessary information about the product at the point of sale, making it a crucial competitive factor considering customer service. (Adisorn et al. 2021.) Customers are provided with clearer instructions on the recyclability of products while recyclers gain more detailed information on materials, for example on their value and hazardousness. On top of this, both companies and their partners along with end-users have accessible and necessary information that supports sustainable decision-making whether it is about procurement or customers' purchasing decisions. (Panza et al. 2023.) Data collected in the DPPs may also serve as qualifying criteria for decision-making objectives, for example, in green procurement (Götz et al. 2022).

The DPPs have the potential to shift the product markets toward including products and services with a lower socio-economical footprint. Innovative manufacturers can gain a significant competitive advantage when performing better than their competitors only complying with the minimum requirements of the DPP. (Adisorn et al 2021.) Companies that perform strongly in sustainability and compliance are anticipated to have reputational advantages and achieve a better brand image (Chen et al. 2019). In the best-case scenario, the EU's shift to implementing the DPPs will also show a global direction to move toward circular production systems and increase the independence of the EU (Adisorn et al 2021).

In the long term, the shift will likely bring cost reductions to companies when resources are in more effective use, new strategies are implemented, and product life cycles are longer (Götz et al. 2022). Plociennik et al. (2022) also stress that the DPP is not intended as a short-term solution but rather as a strategy that brings benefits to organizations over the medium to long term. The proactivity of business activities is expected to ease as using essential and comprehensive data will facilitate the identification of possible issues in the supply chains. Value chains with tight cross-sectoral interactions can enable new markets to open when previously hidden characteristics of products and materials emerge

because of increased transparency. New business opportunities are likely to emerge, especially in the field of recycling or remanufacturing services. (Götz et al. 2022.)

DPPs' information can also be included in sustainability reporting, making it easier to report activities in detail according to obligatory requirements (Panza et al. 2023). Organizations need to report more and more calculations connected to the environmental footprint of products and processes, yet it is a common challenge as information can be hard to reach from different nodes of the supply chain. A key application of the DPP is also the possible automatic emission measurements from the entire value chain. The data connected to, for example emissions, circularity, or recycling, is already in a comparable format, which eases excess work and increases the reliability of information. (Götz et al. 2022).

Table 1 A summary of the expected benefits of a DPP

Subject	Benefits	Reference
System	A standardized method of collecting, storing, processing, and applying relevant and reliable data Facilitates monitoring and reporting	see, for example, Adisorn et al. (2021), Götz et al. (2022), Panza et al. (2023), Plociennik et al. (2022), Psarommatis & May (2024)
Transparency, visibility & traceability	Improved visibility in supply chains enables companies to collect and analyze product & process information better leading to innovative solutions Tracking materials and the entire value chain becomes easier	Adisorn et al. (2021), Panza et al. (2023), Psarommatis & May 2024

Supply chain stakeholders **Communication**	Easily accessible source of product-related information for consumers and supply chain actors Access to making informed choices leading to more sustainable purchasing and recycling behavior Improved collaboration and stronger relationships between stakeholders	Adisorn et al. (2021), Götz et al. (2022), Koppelaar et al. (2023), Solita & Gaia Consulting (2022), Panza et al. (2023)
Competitive advantage and implications for businesses	Possible new markets or business models for producers and manufacturers Comparison of products based on accurate and detailed data→ Identifying "better" manufacturers and products and potential issues Improved brand image and reputation if compliance performance is strong Cost reductions due to resource optimization and sustainability strategies Proactive decision-making A longer product lifecycle leads to higher value	Adisorn et al. (2021), Götz et al. (2022), Lövdahl et al. (2023), Panza et al. (2023), Plociennik et al. (2022), Psarommatis & May (2024), Solita & Gaia Consulting (2022)
Environment	Improved circularity and lower resource use Might accelerate and signal global production systems to move toward sustainability	Adisorn et al. (2021), Ospital et al. (2022), Panza et al. (2023), Plociennik et al. (2022)
Policies & legislation	The ability to drive sustainable product policy closer toward circularity May increase the independence and leverage of the EU Facilitates companies to meet regulatory compliance	Adisorn et al. (2021), Panza et al. (2023)

Moving on to the risks related to the DPP, there are numerous challenges and barriers identified in the literature as many elements of the practicalities and issues of DPPs remain open (Stepke-Müller et al. 2023). The most remarkable and recognized challenges are connected to the information contained in the DPP. To this day, there are no unified and accepted standards about what information a DPP should or may require. Even though it would be possible to contain all product-related information in a DPP, the more complex the system perspective gets, the more intricate also the implementation will be to execute in practice (Götz et al. 2022). For example, complex products often consist of multiple components that need to be separately tracked to achieve complete product information to be recorded in a DPP. This will be a major challenge for companies, especially if the information needs to be specific to an individual item instead of, for example, a general model of a product. (Götz et al. 2022.) To ease the planning and execution process of a DPP, the European Commission has appointed two non-profit organizations, The European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) to evaluate and publish how standards of the DPP will be harmonized in the future (CEN & CENELEC 2022).

The complexity of global supply chains puts a strain on the implementation of DPPs as most multinational organizations do not have adequate visibility over their supply chains, especially beyond the first tier (Chen et al. 2019; Langley et al. 2023). Even if an organization has transparency throughout the supply network, the risk remains that the information differs between the nodes in different parts of the supply chain, which weakens the reliability, accuracy, and measurability of collected data (Langley et al. 2023; Psarommatis & May 2024). Walden et al. (2021) raise concerns about the possibility of not finding harmonized approaches to DPPs between different stakeholders and industries. System alignment is considered an apparent challenge for companies as the DPP needs to be interoperable with multiple systems among different stakeholders. This requires having common data-related standards that all participants must comply with to achieve a data ecosystem, where data is in a unified and comparable format. (Jansen et al. 2023.)

Jansen et al. (2023) found out that one of the key challenges of the DPPs revolves around ensuring secure information sharing and aligning the information between all supply chain parties. Enabling transparency to improve product circularity is a key goal of the product passport but maintaining confidentiality and protecting the information at the

same time requires access control and improved security measures (Götz et al. 2022). Many information-related questions are not yet specified, and scholars have differing views on what information is seen as necessary and safe to provide to all stakeholders and should data access be limited between different level actors (Adisorn et al. 2021; Stepke-Müller et al. 2023). Above all, the confidentiality of information needs to be completely secured to avoid issues in data security and IP protection. Also keeping the information up to date across the entire product life cycle is considered a key challenge. (Walden et al. 2021).

Stepke-Müller et al. (2023) suggest three options for data-sharing access in value chains. Information could be shared with different stakeholders based on the level they make decisions, meaning no excess information would be shared, making the granularity level lower. An alternative way of accessing data would give the full information to all stakeholders, which increases the risks of data security considerably. Lastly, a minimum access approach could be implemented, meaning giving highly restricted information to value chain stakeholders. Granting only minimum access to information would weaken transparency and thus clash with the DPP's goals to achieve a circular economy. There, however, might be a need for some level of differentiation between information sharing with different stakeholder groups. For instance, end customers do not necessarily have the level of understanding to make decisions based on supply chain information tailored for businesses (Götz et al. 2022).

All parts of a supply chain may not have adequate technology to trace and manage the data according to requirements. The integration of systems is already challenging as such, and the lack of clear and harmonized standards for implementing the DPP makes the process exceedingly difficult for disadvantaged companies (Lövdahl et al. 2023). These discrete systems within the Digital Product Passport Ecosystem place additional demands and pressure on producers to invest more in aligning their businesses and products with sustainability regulations. Thus, these significant barriers and challenges need to be addressed to encourage organizations to invest in data sharing with competitors and in transforming these business practices in general. Additionally, it is critical that economic players have incentives to develop innovative business models along the entire value chain. (King et al. 2023.) Adisorn et al. (2021) stress that DPP requirements should ideally be designed in a way that manufacturers and other stakeholders view them as beneficial, rather than an added burden, fostering new business models and intrinsic motivation.
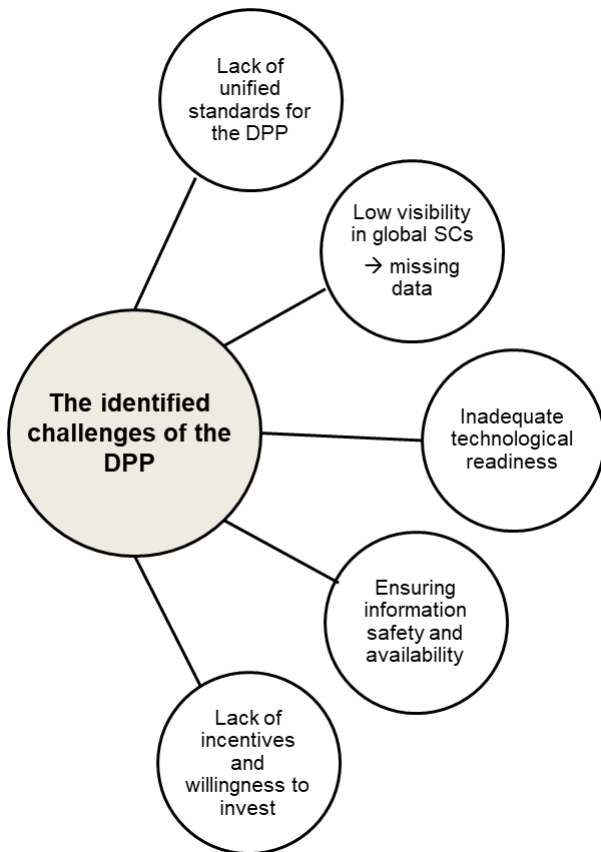
Figure 2 A summary of the most prominent challenges of the DPP

3.4 Preparing for the eventual implementation of a DPP

A key challenge for the utilization of the DPP is finding means to alter the transparent and accessible data into concrete sustainability outputs. In other words, simply disclosing data isn't sufficient for fostering circular economy practices; however, leveraging the insights derived from this transparency can guide the adoption of diverse strategies and approaches to attain these goals. (Langley et al. 2023.) Thus, companies will likely face the reality that only having large amounts of data available and disclosed to stakeholders will not automatically lead to practices that shift the economy towards circularity.

From a technical perspective, seamless integration of the data included in a DPP is a key barrier to companies if not executed properly. The data collected among multiple supply chain stakeholders in different value chain nodes must be determined and standardized. (Langley et al. 2023.) All information on the DPPs and the means of utilizing them must be standardized, since without it, the DPPs of different suppliers are not comparable (Psarommatis & May 2024). However, different stakeholders might have discrepant

needs depending on their position in the supply chain (Adisorn et al. 2021). The starting point is that the DPP should be built on top of current systems to facilitate the integration of existing and new data (King et al. 2023). To achieve true transparency, and thus sustainability, all information recorded in the DPPs should also be verified according to unified standards.

Even though the timeline of the DPP implementation requirements remains unclear, the DPPs will impact nearly all companies despite their size or technical abilities in the future. It is crucial that companies start to act now and prepare for the implementation of the upcoming digital product passports. Opaque supply chains put a great strain on companies considering the requirements of a DPP, as product data is likely not readily available from many parts of a complex supply chain (Chen et al 2019). Stepke-Müller et al. (2023) list four key actions that companies should start doing to prepare early for the DPP launch:

- Action 1: **Influence the shaping of DPP regulation** by engaging in stakeholder consultations, where organizations have the chance to directly discuss with the European Commission as well as different product and industry associations and NGOs.

- Action 2: **Assess the availability of product-related data and fill in the missing gaps** to discern what kind of mandatory data for the DPP is already available inside the company and in different parts of the supply chain and start preparing for the collection of missing data points. Early adoption will facilitate external data gathering when key issues are already located and solved, and suppliers are aware of the DPP requirements.

- Action 3: **Engage all relevant stakeholders** in the upcoming DPP. All teams connected to the requirement areas of the DPPs should be involved in the change and development processes. Clear communication of the upcoming changes and collaboration between different departments is key to the successful implementation of a DPP.

- Action 4: **Prepare for necessary changes in technology** to ensure system and data interoperability and data storage.

All these preventative actions may provide substantial growth opportunities for companies and mitigate the possible risks related to the DPP implementation. Despite the

incomplete development of a DPP, proactively preparing the organization for its implementation is expected to be advantageous (Lövdahl et al. 2023). Early adopters will most likely reap the benefits from shaping the DPP legislation with other actors to serve their needs. Engaging in shaping the upcoming regulation will reduce the risks of inappropriate standards, prioritization, and disregarded regulatory gaps (Stepke-Müller et al. 2023). Langley et al. (2023) also state that organizations should engage openly and transparently in regulation shaping with different policymakers rather than being passive observers in the development process.

Strengthening the collaboration and involving all relevant teams in the implementation process will help to align the DPP with the company's current processes and future goals. Optimizing processes with the DPP will require relevant data from suppliers that may not currently be available. It is of key importance to focus on system integration, ensuring product data is available, and filling in the gaps (Psarommatis & May 2024.) Renegotiating contracts and collaborating with both internal and external partners to ensure that the DPP data is available in a unified format needs to be done proactively and well before the implementation of the DPPs (Stepke-Müller et al. 2023). In general, the DPPs are dependent on having a well-coordinated and actively collaborative supply chain.

Planning will reduce the risk of overinvestments and excess sunk costs as current resources, technological readiness, and shortcomings can be mapped. Having a multi-stakeholder focus on the planning process will also reduce the potentially negative social or environmental risks and promote a comprehensive optimization of the digital product passport (Langley et al. 2023). Collaboration has paramount importance in avoiding resistance to change and encouraging the efficient adoption of a DPP (Psarommatis & May 2024). The DPP is expected to drastically change the supply chains of numerous companies and the risks of being excluded from the market increase if the value chain and business value creation are not properly redefined (Langley et al. 2023).

To encourage the disclosure of information, initiatives, especially to manufacturers, who are the primary source of product-related data, are of key importance to emphasize the significance of data requests (Meda et al 2023). This is particularly important in developing countries where suppliers may be more inclined to commit to a particular DPP implementation if it is compatible with other solutions they use for different customers,

thereby minimizing concerns about vendor lock-in. Organizations should follow DPP principles that don't create barriers to participating in the implementation but encourage all parties to commit actively. Also, stakeholders in the developed regions have a responsibility to support the suppliers in a weaker position when planning to adopt advanced technology in supply chains. (Langley et al. 2023.)

4 Theoretical framework for promoting supply chain transparency and circularity with a DPP

The literature review of this study examines the concept of the upcoming DPPs from the perspective of supply chains, regulation, and technology. Given the novelty of the DPPs, academic research on the topic remains limited and the theoretical framework for the study, presented in Figure 3, was formed based on how different scholars and specialists in the field expect the DPP to affect organizations in the future. The framework helps to interpret the phases and requirements for integrating digital product passport technology into complex supply chains. In this study, the successful implementation of a DPP signifies that its adoption will also lead to a genuine improvement in supply chain transparency. Transition to the circular economy is seen as the fundamental goal of the DPP implementation but enhanced transparency is the key element in reaching a higher level of circularity (Walden et al. 2021).

Factors for implementing the DPP successfully were clearly recognized in the DPP research field but how to overcome the challenges and barriers to achieving these success factors remains abstract. Hence, it is important to consider how companies can tangibly prepare for implementing the DPPs to achieve higher transparency in supply chains. The DPP will require disclosing specific data that is not necessarily available for all organizations now. Hence, complex supply chains put a strain on the DPP implementation as there is often low visibility beyond the first tier (Chen et al. 2019; Langley et al. 2023). Filling in the missing data gaps and ensuring system interoperability are considered some of the most critical success factors in successfully implementing the DPP according to many studies (Jansen et al. 2023; Stepke-Müller et al. 2023). Gathering the available data and mapping out what information is missing requires engaging multiple stakeholders in the planning process of a DPP. Suppliers need to have a clear understanding of what is expected from them, which calls for strong collaboration and stakeholder support. (Langley et al. 2023; Stepke-Müller et al. 2023.)
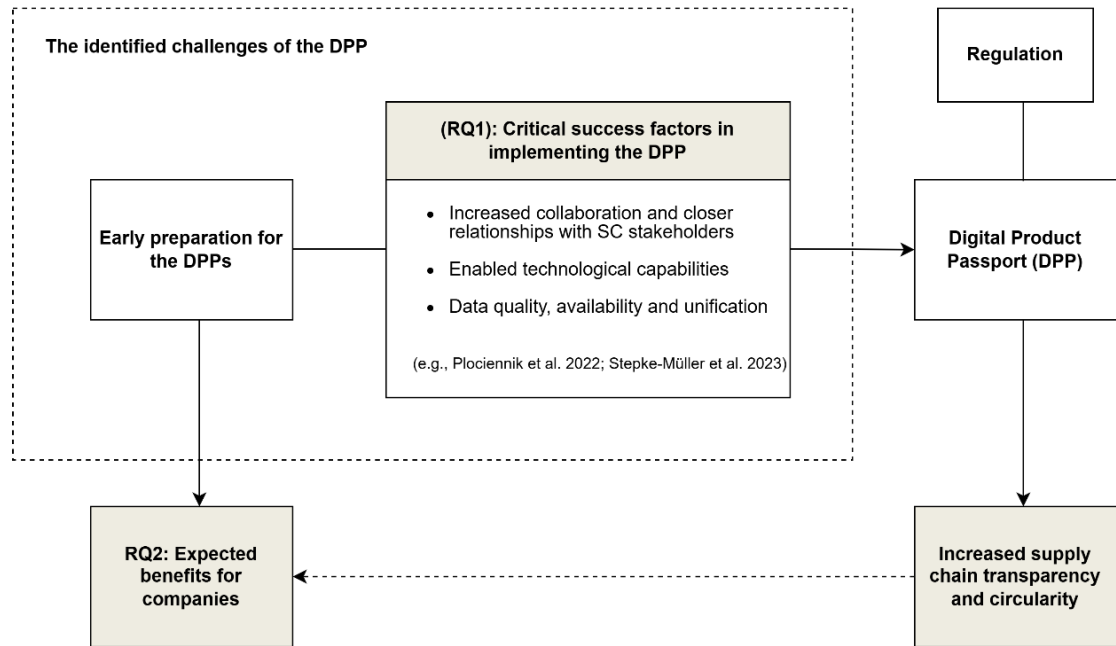
Figure 3 The theoretical framework for the study

Based on these findings from previous literature, the theoretical framework presented above highlights that the early preparation and the critical success factors in implementing the DPP consist in fact mostly of actions that are also identified as the key challenges of the DPP. For example, data unification, system integration, and information availability for all supply chain partners are seen as essential but simultaneously these factors are identified as the most challenging aspects of the DPP concept (Jansen et al. 2023; Psarommatis & May 2024). The literature suggests that overcoming these challenges will lead to a successful and effective implementation of the digital product passport that has the power to foster the circular economy. However, this perspective is not emphasized in the literature, which diminishes the awareness of the true complexity of implementing digital product passports in practice. Zhang and Seuring. (2024) emphasize that a deep understanding of how the DPPs can be effectively utilized within supply chain operations is critical for their successful implementation.

5 Methodology

5.1 Research approach

Qualitative research is considered particularly valuable when there is a limited prior understanding of the phenomenon under scrutiny (Eriksson & Kovalainen 2008). This research aims to form a comprehensive picture of the key success factors of implementing the new EU DPP to improve supply chain transparency and circularity as well as investigate the most prominent benefits of the DPPs' early planning. As the DPPs have not yet been implemented on a larger scale, the information on the subject is predominantly based on the expectations of different specialists in the field. Thus, a qualitative research approach was primarily chosen, where the objective is to understand and interpret the research topic holistically rather than to test and verify existing theories. Qualitative research focuses on specific phenomena that are often studied through the people connected to and interpreting the research topic. The extent to which a researcher interprets and understands human behavior and interaction depends on how well the researcher can immerse themselves in the social world where the studied activity takes place. (Puusa et al. 2020.) Thus, in qualitative study, it is often necessary to make subjective evaluations and judgments of the research subject (Walle 2015).

Qualitative research topics are often the ones that remain unclear in quantitative studies. Quantitative research is not the opposite of qualitative study, but it strives to explain the results, test hypotheses, and create statistical analyses, which as a research approach does not meet the objectives of this study. (Eriksson & Kovalainen 2008.) However, it is important to understand why one research approach may be more suitable for a specific research topic as the approach often defines what is achieved by the research (Puusa et al. 2020). A qualitative study is inductive, meaning that conclusions are drawn based on empirical findings. Theory is used as a tool for planning, analyzing, and interpreting findings rather than merely trying to add value to existing theory. Altogether, the goal of qualitative research is to create a new holistic understanding of the research study. (Puusa et al. 2020.)

The research approach should be determined based on the research questions and their aim regarding the findings of the study (Tuomi & Sarajärvi 2018). In qualitative research, there can be multiple simultaneous approaches, and the process of the study is rarely

linear as it is typical to make changes along the research process. (Eriksson & Kovalainen 2008; Puusa et al. 2020). The reason for the elasticity of the process is that the researcher has a preliminary understanding of the subject that is first deepened through the literature review and then the empirical findings. If necessary, the research questions and the aim of the study can then be reevaluated until the conclusions are ready to be made based on the prior research and new empirical data. (Puusa et al. 2020.)

This study employed an exploratory research approach, which is considered particularly suited for topics with limited prior research and an ambiguous context or research problem. Exploratory research requires a flexible research design and a curious mindset from the researcher. (Silver et al. 2013.) According to Yin (2018), the exploratory study involves the initial formation of theories and hypotheses, making it suitable for the relatively new and under-researched concept of the DPPs.

5.2 Research design

5.2.1 Sampling

In qualitative research, it is typical to strive for a deep understanding of the phenomenon being studied, hence, a detailed and rich nature of data is considered particularly important. Even though qualitative research does not adhere to a rightly defined plan, it is primarily based on the subjective experiences and sights of individuals connected to the study, which makes the purposive sampling of research subjects essential. (Puusa et al. 2020.) An unsuitable sample can weaken the study's credibility, which increases the importance of the sampling method chosen. In sampling, there is always the possibility of errors that need to be acknowledged and addressed especially relative to the usefulness and reliability of the study. (Walle 2015.)

An advantage of purposive sampling is that it allows the selection of individuals for interviews who have extensive experience and relevant expertise in the phenomenon under study (Tuomi & Sarajärvi 2018). The number of samples is always dependent on the goals and purpose of the research and thus a large amount of data is not seen as the only way to create successful qualitative research (Puusa et al. 2020). Qualitative study often focuses on a relatively small number of cases that are analyzed as thoroughly as possible (Jussila et al. 1998).

As the DPPs are a highly new research topic, the quality of information is considered more relevant compared to the amount of empirical data. In this study, the empirical data is collected from five business experts who have extensive practical experience with digital product passports and their implementation. The interviewees were selected using a maximum variation sampling method, which aims to achieve the most comprehensive understanding of the research topic by examining cases that differ across multiple dimensions (Suri 2011). To achieve a larger variation between experiences and perspectives, the participants were chosen from different industries and backgrounds and their positions varied greatly. It is important to highlight that the novelty of the DPP delimited the number of experts who had profound knowledge of the concept. However, all interviewees taking part in this study have participated in digital product passport pilots, worked with producing the DPPs, or have some other way been actively involved in publications related to the concept. Since this is not a case study specifically focused on companies but rather on the concept of DPPs and their implementation in general, the employers of the interviewees have been kept fully confidential. Also, to ensure anonymity, no further information, except the interviewees' professional titles or areas of expertise is published in this research paper.

5.2.2 Data collection

Interviews, focus groups, and surveys are the most common sources of evidence in qualitative studies. In all these methods, data collection is based on interviewees recounting their thoughts on the research subject (Walle 2015). An interview is a discussion that has a predetermined objective. It is important to remember that the parties involved in the interviews influence each other and their perspectives, as it is a form of interaction. Ideally, an interview allows the researcher to gain deep insights into the interviewee's thoughts, views, expectations, and personal experiences regarding the topic being studied. (Puusa et al. 2020.)

Semi-structured interviews were chosen as the interview method and a common interview frame was formed to bring clarity and consistency to the data collection process. In semi-structured interviews, all interviewees are primarily asked the same set of questions. Still, the interviewer has the opportunity to explain the questions in their own words and ask follow-up questions depending on the situation. The advantage of a semi-structured interview is that the process remains relatively systematic, even though the aim is to create

a conversational and informal atmosphere where it is possible to gather broad and in-depth responses on the subject being studied (Eriksson & Kovalainen 2008.) This interview method was considered particularly appropriate for the study, as the goal is to generate in-depth information about different specialists' experiences while ensuring that the data remains relatively consistent and comparable.

The semi-structured interviews were conducted remotely during October 2024. The interviewees were five DPP experts, who actively work among the DPPs or have been involved in DPP pilots. The interview questions were formed based on the theoretical framework presented in Chapter 4. The interview framework was sent to the interviewees in advance, so they would have the opportunity to familiarize themselves with the questions and prepare their responses ahead of the interview. Allowing the respondent to prepare in advance is considered essential for the quality of the information and the overall success of the interview (Tuomi & Sarajärvi 2018). A maximum of one hour was allocated for the interview, during which the aim was to discuss the interview questions in detail within the available time. Before the interview began, permission to record the conversation was requested from each interviewee and it was reiterated that the results would be analyzed anonymously in the study. In analyzing the findings, all interviewees are referred to by high-level titles to ensure anonymity.

5.2.3 Data analysis

One of the main challenges in qualitative research is deciding which data is valuable enough to analyze. Organizing the interview data question by question is useful for effectively identifying meaningful themes in large volumes of text data and creating a structured data analysis (Vaughn & Turner 2016). In the data analysis process, it is critical to acknowledge the researcher's inevitable influence on both data collection and analysis. Recognizing one's preconceptions and assumptions about the research topic, as well as their impact on the analysis and interpretation of the research findings, is essential. For instance, forming thematic codes is closely connected to the literature reviewed and the frameworks identified within it. (Puusa et al. 2020.) Thus, subjective assessments and judgments of the collected data are accepted and often necessary. (Walle 2015).

The data analysis process of this study was conducted following the strategies for analysis presented by Vaughn and Turner (2016) in Figure 4.

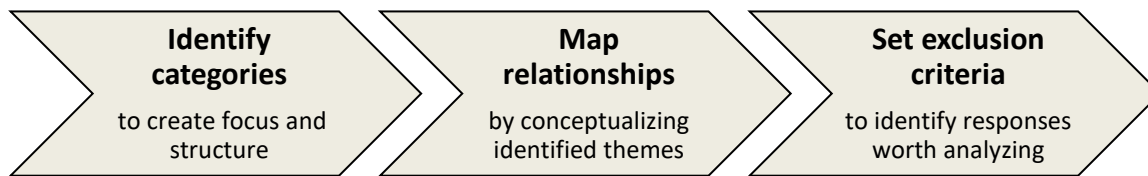| Identify categories		Map relationships		Set exclusion criteria
to create focus and structure		by conceptualizing identified themes		to identify responses worth analyzing

Figure 4 Strategies for qualitative analysis (Vaughn & Turner 2016)

Analyzing the empirical data started with transcribing the interview recordings and reading them thoroughly to obtain an initial understanding of the emerging themes connected to the research questions. The data was analyzed by comparing the content from individual interviews with one another. This analysis method aimed to identify parallelism and differences within the data and reflect the findings to the theoretical background of the research field. Analyzing each interview separately resembles a within-case analysis, in which each empirical case is first examined separately to gain a thorough understanding of the specific case and the key emerging themes. (Eriksson & Kovalainen 2008.)

In thematic analysis, it is common to have predefined propositions that provide a foundation for a pre-established thematic coding framework to guide the data collection. In this study, indicative thematic codes were already formed in the data collection phase and later supplemented according to the content of the text data. The interview data was then thoroughly reviewed, and excerpts from the text were categorized into the identified themes. At this stage of the analysis, all information related to the topic was transferred under the categories and later filtered based on the relevance to the study's theoretical framework and research questions. The excerpts were then used to create a comprehensive picture of the key findings that emerged from the interviews, which were thoroughly addressed in the research findings. The most informative and relevant excerpts were presented as quotations to highlight the core perspectives of the interviewees engagingly.

5.3   Research quality

In qualitative research, the researcher serves as the key standard of the reliability of the study as they must continuously reflect on their decisions and consider both the scope of their analysis and the credibility of their findings (Eskola & Suoranta 1998). A fundamental challenge and aim is ensuring the trustworthiness and quality of the study by adopting different evaluation criteria already in the early stages of the research process (Eriksson & Kovalainen 2008). Multiple scholars have identified a set of criteria to evaluate and test the quality of research designs (e.g., Eriksson & Kovalainen 2008, Miles & Huberman 2014; Yin 2018).

Eriksson and Kovalainen (2008) list *reliability, validity*, and *generalizability* as the three key standards to help judge the quality of the research. Reliability shows the degree to which a measure, procedure, or instrument consistently produces the same outcome across repeated trials. Reliability is therefore connected to the saturation of the empirical findings. However, reliability is not solely linked to the number of empirical cases; rather, the materials obtained, the quality of the interviews, and the logic behind the data collection process play a crucial role in determining the study's quality (Eriksson & Kovalainen 2008). The reliability of the research is supported by the fact that the interview framework and the analysis of the empirical data are structured to keep the focus on issues relevant to the research questions. Also, to ensure the reliability of this study, the interviewees were chosen carefully and purposefully, and data collection was conducted in an organized manner to extract all possible information as reliably as possible from a relatively small amount of data. However, the research critically considers that the amount of data may not reach the saturation point, which undermines the reliability of whether another researcher could replicate the results obtained in this study.

Validity pertains to how accurately the conclusions drawn from research describe or explain the events that occurred. The results must reflect the phenomenon accurately and findings and conclusions need to be backed up with relevant evidence, ensuring their certainty. (Eriksson & Kovalainen 2008.) Digital product passports are still an emerging concept, which means that the current research knowledge may not accurately reflect reality, particularly regarding legislation or other practical matters at the time of implementation. Given the nature of the research topic, the study inherently contains a

significant amount of uncertainty, which is mitigated through accurate data analysis and the presentation of conclusions in active dialogue with previous research.

Generalizability refers to how well-argued and grounded the empirical research subject is to enable extending the results to apply in a wider context (Eriksson & Kovalainen 2008). The diversity of the data enhances the generalizability of the research (Miles et al. 2014). The concept of digital product passports currently lacks a consistent and widely repeated theory. It is an emerging research field, where a significant portion of the information is non-academic and non-peer-evaluated publications. In this study, the references are mostly academic articles to enhance reliability and generalizability as well as avoid biases. However, generalizability testing does not apply to this research, as it is not relevant to expand beyond the investigated concept of digital product passports, which is already under-researched.

Yin (2018) also outlines four key criteria for testing the quality of the chosen research design, especially applicable to social and case study research. These criteria, also called tests, help the researcher map out the findings' validity and reliability. The four criteria are construct validity, internal and external validity, and reliability. Not all these criteria are directly applicable to this study, but the quality of the research can still be evaluated. Construct validity refers to the identification and definition of the concepts being examined and how they are measured, especially in a way that reflects the study's theoretical framework. In case study research, this test is particularly challenging as subjectivity and low measurability are part of the data collection phase. The construct validity can, however, be achieved by using multiple sources of evidence, clearly showing how conclusions are drawn from the empirical data, and having informants review your study report. The second and third criteria are internal and external validity. Internal validity is used for explanatory and causal studies as they aim to explore cause-effect relationships, which makes it a non-suitable quality criterion for this study. External validity explores the generalizability of the findings. Yin (2018) states that generalizability can be achieved by creating a strong theoretical framework and writing the research questions in "how and why" form to help the generalization of data. From this perspective, the study also meets the criterion for generalization based on the theoretical framework presented in Figure 3 as well as the research questions.

6   Findings

This chapter presents the research findings based on the data collected from five expert interviews. All interviewees are referred by their following high-level titles to ensure anonymity: *Supply Chain Data Expert, Data Economy Specialist, DPP Service Provider, Tech and Circularity Specialist, and Sustainability Specialist*. The first section of the findings addresses the key opportunities and challenges of the digital product passport in order to create a foundational understanding of the concept, which will then be explored in greater depth through the core themes of the research questions. The second chapter shifts the focus to examining the experts' views on the successful planning and implementation of the DPP. The identified critical success factors are categorized into four main themes and discussed thoroughly. Then, the most prominent benefits of organizations' proactivity toward planning and implementing the DPP are addressed. Lastly, findings connected to the DPPs' power to promote supply chain transparency, and the adoption of circular business models are discussed.

6.1   General opportunities and challenges of the DPP concept

All interviewees found the concept of the digital passport to be a groundbreaking driver of supply chain traceability and sustainability. Enhanced traceability and transparency throughout the product life cycle not only promote sustainability and the adoption of circular business models but also build trust between companies and consumers. One key enabler of circularity is mentioned to be the increased efficiency in supply chains through the advanced use of technology and standards. Sustainability efforts in a digital form may open up new business opportunities as the data, that is easily available and in a usable form, has the power to revolutionize the closed-loop activities in supply chains. When materials get a longer life cycle and organizations know at what end of the supply chain, for example, waste exists, they can develop new and more efficient production processes. For example, the DPP Service Provider saw an opportunity to strengthen the Finnish industry by providing more accurate material- and product-related digital data related to responsible business operations.

> "The digital product passport makes the need for traceability and
> transparency within the supply chain visible. Its construction provides the
> ability to track the entire lifecycle of a product along the lengthy value
> chain, from raw materials and components to production, distribution, and
> delivery to the consumer, and even beyond to the different possibilities for

> reuse and, ultimately, recycling of raw materials. There is, of course, a great opportunity here to build trust between companies and toward consumers, as it also enables the presentation and verification of reliable information." – Supply Chain Data Expert

Most interviewees hoped the digital product passport to revolutionize products' value-creation process, particularly through unit-level tracing and enhancing the end-of-life handling of materials. The Tech and Circularity Specialist pointed out that if we can target the tracing to a specific product, and that specific product, like your shirt, has its own unique story, digitalization enables an individual product to have greater value. A Data Economy Specialist shared similar thoughts, reflecting on the potential of having more detailed product information moving throughout the product's lifecycle. This could enable consumers to take better care of their products, for example, by extending the lifespan of clothing. From a business perspective, this also opens opportunities for additional sales, and while it may not necessarily foster customer loyalty, it certainly would strengthen brand reputation and customer relationships.

> "One aspect is about extending the product's lifecycle. So, if we could achieve a longer lifespan for the materials or the product itself, because it could be repaired, and we would know about its properties through that, then it would be beneficial. And if the materials could be reused, companies see that this could also benefit them. If we can separate and reuse materials, whether they are waste materials from the beginning of the chain or the recycling side, and reintroduce them into production, then from a business and economic perspective, this could be seen as an efficiency gain or, at the very least, potentially lead to new business opportunities." – Data Economy Specialist

While the potential benefits of digital product passports for promoting sustainability and circular economy practices are evident, significant challenges were also addressed. Enhanced collaboration, standardization, willingness to invest, and a focus on data availability and quality will be critical in realizing the full potential of DPPs. Almost all interviewees viewed the poor quality of product data and the currently incomplete and unclear regulation and standards as critical concerns, as the upcoming EU legislation will require companies to collect and disclose data in a highly detailed manner. For instance, the requirement for unique identifiers for each product is still under discussion, leading to uncertainty among stakeholders on how to effectively plan and execute the flow of data to meet compliance in the future. Also, as the volume of data increases significantly, how to ensure data safety and confidentiality also emerged as an apparent concern in the DPP concept.

"Then there are probably quite a few questions related to authentication, data security, and data sharing, and these pose a significant challenge to the whole issue. This also affects companies' commitment, so it is important to alleviate fears and build trust in the idea that transparency does not mean that all parties need to share everything. However, it should also prevent a situation where a company can say that all the information is so business-critical that nothing can be shared. The aim should be to find the right way to make this reasonable for all parties involved." – Supply Chain Data Expert

The implementation of DPPs relies heavily on robust technological infrastructure, which is seen as difficult to build in complex supply chains because of the lack of technological readiness, know-how, and standardized systems. All interviewees, except one, felt that particularly smaller companies are in a difficult position due to fewer resources, financially and in practice, to adopt the collective DPP requirements effectively. The Tech and Circularity Specialist, whose perspective was partially opposite, considered the simpler supply chain as a possibility for gaining a competitive advantage, especially regarding companies that have quite high traceability in their supply chains and have already adopted sustainable operations and values.

"The challenges definitely relate to technology, expertise, and collaboration within the supply chain, as many do not have the necessary infrastructure to support product passports, and the data flow involved. I don't know how many truly grasp this, and I certainly don't fully understand it myself, except that there is a significant sore point regarding how much the volume of data, and the amount of data to be managed, increases as we move towards traceability and item-level information. So, the challenge is whether, even if some technology exists, it is sufficient to manage the exponentially increased data volume." – Supply Chain Data Expert

Two interviewees heavily emphasized the fact that the digital passport is only a way to disclose information to users; the real challenge is to build a data ecosystem behind the passport. Yet, all participants referred to at some point during the interview that there is a pressing need for increased collaboration between systems as well as people in DPP ecosystems. The lack of motivation, willingness to invest, and active participation from all SC stakeholders arose as key barriers to the planning and implementation. All interviewees addressed that businesses are also by no means ready for the implementation of the DPPs or even fully understand its concept.

"In my opinion, the product passport is merely a channel for presenting information to the consumer. However, our biggest challenges lie in the fact that for each raw material stream, you need to be able to generate data for sustainability reporting, which is practically impossible to do manually.

Creating a QR code and linking it to a webpage is not that difficult; that's not the real challenge. The real challenge arises when you need to establish an ecosystem behind it." – DPP Service Provider

In general, the interviewees also expressed concern about how unclear the concept of the digital product passport has remained at a practical level. Uncertainty regarding the requirements, internal company roles, data ownership, and demand for the DPP were highlighted. Three interviewees stressed that despite the need for a digital product passport as a climate-driven accelerator for circular economy models, it must also provide business benefits for companies. The challenge is seen in how to motivate participants to invest and commit to the DPP as well as later ensure that companies who are actively involved can maximize their benefits and create a market around the digital passport.

"In light of current regulations, as a lot of responsibility regulations are emerging now, it's difficult to determine whether the digital product passport should be classified as a responsibility task, a supply chain task, or a purchasing task? Or perhaps sales or marketing... To which department should it actually belong, and who would even take the initiative to work on it? Companies likely don't have the capacity, since not all companies even have a sustainability department, and in many cases, sales and marketing are combined, with their hands already full. There certainly isn't the kind of infrastructure in companies where this responsibility could just be handed off, saying, "This belongs to you, please take care of it." – Sustainability Specialist

6.2   Critical success factors in implementing the DPP

The collected data revealed four main themes related to the successful implementation of a DPP to increase supply chain transparency. The categories presented in the following sub-chapters analyze the most recurring findings in a detailed manner aiming to pinpoint the key similarities and differences between the views of the experts. The interviewees somewhat emphasized different success factors depending on their background and job roles related to digital product passports. Despite this, almost all interviewees mentioned aspects belonging to each category, which supports the relevance of the pre-coded themes, which were formed partly based on previous literature.

6.2.1 Technology, data, and system integration

Technology was considered a self-evident prerequisite for the implementation of the digital product passports. Almost all interviewees mentioned the importance of

technology first, yet quickly shifted into stressing other themes as supporting factors necessary to achieve technological readiness in the first place. The Tech and Circularity Specialist described having ownership and a clear vision of the organization's data as a baseline for implementing the DPPs. Without this, the ability to produce reliable and usable data for a DPP was not seen as possible. It was also stressed in the interviews that companies need to ensure that the data flows seamlessly from the beginning of the value chain to the very end of the materials' lifecycle.

> "New circular economy business models cannot emerge without the implementation of something like product passports. The idea is that information travels with the product from the very beginning, from material production all the way to the end—recycling, waste, and even reuse—so that the material can circulate back. In other words, different new circular economy business models cannot be implemented without the technical ability for product information to flow and be shared between various parties." – Data Economy Specialist

> "The critical success factors are certainly closely related to technology, expertise, and collaboration within the supply chain. Many companies lack the infrastructure needed to support the product passports and the flow of data, especially in terms of the volume of data." – Supply Chain Data Expert

As the interviewees mentioned in relation to challenges, the quality of product data is extremely poor. Actively improving the availability of unified data from all parts of the supply chain is considered critical regarding the successful implementation of a DPP. When data is available and in the right format, a digital product passport can be produced. This, however, requires building a coherent DPP system structure, where data can be integrated behind a specific product batch, for example by using a digital twin.

Numerous interviewees strongly emphasized the importance of building a data ecosystem as a critical success factor. Technology enables the formation of a data ecosystem, but its effectiveness hinges on seamless collaboration with stakeholders and a shared commitment to reforming complex operational models. The Tech and Circularity Specialist mentioned that the technology itself is not the issue; rather, it is the decision to invest in building the necessary data ecosystem, which will likely be the biggest differentiating factor between companies.

> "I see this more as an ecosystem approach, where individual companies don't necessarily need to be extremely deep experts in managing the technical solutions for product passports, but rather, services should emerge to support this." – Data Economy Specialist

The Data Economy Specialist also highlighted the ability to integrate the digital product passport ecosystem into companies' existing systems as a particular success factor. Filling in the missing gaps and ensuring that all relevant stakeholders in the supply chain understand and agree upon the data usage and what is required from them is considered critical. As the DPP's implementation requires seamless data flow and interoperability across various platforms, organizations must consider how to effectively utilize their existing data to mitigate excessive cost burden and complexity. The Sustainability Specialist shares similar views on the importance of technology being embedded in the companies' current systems, yet highly stresses that the necessary IT expertise for the implementation may not often be found within the company.

> "I would by no means want to create any new layer where companies would have to produce something on top of all their existing systems, like a product passport solution. Instead, the focus should be on how we can leverage the current systems, and often it's about getting the data from ERP systems and transaction systems." – Data Economy Specialist

6.2.2 Building an ecosystem through collaboration

The findings suggest that organizations must understand the importance of an ecosystemic approach, where individual companies do not need to be experts in all areas of the digital product passport. Change cannot be accomplished in isolation and innovative solutions are often created through partnerships that facilitate the data sharing and handling, not make it more complex. Four out of the five interviewees highlighted collaboration as a critical success factor for implementing the DPP. A shared and clear vision, where all stakeholders are involved in the planning and implementation of the passport was found crucial to produce and disclose the right data. Thus, building an ecosystem simply requires the contribution of all stakeholders in the supply chain.

> "Again, I don't like the word ecosystem, but in a way, companies that can build these (ecosystems) are the ones that can form partnerships... through partnerships, they can create solutions that meet the need to share data within the supply chain or between organizations. And if you have these deft partners who could handle the technical aspects, I believe these kinds of players would succeed in the market." – Data Economy Specialist

The Tech and Circularity Specialist described the digital product passport as a "mindset change," where we radically move away from not knowing what the supply chains

contain, towards strong strategic collaboration. It was highlighted in the interviews that organizations need to look beyond specific functions and have a mutual internal and external ambition to succeed in implementing the DPP. The technological aspect of the DPP cannot be put into practice without this cross-border collaboration, including cooperation with lower-tier suppliers, as the necessary data simply would not be available.

> "I would say that the most critical success factor is a shared commitment that transcends functional boundaries. This means involving marketing, logistics, warehousing, sales, and sustainability all together. There should be a common commitment that goes beyond organizational and functional borders, as it requires collaboration; I cannot achieve this alone from my desk." – Sustainability Specialist

The Supply Chain Data Expert also emphasized the importance of cross-industry cooperation particularly in Finland, as a means to develop open standards and strengthen the domestic implementation process. Without this collective vision for creating a common "language" for the DPP concept, adopting approaches that lead to achieving organizational goals is seen as unattainable. Even though unified standards and clear regulation are categorized as their own critical success factors separate from the collaborative and ecosystemic approach towards the DPPs, their many obvious overlaps cannot be addressed separately.

> "Collaboration and the construction of an ecosystem—specifically, a data ecosystem around this topic—are, in my opinion, critical success factors. The entire Digital Product Passport concept is a topic that a company cannot solve alone, as it involves at least the entire supply chain, and one could even extend this to a global context. You also cannot narrow your focus solely to your own supply chain; instead, you should be able to see the ecosystem around it, including competitors, and understand that the competition authority or anyone else will not come and say that you cannot work together on such matters related to open standards and sustainability." – Supply Chain Data Expert

6.2.3 Leadership, motivation, and willingness to invest

A key challenge that emerged in multiple interviews was companies' reluctance to invest in the DPP as well as the general lack of interest in developing the product passport to be a part of their operations. Expressing this concern, the DPP Service Provider mentioned that these kinds of investment decisions related to, for example, traceability, are the ones

that are not getting approved right now; instead, they are primarily being postponed. However, based on the interviews, it is evident that the successful implementation of the digital product passport requires significant investments and willingness to embrace the upcoming change.

> "There are many actors, systems, and technologies involved, so for everything to function automatically and smoothly together seems to be somewhat of a utopia. It requires a commitment to the rules of the game and will certainly need investments at the level of system technology." – Supply Chain Data Expert

> "In my opinion, technology is not the problem per se; it's more about leadership and the decisions that come with it. It requires investments, and you really have to think about the concept... Because ultimately, I believe the digital product passport represents a comprehensive change, and I think it's a very positive change since it drives the company towards circular economy processes and forces them to consider data and data usage. So, I see it more as a leadership issue: whether you want to be part of this change or choose to wait and see." – Tech and Circularity Specialist

Two interviewees found leadership as a key factor in deciding to start planning the DPP and creating the technological solutions to support it. It is a matter of choice whether to start planning on how the DPP can benefit the business in the long run or stay waiting for the mandatory requirements and implementation to enter into force. Considering the potential use cases of the passport and their benefits, as well as making the content of the digital product passport clear, merchandisable, and advertisable is seen as beneficial for the financially successful planning and implementation of the DPP.

> "Businesses need to carefully consider from their own perspective what would bring them the greatest benefit relative to the investment. I believe the key success factors start with the understanding of leadership and management regarding how this could support their business. For instance, if the circular economy is a potential direction for their business, then that could be the focus. But it could also be something as simple as improving efficiency in a global supply chain. Could this help enhance customer experience or generate additional sales? I believe it all starts with the business case, and then the technological and other implementation aspects follow." – Data Economy Specialist

Concerns regarding the appeal of the DPP to end users also emerged in the interviews. Two interviewees shared similar concerns that the successful implementation of a digital product passport will be challenging, especially in a way that promotes circularity if end users are not interested in reading the contents of the passport. Motivating end users in addition to the owners of the digital passports emerged as a critical success factor,

especially considering the DPP concept in terms of what the implementation could lead to environmental-wise in the long term. The Sustainability Specialist strongly highlighted the need to motivate companies to also build a strong business around the DPP as they need the return on investment (ROI) to stay competitive in the market.

> "As a sustainability professional, I would love if all products had their carbon footprints, countries of origin, and everything related to sustainability openly available. Still, sustainability costs, and it's only a small fraction of people who actually make purchasing decisions based on being able to read something about a product…. This product's transportation carbon footprint is 0.00081 kilos of CO_2 emissions. I mean, that doesn't even mean anything to anyone—like, is that a lot, or is it a little?" – Sustainability Specialist

6.2.4 Clear regulation and standards

A shared language regarding standards was identified as a key prerequisite for success, as it is essential for building a common infrastructure. Three interviewees expressed concerns about how data management and the quality of data can be achieved without common standards guiding the complex nature of the DPPs. Since comparability has been defined as one of the key requirements between products and organizations, the interviewees consider having too many different calculation methods and ways of presenting data as overly complex compared to unified standards.

However, the Supply Chain Data Expert points out that while the idea behind regulation is good and the adoption of unified and open standards is essential, the regulation cannot be so complex that companies begin to question whether they can continue producing their products to the market. Especially players, who have fewer resources to successfully meet the requirements, would be disadvantaged by the overly complex DPP standards. Two interviews stressed the need for utilizing global standards that are already widely used by companies, such as the GS1 standards.

> "Efficiency arises, for example, from standards when a certain critical mass is achieved, with a general rule of thumb being around 70%. When 70% of companies utilize standards, significant efficiency begins to develop. This understanding implies that one cannot limit their perspective solely to their own supply chain" – Supply Chain Data Expert

As the legislation concerning the DPPs continues to develop, the Supply Chain Data Expert highlighted the importance of organizations and experts actively participating in shaping the upcoming regulations and standards. A clear DPP regulation is considered a

critically important aspect of diminishing ambiguities and inequality related to the concept and easing the planning process remarkably. However, the specific requirements guiding the DPP unity are still widely unclear despite the regulation entering into force in 2024. The Data Economy Specialist sees similar possibilities with standardization and finds active regulatory-related discussion as an opportunity to further beneficial requirements for the company itself and other players in the market.

> "If you are at the forefront of implementing something, you may also set certain standards for others in a way. For example, at the EU level, there are expert groups that define the requirements coming directly from EU regulations. They engage in discussions with these standardization bodies and groups about what the standards should be for data interoperability and other aspects of availability and mobility that should be implemented." – Data Economy Specialist

6.3   Benefits of early planning and implementation

The importance of a proactive approach towards the planning and implementation of the DPP was highlighted in all interviews. Gaining a competitive advantage through differentiating themselves in the market through transparency, responsibility, and trust was seen as essential. Creating a strong market postion will be beneficial when navigating through upcoming changes and complexities connected to the digital product passport. Thus, companies that take advantage of the possibility of preparing early will have a solid foundation for the DPP when requirements arise. Those who actively test their ideas and the concept of the DPP will gain valuable insight into what the missing gaps in their processes, systems, and data are. One interviewee, the Sustainability Specialist, pointed out that if we start smoothly planning and testing the DPP before it becomes mandatory, the actual implementation will be business as usual, at that point, a normal part of the companies' day-to-day tasks.

> "It would be wise to build the foundation in such a way that there is granularity because you can always generate a certain level upwards. If you don't need every serial number, you can combine the data and create something from it. However, if you've only tracked a model number, it will be difficult to obtain more detailed information later, or it will require a lot of work. So, we need to find the right level now. The pioneers have had the opportunity to examine this from a broader perspective and from their own business process viewpoint, which may help them identify the key points that are important for us to track and at what level. This would also assist in

addressing future needs, not just the current ones." – Supply Chain Data
Expert

The financial aspect of adopting the DPP early is found significant among all interviewees. The notable costs of sustainability-promoting actions were highlighted but being reactive rather than proactive was considered to cause a worse cost burden for organizations in the long term. The pioneers may have to invest more at the beginning of the planning process, but those following behind are missing out on the concrete learnings and challenges others have already experienced and most likely later must execute technological solutions quickly with high costs and lower operability. Two interviewees also stressed that the EU is now actively investing in DPP pilots, which is seen as a major opportunity to test where you are as a company and map risks related to the DPP concept with a significantly lower price tag.

However, the Sustainability Specialist had a slightly different perspective regarding the financial aspect, stating that the prices charged by DPP service providers are exorbitant at the moment, increasing the costs for trailblazer companies. Once the digital passport becomes mandatory, the number of service providers will grow significantly. Prices will drop, and the barrier to developing the DPP will be much lower, meaning it may not be as necessary to achieve high-profit margins as implementation costs decrease. This perspective stems from the interviewee's view that current prices are extremely high compared to the fact that the market or customers are not yet ready to adopt the digital product passport.

Organizations may also get notable sanctions or must make greater investments to ensure traceability if for example mandatory sustainability reporting is not done properly or the DPP planning and implementation is executed too late. The DPP Service Provider stressed the fact that as ESG reporting will be mandatory for companies, the same data can be utilized more cost-effectively to plan and produce the DPP as well.

> "In my opinion, there probably won't be significant sanctions related to the digital product passport initially. However, in the global economy that I've been part of, if there is a possibility of imposing a fine of 4% of a company's revenue, then as a CFO, I would have prioritized the issue of traceability reporting very differently. After all, very few companies can withstand a 4% reduction in their operating margin." – DPP Service Provider

If participating early, organizations can reap the benefits and even set standards for other participants in the market. Companies have to power to influence upcoming legislation

as standardization bodies and expert groups are currently deliberating on potential standards, for example, related to data availability and interoperability. This process will ultimately shape the standards that will be adopted. According to the Supply Chain Data Expert, all propositions submitted to the Commission by organizations or other actors must be handled and if an initiative is good, it will be acknowledged. The Tech and Circularity expert supports the curious and unprompted attitude toward planning and implementing the DPP as it is a way to gain an upper hand in the market, especially reputational-wise.

> "You have two avenues to consider: one is to focus solely on this legislative change and wait to see what we can do once the legislation is in place, which I think is a bit of a risky option. Then you have this curiosity and mindset shift, where we are talking about the digitalization of value chains and these physical products, which is really important. In a way, through that data, you are creating the future for your company, and this is very beneficial even if you don't fully prioritize the product passport. Understanding all the digitalization related to it would be desirable, so hopefully, we can move forward in that direction." – Tech and Circularity Specialist

The interviewees also highlighted several risks if the planning of the digital product passport is handled poorly or too late. If organizations fail to meet compliance by some parts of the supply chain and are unable to produce the required product-related data, the pressure accumulates on both the owner of the product passport and the suppliers. Organizations struggle to enter the market if they don't have the requirements in order. If the implementation is done too late and the involvement of a system provider or other changes are needed, it becomes a challenging equation. In scenarios where requirements are introduced after insufficient planning and implementation, companies may find themselves unable to offer their products in the market. Another perspective is that if a supplier cannot provide the required information within the designated timeframe, especially if such information is requested too late, it could result in severe consequences, including the potential loss of business for subcontractors.

> "I would definitely emphasize this reality of the real world, especially in the role of a subcontractor. It is quite alarming that if you cannot provide that information and it comes as a surprise that such data is required, it could mean, at worst, that you are no longer a supplier." – Data Economy Specialist

6.4 Effects of the DPP on supply chain transparency and circularity

The DPP aims to promote the transition to the circular economy, however, the interviewees present numerous obstacles to achieving this goal. Implementation alone does not lead to truly improved transparency and circular economy; rather, the content of the digital product passport plays a crucial role in this process. While transparency provides opportunities for businesses to engage with consumers and stakeholders, there is a risk that companies may attempt to oversimplify or manipulate information. This could diminish the perceived value of transparency for consumers, supply chains, regulatory bodies, and the companies themselves.

> "There is a risk that we may end up cutting corners, and while there are opportunities with this transparency information, they can be compromised if we take shortcuts. As a result, the added value for all parties—consumers, supply chains, regulatory authorities, and the companies themselves—may not be realized. Without that added value, interest in the initiative will fade."
> – Supply Chain Data Expert

Multiple interviewees highlighted the importance of accurate and reliable data to achieve transparency and suggested creating processes that facilitate auditing and mitigating data forging. To some extent data forging will almost certainly occur, but the risks that follow create pressure for companies to build trust through legitimate information. The Data Economy Specialist highlighted that the trust of a consumer or a partner in the supply chain can only be betrayed once, which certainly poses a significant risk if requirements are not being followed. The DPP Service Provider supports the likelihood of data accuracy by noting that, for example, sustainability reporting is part of a company's financial statements, making the board responsible for its integrity. Thus, if the board signs off on such a document, it has to be relatively robust.

> "Depending on the quality of their master data, that will determine how reliable the information is. And this also affects the level of transparency." – Sustainability Specialist

> "Another thing is that in today's age of social media, companies can quickly face backlash if transparency information is distorted; I believe that the risk of reputational damage should be the greater threat for companies" – DPP Service Provider

One topic that emerged from the interviews was the overall motivation towards utilizing the passport to promote transparency and circularity. Both the Tech and Circularity Specialist, as well as the Sustainability Specialist, emphasized that the DPP concept

requires incentives to achieve its ultimate objectives. Organizations can implement the DPP and enhance transparency, but the real challenge lies in the fact that how many companies are willing to go beyond compliance and show through their actions and concrete practices what they do at the operational level to move towards circularity. The Data Economy Specialist emphasizes the need for companies to understand and build business value around the digital product passport.

> "For the implementation of the digital passport, there needs to be some incentives. I think this development is quite interesting, and it raises the question of whether we can truly achieve it. For instance, data could be utilized for resale events, allowing consumers to follow the process where they can go in, scan the code, and then sell the product again. You could argue that brands need to leverage this engagement opportunity and create customer programs, such as offering a twenty-euro discount if you do something like return a product." – Tech and Circularity Specialist

> "There are only a few of us who genuinely care about sustainability. When market and customer research is conducted, asking whether you'd choose this product or that one—where one is sustainable or marginally more sustainable than the other based on certain criteria—the price tag ultimately makes the decision." – Sustainability Specialist

A fear is that the DPP will have countless loopholes and organizations will be able to meet even the minimum requirements without altering their supply chains. There are, however, policies such as EPR, that hold organizations accountable in the future and may even encourage companies to make circular business models the focus of their value creation.

> "I think one major factor influencing this is EPR, extended producer responsibility, where legislation aims to hold brands accountable for what happens to their products at the end of their life. If brands do not implement circular economy solutions and offer them to customers, they may face some form of sanction. This could serve as an incentive or at least as motivation for brands to adopt such practices more actively." – Tech and Circularity Specialist

Despite the multiple risks and obstacles considering the DPPs' effects on transparency and circularity, the interviewees also saw evident opportunities, which were addressed and discussed in detail in the context of expected opportunities. One interesting aspect that arose later regarding the DPP's effect on transparency and circularity, was the Data Economy Specialist's view on the DPP's potential to improve the overall sustainability of manufacturing in Europe as well as change the mindset of customers towards sustainable consumption.

"On a global level, I believe this could actually be beneficial for Europe, as we are raising sustainability standards or quality criteria to prevent truly low-cost producers from entering our internal market. In this regard, the role of the authorities is also quite significant. I see that, in the big picture, this product passport can support high-quality European production by ensuring that low-quality or unsustainable products do not make it to the market." – Data Economy Specialist

7 Discussion and Conclusions

This chapter discusses the empirical findings of the study in close dialogue with existing literature. Both research questions are answered comprehensively reflecting whether the interview findings support or contradict previous research observations. Conclusions on the main findings of the study are drawn throughout the chapter. Additionally, this chapter presents the study's limitations and potential topics for future research.

7.1 Answering the research questions

The purpose of this study was to develop a thorough understanding of the critical success factors for implementing the new EU DPP to enhance supply chain transparency and circularity, while also examining the main benefits of proactive and early-stage planning for the digital product passport. This objective is pursued by answering the following research questions:

- *RQ1: What are the critical success factors for implementing the Digital Product Passport to improve supply chain transparency and circularity?*

- *RQ2: How can companies benefit from preparing early for the implementation of DPPs?*

7.1.1 Critical success factors in DPP implementation and possible impacts on transparency and the circular economy

The empirical findings of this study provide strong support for the evident connection between the identified challenges and critical success factors for the DPP implementation highlighted in the previous literature. This connection emerges as the study's most significant finding, as it is suggested that the DPP cannot be successfully implemented without overcoming the main challenges of the concept. While the study's primary objective was not to specifically examine the challenges of the DPP, the connection between challenges, critical success factors as well as organizations' proactivity was considered to have a key importance in the concept. Hence, it was decided to explore the potential interaction between these themes in depth by first investigating what the interviewees perceived as the main challenges or barriers to the DPP concept.

The intricacy of data and system integration as well as the complexity of global supply chains, lack of collaboration, and standardization were identified as the most challenging aspects of the DPPs in previous literature. (e.g., Chen et al. 2019; Langley et al. 2023; Jansen et al. 2023; Psarommatis & May 2024) Also, multiple scholars were concerned about how to ensure information safety and create incentives for companies and consumers to start adopting the DPP (Götz et al 2022; King et al. 2023; Jansen et al. 2023). These observations are aligned with the empirical findings of the study as challenges related to technology, data integration, standardization and regulation, and lack of company resources were the most recurring themes that emerged from the interviews. Also, ensuring data safety and confidentiality as well as the lack of technological readiness, were addressed as apparent challenges of the DPP concept. King et al. (2023) highlighted the critical need to incentivize economic actors to develop innovative business models related to the DPP across the entire value chain. Some interviewees raised similar views on the importance of motivating companies, stating that low willingness to invest and actively participate in the process can act as a key barrier to the implementation of the DPP.

Although the interviewees saw great potential in the concept of a digital product passport, a unified consensus was that the multiple challenges hindered the implementation of the DPP. A theme that three interviewees strongly highlighted was the challenge of building a business around the DPP as currently the demand for the passport largely arises from the EU and environmental considerations rather than from the market and especially end users. This view is not directly supported in the existing literature; however, for example, Langley et al. (2023) stress the need to redefine the value-creation process of the organization to stay competitive in the market. Also, Adisorn et al. (2021) highlight the challenge of increasing the overall appeal of digital product passports for users and investors. While the information contained in the passport is valuable for circularity, it also needs to hold value for other stakeholders.

The interviewees did not necessarily highlight the consequential connection between challenges and success factors explicitly, but each theme that emerged in relation to challenges also appeared in the context of critical success factors. Based on this, the conclusion has been drawn that the factors with the greatest impact on the success of digital passport implementation are also the concept's most intricate challenges and thus the most difficult to overcome.

Technology-related aspects of the DPP, such as the need for system and data integration, improved quality of data, and ecosystemic approach towards the DPP system, appeared as critical success factors among all interviewees. In general, technology was perceived as a critical prerequisite for the successful implementation of the DPP. Engaging stakeholders from all parts of the supply chain to improve accessibility to data was also mentioned as a critical success factor according to three interviewees. In the existing literature, there are no universally accepted "critical success factors" for the implementation of a DPP, yet numerous researchers emphasize certain requirements that companies should meet to ensure successful implementation. Zhang and Seuring (2024) also highlight that companies need to assess their readiness, understand the barriers to DPP implementation, and examine critical success factors to ensure a smooth and efficient DPP rollout. In line with the empirical findings, existing literature considers filling in the missing data gaps and ensuring data and system interoperability with all relevant stakeholders necessary to meet the requirements of the DPP (Langley et al. 2023; Stepke-Müller et al. 2023). Also, if the systems and data are not integrated properly, it can act as a key barrier to the DPP implementation (Langley et al. 2023). Multiple scholars (Adisorn et al. 2021; King et al. 2023; Suomi et al. 2024) also highlight the need for DPPs to be built on top of current systems to mitigate complexity and facilitate the integration of existing data. Two interviewees in the study supported this view by stressing the advantages of building the DPP as a part of the company's existing systems to reduce costs and overall complexity.

The findings also highlighted the need to view the digital product passport as a data ecosystem enabled by close collaboration among stakeholders. Previous literature supports this perspective, as numerous researchers cite achieving a data ecosystem through, for example, unified data standards and cooperation as essential (King et al., 2023; Jansen et al., 2023). Collaboration, more specifically building an ecosystem through collaboration, was identified as the second category of critical success factors. Almost all interviewees strongly highlighted the importance of collaboration stating that change cannot be accomplished in isolation and the implementation requires active participation from all relevant stakeholders in the supply chain. Also, the literature undeniably emphasizes collaboration as a critical factor for building and optimizing processes, minimizing risks, and achieving data availability, authenticity, and

comparability (Stepke-Müller et al., 2023; Psarommatis & May 2024; Zhang & Seuring 2024).

The interviewees felt that companies currently have a relatively low willingness to invest in the development of digital product passports, while at the same time, such investments were seen as an absolute requirement for their successful implementation. The literature has not yet thoroughly investigated the level of willingness to invest in the DPP among companies, which diminishes the meaningfulness of making broad generalizations from this perception. Nonetheless, more than one interviewee agreed that careful planning of the digital product passport, and thus successful implementation, largely depends on management's decision to begin modernizing processes and ensuring technological readiness within supply chains. The specific role of top management has not been extensively studied in the context of digital product passports, but supply chain management literature has established that effective information sharing and building close collaboration require strong support and leadership from top management to achieve set goals and strong partnerships (Brun et al. 2020). From this perspective, previous literature supports the findings of this study. Especially, King et al. (2023) and Meda et al. (2023) stress the importance of initiatives to encourage the disclosure of information and committing to the set standards. Two interviewees stated that organizations and end users need to be motivated to utilize the DPP in a way that benefits the participants. Both previous literature and the empirical findings of this study suggest building innovative business models around the DPP as critical success factors regarding their implementation (King et al. 2023).

The findings of this study concerning the final identified success factors, clear regulation, and standards, are strongly in line with the existing literature. Researchers have clearly emphasized the benefits that companies can gain by actively participating in the development of regulations for the DPPs (Langley et al. 2023; Stepke-Müller et al. 2023). By doing so, companies can avoid standards that are unfavorable to their interests and business processes, as well as mitigate gaps in regulation (Stepke-Müller et al. 2023). The findings are fully aligned with the literature, as two interviewees strongly emphasized that companies have a real opportunity to influence the formation of regulations and even set standards for other stakeholders, in addition to the benefits they receive for themselves. Common standards and having a "unified language" also reduce ambiguities and complexities related to the digital product passport, which has been recognized as a

success factor in the literature as well (Suomi et al. 2024; Psarommatis & May 2024; Stepke-Müller et al. 2023). Interviewees also stressed that too many competing standards and calculation methods over-complexify the DPP concept and may lead to a disadvantaged position for companies with fewer resources, which could even result in a forced exit from the market. Panza et al. (2023) support this view by stating that involvement in the DPP should not cause excessive costs or technical challenges that could exclude smaller economic players in the market. The findings are supported also by other previous literature (Solita & Gaia Consulting 2022) and the importance of strong stakeholder support when the implementation enters into force is highlighted (Langley et al. 2023).

The findings indicate that without the necessary technology, multi-stakeholder collaboration, unified standards, and motivation or incentives towards adopting the concept, the DPPs cannot be successfully implemented from a practical perspective. However, the study also aimed to investigate how the DPPs are expected to affect supply chain transparency and promote the shift toward the circular economy. There remains ambiguity about how the design and execution of transparency improvements could catalyze beneficial and possibly transformative change (Gardner et al. 2019). According to Adisorn et al. (2021), if a DPP is implemented thoughtfully to enhance benefits for different types of stakeholders, while ideally reducing costs or required efforts, it holds strong potential to guide sustainable product policy toward greater circularity. On a practical level, however, it is challenging to define what a successful or thorough implementation means. The interviews revealed that merely adopting the digital passport is insufficient for promoting transparency and circular economy models; rather, the information contained within the digital passport and its utilization are considered crucial. Langley et al. (2023) share similar views, stating that simply disclosing information is not enough to embrace circular economy models, but leveraging the achieved transparency can lead to the adoption of various operational models and the attainment of set goals.

Once again, the interviews highlighted the need to motivate companies to act honestly, go beyond compliance, and create business value to achieve the digital passport's goals, ultimately achieving the shift to a circular economy. According to the interviews, a risk associated with the concept of DPPs is that the regulation may contain loopholes or companies may start to distort information to some extent, which would not support the objectives of the DPP, such as changing consumer behavior. This perspective has been

somewhat addressed in the literature but remains under-researched. An issue that emerged from only one interviewee, although has been emphasized extensively in the literature, is the extent to which data must be disclosed to customers to achieve transparency. For example, Stepke-Müller et al. (2023) raise concerns about the low granularity level of information disclosure weakening transparency and thus the possibility of attaining the DPP objectives. Adisorn et al. (2021) argue that the levels of detail of relevant data can vary greatly between different stakeholders, which may complicate decisions about what type of data companies should disclose openly to all stakeholders. The Supply Chain Data Expert highlighted the need to strike a balance between encouraging companies and building trust in the fact that transparency does not necessarily mean that all information must be shared with all stakeholders, while also preventing the situation where all information suddenly becomes business critical. Other interviewees did not raise this concern, which reduces the relevance of making general conclusions about the connections of the level of information disclosure to the previous literature.

7.1.2 Assessing the value of early preparation

Both the findings of this study and previous literature strongly emphasize the benefits of a proactive approach toward the design and implementation of digital product passports (e.g., Lövdahl et al. 2023; Stepke-Müller et al. 2023; Walden et al. 2021) The interviewees particularly highlighted the significant advantages of establishing a solid foundation for the DPPs and the importance of piloting, which enables the identification of the potential missing gaps in supply chains, especially related to data and system infrastructure. The DPP will affect almost all companies operating inside the EU market despite their ability to meet the set requirements (GS1 2023). As product data is most likely not automatically available from all parts of the supply chain, it is vital that companies start assessing their abilities proactively to mitigate risks and create competitive advantage (Stepke-Müller et al. 2023).

Proactivity can mitigate the resistance to change and lead to achieving more viable and effective processes in the future (Walden et al. 2021). The findings strongly support this view as creating a strong market position well in advance is highlighted and expected to ease the implementation process when the DPP requirements arise. Another finding that is in line with previous literature is the possibility of actively influencing the upcoming legislation. Organizations that openly engage in regulation shaping rather than merely

observing the development of upcoming requirements can reap the benefits of creating advantageous standards alongside market competitors who share the same needs (Langley et al. 2023; Stepke-Müller et al. 2023). Psarommatis & May (2024) also highlight that organizations should collaborate with policymakers to ensure that DPP implementation aligns with current and evolving standards, turning compliance into a direct incentive for DPP adoption. Two interviewees fully agreed with this view, emphasizing how critical early involvement in regulatory planning is for establishing clear and consistent frameworks around the digital product passport concept.

The financial aspect of early preparation for digital product passports has been largely overlooked in scientific literature, aside from mentions of reduced risks and the creation of competitive advantage (Adisorn et al. 2021; Psarommatis & May 2023). However, the findings of this study indicate, with one expert exception, that even though initial investments in developing the digital passport are significant, late adopters face considerably higher risks that are likely to incur greater costs later, particularly if the implementation of the digital passport is completed in great haste and without careful planning. This may lead to adopting systems with lower functionality or even result in considerable sanctions if requirements are not met.

Lastly, a finding that strongly aligns with existing literature is the impact of proactivity on a company's suppliers. If the requirements for producing and disclosing materials-related data for the digital product passport are causing an excess burden for smaller actors, there is a risk of being shut out of the market, which emphasizes the need to give support to suppliers in developing markets in terms of system implementation and utilization. (Langley et al. 2023; Panza et al. 2021). On interviewee, the Data Economy Specialist highlighted that organizations must engage suppliers early in the planning process of the DPP to avoid the potential loss of business for suppliers or the company itself. To conclude, the findings indicate that proactivity plays a key role in the overall ability to successfully implement the DPP at the time ESPR's practicalities enter into force, while simultaneously mitigating risks and creating a competitive advantage.

7.2   Limitations and future research suggestions

Digital product passports represent an emerging technological concept and remain, in many respects, a highly under-researched field. Numerous questions remain open regarding the general requirements of the DPPs and their practical implementation, as

outlined by multiple scholars (Adisorn et al. 2021; Langley et al. 2023; Psarommatis & May 2024; Walden et al. 2021). As a result, this study inherently contains a degree of uncertainty that can only be mitigated by acknowledging the key limitations of the study. As highlighted in relation to the research quality, the availability of empirical data is considerably limited due to the emerging nature of the DPPs. While the empirical findings align closely with previous literature, it is addressed that the amount of collected data may not reach an adequate saturation level to reliably serve as a base for future research. However, the consistency of the empirical results between the interviewees as well as the existing literature may, on the other hand, suggest that a sufficient level of saturation has been achieved, given the context and initial limitations of this study. A key observation that arises is that the topic has been significantly under-researched from a practical perspective, as evidenced by the highly similar levels of knowledge and understanding among multiple experts in such a complex research area.

It is evident that there is a pressing need for extensive further research on various aspects of the DPPs, all of which remain underexplored. Future research holds particularly valuable potential in researching the practical implementation of the DPPs across different-sized companies, particularly from the perspectives of data and system integration. Furthermore, investigating the upcoming requirements and standards, as well as their impacts within corporate contexts would add significant value to previous research. However, the most interesting direction for further study, specifically considering this research, is examining the appeal of the digital product passport for both companies and end-users. As noted, demand for the passport is currently largely driven by regulation, and companies have yet to face strong external incentives or market-driven demand for the DPPs' planning or adoption. Additional research is needed to examine the possibilities for shaping the DPP concept so that both companies and consumers are genuinely motivated to use it to improve transparency and thereby adopt circular business models. Ultimately, such a radical and transformative change to organizations' supply chains and value creation process requires building a concept that offers tangible benefits to companies and encourages its widespread adoption.

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Appendices

Interview frame

1. What is your area of responsibility in your work?

2. What led you to work with digital product passports, and what kind of work have you done related to DPPs?

3. What opportunities do you see in the digital product passport concept? What do you consider the key challenges or barriers?

4. How capable do you think companies currently are for implementing digital product passports?

    a. Do you see any differences in capabilities across different industries? If so, what are the reasons for these differences?

    b. What do you see as the main shortcomings and how could companies overcome them?

5. What factors do you consider essential for successfully implementing digital product passports (i.e. critical success factors)?

6. How do you anticipate digital product passports to impact supply chain transparency?

    a. How could the reliability of information be enhanced?

7. What benefits can early preparation for digital product passports bring to companies?

    a. What risks might a digital product passport pose if its practical implementation is poorly planned or delayed?

8. Do you have anything to add that we've not yet discussed?