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INGEGNERIA GESTIONALE**

BUSINESS STRATEGIES TO OVERCOME DRIVERS AND BARRIERS TO THE IMPLEMENTATION OF THE DIGITAL PRODUCT PASSPORT

Tesi di Laurea Magistrale in

SUSTAINABILITY TRANSITION MANAGEMENT

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The war in Ukraine is underlining that it is essential that we live within our means and find ways to be more geopolitically independent with our materials in Europe. A well-designed Digital Product Passport will be an invaluable policy and business tool in support of this goal, as it will enable businesses to create more sustainable and circular materials and products by monitoring how they are made throughout the supply chain. It will also support consumers to make well-informed choices based upon sustainability criteria. This could be game-changing in the effort to build a European circular economy.

Eliot Whittington

The EU fosters digitalisation and the transformation towards a climate-neutral, sustainable economy and describes this parallel process as the green and digital 'twin' transition. A Digital Product Passport (DPP) as envisaged in the EU's European Green Deal and Circular Economy Action Plan is a great opportunity to modernise product information throughout the entire value chain. DPPs could be a big step forward for more sustainable products and consumption, boosting energy and resource efficiency by enabling new business models based on e.g. digital data sharing. DPPs could also substantially contribute to an improved security of energy and material supply for a resilient economy.

Prof. Dr.-Ing. Manfred Fischedick

Abstract

Achieving a circular, climate-neutral economy is a key global sustainability goal, with the EU leading efforts through the Green Deal and Circular Economy Action Plan. The Digital Product Passport offers a solution to improve transparency, traceability and material reuse across product life cycles. This study examines factors promoting or hindering DPP adoption in the EU, proposing strategic recommendations to address barriers and leverage drivers for successful integration into organizational and regulatory frameworks.

A mixed-methods approach was used, combining the Delphi method with Total Interpretive Structural Modeling. This approach enabled both qualitative and quantitative analyses, with data collected through a structured questionnaire and nine expert interviews.

Key findings revealed regulatory pressures, digitalization, and circular economy support as critical drivers, while high costs, lack of skills, and data standardization issues pose significant barriers. The study mapped these interconnections, identifying strategic intervention points and recommending investments in digital infrastructure, training programs, and standardized data protocols for seamless DPP integration.

While the research enhances understanding of DPP implementation, its focus on the European context and reliance on a limited expert sample are noted as limitations. Future studies should expand to global and sectoral perspectives and explore broader structural dynamics.

This thesis highlights the DPP's transformative potential as a practical tool for fostering sustainability and resilience, representing a critical step in advancing global development goals and circular economy principles.

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Chapter One: Introduction

In the current economy and social scenario marked by environmental globalization and rising pressure on sustainable production systems, the philosophy of a circular economy issues a call to international policies. The European Union itself has invested in the change to a climate neutral economy by 2050 according to the Green Deal as well as the Circular Economy Action Plan. Within this framework, the Digital Product Passport (DPP) appear as a progressive and effective instrument which lays the groundwork for increasing transparency and circularity throughout the life cycle of products with a view to the reuse and recycling of materials and thus for reducing the negative effects on environment.

The DPP represents a concrete response to the need to overcome the limitations of the traditional linear economic model, based on extraction, production, and disposal. The DPP facilitates the acquisition and exchange of important product information, including chemical content, component origins, ecological footprint and disposal choices, through utilizing latest technologies like the blockchain and IoT systems. For these reasons, it becomes crucial for facilitating circular economy approaches and adhering to new regulations, like the Eco-Design for Sustainable Products Regulation (ESPR).

Despite its potential, the utilization of the DPP also has many difficulties attached to it. Among these, the lack of data standardization, high digitalization costs and insufficient technical and managerial skills represent significant obstacles for businesses, especially small and medium-sized enterprises. In addition, the process of adopting such measures involves the efficient management of the different sets of players specifically the regulators, the companies and consumers.

The overall objective of this thesis is to understand the drivers and barriers to the uptake of Digital Product Passport with a focus to the European context. Through a combination of qualitative and quantitative methods, such as the Delphi method and Total Interpretive Structural Modelling (TISM), the research aims to:

1. Identify and validate the main drivers and barriers of the DPP.
2. Find out the relationship between these factors and their influence in the uptake of the DPP.
3. Offer strategic recommendations for businesses and policymakers to facilitate the utilization and implementation of the DPP into corporate processes.

The structure of the thesis is as follows: Chapter Two explores the background of the circular economy model, its underlying concepts, potential advantages and relevance in the current socio-economic context. It also examines the history of the Digital Product Passport, establishing it as a key

enabler for transparency and sustainability, and synthesizes prior studies on drivers and barriers to DPP implementation, forming the basis for the analytical framework. Chapter Three describes the mixed-method research design employed in the study, detailing the rationale for using the Delphi method to gather expert opinions and the Total Interpretive Structural Modelling (TISM) approach for analysing the relationships between drivers and barriers. It provides a thorough explanation of the participant selection process, data collection tools and analytical techniques to ensure transparency and replicability. Chapter Four presents the findings, summarizing the key drivers and barriers identified through expert input and their importance. It further analyses the interconnections between these factors using TISM, revealing hierarchical relationships and systemic dynamics, and interprets the results to provide actionable insights for businesses and policymakers while highlighting opportunities and challenges in DPP adoption. Chapter Five revisits the thesis topic, emphasizing its significance and providing a concise summary of the findings. It evaluates the importance of the research, discusses its limitations, and offers suggestions for future studies, ensuring a comprehensive conclusion.

This thesis aims to contribute to the academic and practical debate on the implementation of the DPP, offering a systematic perspective and addressing the main challenges associated with this innovative tool.

Chapter Two: Literature Review

2.1 Circular Economy

The circular economy is defined as a model of designing products and processes to indefinitely use goods and resources rather than disposal. This approach increases the useful life of products and reduces the amount of waste. In practice, it means minimising the generation of waste products to as low as is practically possible. Products are used up and their material aspect returned to the economy to be used again and again producing sustained value. This model may be seen as opposite to the conventional Linear Economy in its "take-make-consume-dispose" model. Linear approach is highly reliant of cheap, available, energy, and in, and most often included a planned obsolescence where the designed products have limited use which makes the customer to purchase the same in the future. There are appropriate legislative proposals for protecting consumers from such risks which the European Parliament has recommended.[1]

Why do we need to transition to a Circular Economy?

Protecting the environment

The circular economy slows the depletion of natural resources by promoting the reuse and recycling of products, which helps reduce habitat destruction and biodiversity loss. It also contributes to lowering annual greenhouse gas emissions. Designing more efficient and sustainable products from the outset reduces energy and resource consumption, as over 80% of a product's environmental impact is determined during the design phase.

For example, packaging waste is a growing concern, with the average European generating around 190 kilograms of packaging waste annually. Addressing excessive packaging and improving its design to encourage reuse and recycling are key goals of the circular model.

Reducing dependency on raw materials

With people population increasing every day the, the demand for raw materials also increases but the supplies are limited. As of importing nations, 90% of EU's total demand is imported and, with an estimated imports of 14,925 thousand tonnes of raw material per head per 2022, each European imports 14.9 tonnes. As mentioned above, the EU remains a net importer of raw materials and in 2023 a raw materials trade deficit of €29 billion was reported. Recycling reduces the dangers that raw materials are probably to encompass, for instance, unpredictability of prices, and shortages. This is

[1] European Parliament. (2023, May 24). *Circular economy: Definition, importance and benefits*. https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits

particularly important for critical raw materials that are utilised in technologies that are considered critical to climate objectives such as batteries and electric engines.

Creating jobs and saving money for consumers

Implementation of circular economy has the potential of boosting the competitiveness of firms and industries, encouraging innovation, acting as stimulus for economic growth, and can create employment – with European Union numbers exceeding 700,000 by the year 2030. Circularly reinstating materials and products to support multiple uses will set the pace for innovation in many industries. Consumers themselves will be benefited by getting more long-lasting, higher quality products, and as a result will have better quality of life, and spend less in the long term.

What is the EU doing to build a Circular Economy?

The European Union aims to establish a circular and climate-neutral economy by 2050. To achieve this, it has introduced numerous measures to reduce waste and promote sustainability.

- *Eco-design*: encouraging the development of products designed for longevity and recyclability.
- *Packaging:* reducing waste and improving reuse and recycling efforts.
- *Greenwashing:* tackling misleading claims about environmental benefits.
- *Right to Repair:* ensuring consumers can repair products instead of replacing them.
- *Waste Management*: implementing improved systems to reduce and manage waste efficiently.

These efforts represent a comprehensive strategy to shift toward a more sustainable and circular future.

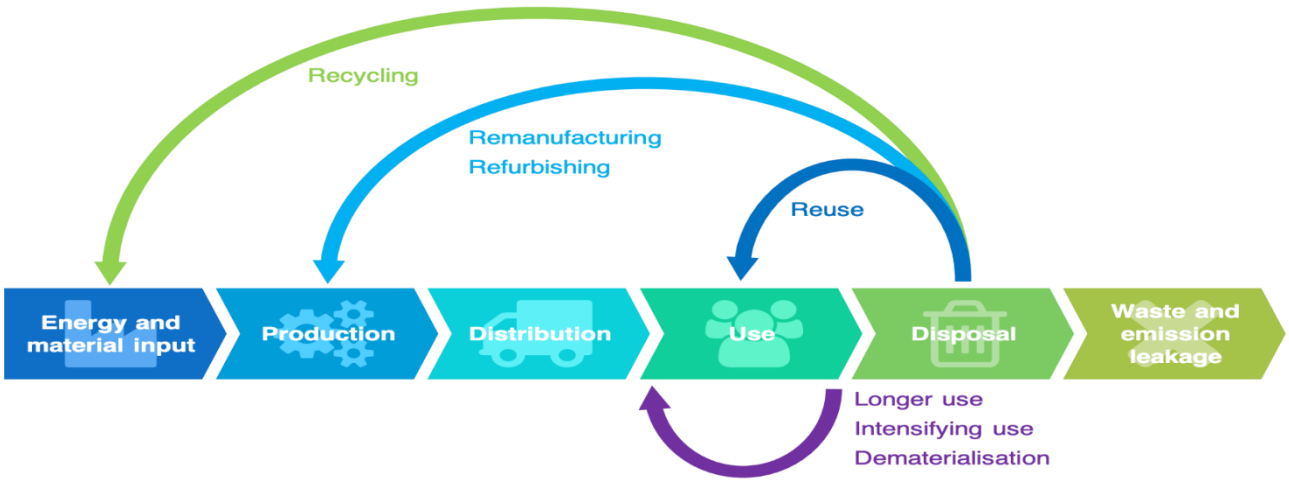


Figure 1 - An illustration of the circular economy concept (Wikipedia, 2023)

2.2 The Digital age, Industry 4.0 and the Digital Product Passport

2.2.1 The Digital Age and Industry 4.0

The Digital Age and the Fourth Industrial Revolution named Industry 4.0 are already changing the very nature of doing business and building economies. These changes are being facilitated to some extent by digital transformation and the incorporation of, for example, artificial intelligence or the Internet of Things, big data, robots or automation. Technological changes are enhancing effectiveness, output and adaptability across various industries and transforming business models and supply chain systems around the world.

Industry 4.0 refers to technology-driven strategic product and service differentiation concept characterized by interconnected smart production systems in which production systems, machines, plants as well as people are almost integrated in a manner that they work in real time data. They enable more accurate product customization, improved response times as well as efficient resource management, making production more flexible and adaptive process. The change that has most affected this sector is the advent of information communication technologies especially by enhancing the management of the logistic operations. In this light, the Digital Product Passport (DPP) appears as an essential instrument to stand for transparency and traceability within the supply chain. In case of DPP, firms have an opportunity to collect and exchange comprehensive data relating to material and product provenance, which improves responsibility and is environmentally friendly.

Modern logistics increasingly relies on connectivity and automation, enabling real-time monitoring and optimization of goods and information flows. This ability to track and manage operations more accurately is becoming essential in a highly competitive, globalized economic context. The DPP, integrated with advanced digital tools, supports these practices by offering immediate access to product lifecycle data and facilitating strategic decision-making based on reliable information.

Overall, Industry 4.0 represents a transformative shift that is revolutionizing not only production and logistics but also services, agriculture, and many other sectors. Companies that embrace these new technologies, including the DPP, can benefit from significant competitive advantages such as enhanced operational efficiency, improved product quality, and reduced operating costs. Additionally, adopting the DPP helps ensure compliance with emerging sustainability regulations, making companies more resilient and responsible.[2]

[2] McKinsey & Company. *What are Industry 4.0, the Fourth Industrial Revolution and 4IR?* December 13, 2024, from https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-are-industry-4-0-the-fourth-industrial-revolution-and-4ir

This landscape of innovation and transformation is set to expand even further, opening new possibilities for the future of the digital economy and for an increasingly connected and automated society. The integration of tools like the DPP not only represents a step forward in digitalization but also constitutes a key element in promoting sustainable and responsible business practices.

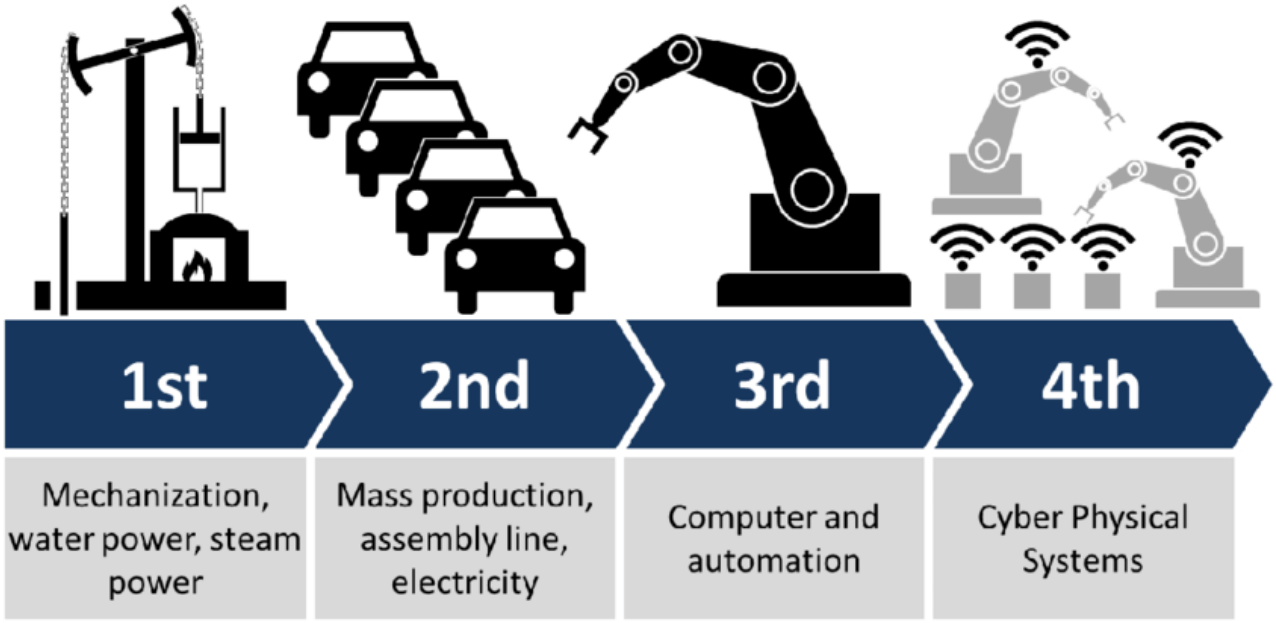


Figure 2 - Industry 4.0 builds on past revolutions: steam power, electricity and computerized automation. (Wikipedia, 2023)

The Fourth Industrial Revolution and the Drive for Digitalization

Without doubt, among the most obvious and perceptible manifestations of the Fourth Industrial Revolution was the growing digitalization of practically all process occurring in production. Robotic technologies allow controlling the process of generating data and advancing production and resource usage across industries in ways that previously were only in dreams. The concept of the "smart factory" exemplifies this shift: disconnected and independent elements of production systems work in coordination, resolve challenges, and optimize processes without the need for further human interference. But digitization is not only restricted to manufacturing industries only. These changes are also being experienced by urban management. Owing to the increased pace of urbanization, the effective management of urban resources is highly important such as energy, water, mobility, and security. IoT technologies are being adopted by cities in order to drive efficient consumption and stem negative impacts on the inhabitants of the cities. For instance, these technologies allow better control of traffic and wastes, thus making cities sustainable. Technology also greatly influences other areas of operation such as consumer relations within organizations. In particular, Big data analytics help to determine customers' needs, which ultimately leads to attaining greater success in providing tailored solutions. This results into high competition and faster response to the market dynamics. Industry 4.0

therefore modernises companies' working models and helps to invent new ways to deliver value to customers, about which can be referred to such trends as the sharing or on-demand economy.

The role of the Digital Product Passport in Industry 4.0

In view of such cultural change through digital opportunity, one of the pivotal instruments is the so-called Digital Product Passport (DPP). Technological and performance data on all aspects of product life cycle are tracked and deposited in this unit by the DPP. By linking with other supply chain tracking systems, the DPP offers full visibility over the product's provenance and properties and thus makes operations more transparent and contributes to the creation of a responsible supply chain. However, one of the closely related aspects of the DPP is to enhance the cooperation of the companies in the supply chain. Another advantage of the DPP is the promotion of transparency in providing accurate and verified information of materials and production processes of the various actors that would otherwise lead to uncertainties in resource use. For example, a supply chain using the DPP can easily identify suppliers that meet sustainability criteria and establish business relationships based on shared values. Additionally, thanks to the detailed traceability provided by the DPP, companies can optimize end-of-life product management, facilitating recycling and material reuse.

The DPP is not just a data collection system but a catalyst for corporate sustainability. Access to detailed information allows companies to monitor the environmental impact of their products and adopt measures to reduce emissions and the use of non-renewable resources. For instance, with the DPP, companies can calculate the carbon footprint associated with each product and implement corrective actions to improve the energy efficiency of production processes. This type of analysis also helps companies comply with European sustainability regulations, such as the Green Deal and the Circular Economy Action Plan, which require responsible resource management and emission reduction.[3]

The DPP's role becomes even more strategic in a context of globalization and interconnected economies, where supply chains often span multiple continents. The DPP's ability to track products in detail and retain accessible, verifiable information is crucial for ensuring the quality and safety of goods circulating internationally. For example, in sectors such as electronics or textiles, characterized by a high supply chain complexity, the DPP can help ensure that products meet the quality and sustainability standards required by different markets.

Last but not the least DPP has been integrated with Industry 4.0 technologies like blockchain & decentralized identifiers (DID thus preserving the information security & efficiency. If applied to

[3] IDTA (International Digital Twin Association). *Digital Product Passport 4.0*. December 13, 2024, from https://dpp40.eu/

supply chains, blockchain permits creating tamper-proof certificate chains in which product information can be checked and exchanged among supply chain parties. Besides decreasing the potential for manipulation and fraud, this system also guarantees data a data integrity over time. Thanks to these features, the DPP proves that it is a tool without which it is impossible to guarantee sustainability, transparency, and competitiveness for companies operating in the Industry 4.0 environment.

Challenges and Opportunities of Digitalization

The Fourth Industrial Revolution and the advancement of technology have enriched a range of opportunities that radically changed resource logistics, manufacturing processes technology-based interactions between companies and suppliers and consumers. However, this transformation has been found to pose challenges that need to be met to enhance the efficiency and sustainability of innovations adoption. The increasing use of digital technologies poses a number of concrete questions: cybersecurity, privacy, and exclusion for the least equipped countries and companies.

One of the primary challenges is cybersecurity. As digitalization progresses, an increasing amount of data is shared and interconnected, raising the risk of cyberattacks that could compromise not only corporate information but also the security of national infrastructure and the integrity of critical systems. For this reason, organizations must invest in advanced security measures, such as the use of blockchain and decentralized identifiers (DIDs) in the DPP, to ensure data protection across the entire supply chain. Although these technologies offer reliable tracking and verification solutions, they still require significant resources and specialized skills, accessible only to companies with a certain investment capacity.[4]

The rapid adoption of digital technologies risks widening the digital divide, both among countries and companies. While advanced economies can quickly integrate Industry 4.0, countries and companies with limited resources risk falling behind. This digital divide can create a situation of exclusion, limiting access to the benefits of digitalization and hindering the active participation of many organizations in global value chains. Digitalisation is a capital-intensive process that demands investment in infrastructure, people and ideas – still more pressures on governments and companies worldwide. If there isn't sufficient collective will to address these disparities, the Fourth Industrial Revolution might actually increase such divides, and not advance equitable development. Nevertheless, the promotion of digitalization and implementation of the DPP possesses more benefits than risks. Industry 4.0 technologies opens up opportunities for generation of new form of values

[4] International Labour Organization. (2024). *Challenges and opportunities of digitalization [PDF document].* From https://www.ilo.org/meetings-and-events/challenges-and-opportunities-digitalization

adding efficiency to operations and calling for managerial efficiency in the use of resources. With tools such as the DPP, there are enhanced methods to track the performance of products on the environment and have efficiencies in the supply chain to support circular economy business concepts. The ability to trace a product's lifecycle in detail enables companies to make strategic decisions based on accurate data, thus promoting concrete operational sustainability.

Looking to the future, the DPP represents a milestone in digitalization, offering both economic and social benefits. Digitalizing production and urban processes, along with adopting the DPP, can help reduce resource waste, break down geographical barriers, and create new economic models based on connectivity, automation, and global collaboration. Altogether, while acknowledging that the risks of digitalisation are rather presented and are essential for concern, the benefits arising from the implementation of the DPP as a means of improving the traceability/transparency ratio issues a challenge to companies. Hence, to invest in this tool, even in the light of the challenges that this effort entails, is to undertake much more than a simple rationalization of production and the improvement of competitiveness; it is to work for a less vulnerable, more viable type of economy. Those organizations that will be able to capture these opportunities and manage barriers of digitalization will operate in the area of one of the great shifts in modern history and will be among leaders of the forthcoming digital and circular economy.

2.2.2 The Digital Product Passport (DPP)[5]

The Digital Product Passport is a key and unique element in the EU sustainable agenda to progress to a circular climate-neutral economy. That is why it is planned as part of the Circular Economy Action Plan (CEAP) and the European Green Deal, the DPP approach is to shift from the linear economy model ‘extract, produce, consume, dispose’ to one that is circular, in which every product is conceived with minimal environmental footprint and when at end of its usage, is designed with the intent to recover every molecule of material used in its making .

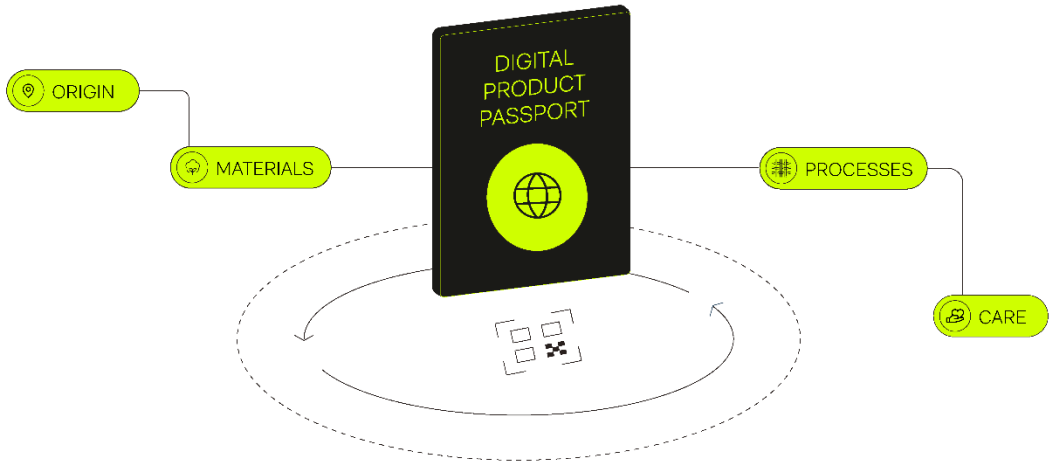
The CEAP highlights that global consumption of materials such as biomass, fossil fuels, metals, and minerals is expected to double over the next 40 years, while annual waste generation is projected to increase by 70% by 2050. It is estimated that up to 80% of a product’s environmental impact is determined at the design stage, as the traditional linear model does not provide sufficient incentives for producers to make their products more circular. The DPP, therefore, aims to bridge this gap by enabling the collection and sharing of specific data throughout a product’s entire lifecycle, supporting monitoring and optimization of its sustainability.

[5] *Digital Product Passports: A Complete Guide*. (2024, Agosto 23). https://root sustainability.com/blogs/digital-product-passport/

To support this, the use of technologies like blockchain, decentralized identifiers (DIDs) and verifiable credentials (VCs) can be incorporated into the DPP architecture to facilitate the traceability, authenticity, interoperability of the product data, thus making this information available across the end user including companies, authorities and consumers in the supply system. In this way the DPP fosters European efforts towards lower greenhouse gas emissions and towards the promotion of circular materials and products that will lead to improved resource management.

The DPP is implemented through the Eco-design for Sustainable Products Regulation (ESPR), which came into effect in July 2024. This regulation establishes guidelines and requirements for sustainable product design, focusing on aspects such as durability, reusability, and resource efficiency. In the future, the DPP will become mandatory for most products sold within the European Union, ensuring transparency and access to information on materials, environmental impact, and disposal or recycling methods. Additionally, the DPP will be adaptable across various sectors, such as textiles, construction, and electronics, addressing the specific needs of each industry segment and facilitating the monitoring of companies' "green claims."

Figure 3 - The Digital Product Passport



Later, DPPs are thus expected to become crucial enablers of new notions of product stewardship through the exchange of information on sustainability performance attributes such as carbon or recyclability across the value chain. In a broader sense, DPPs might be helpful in supporting the circular economy and carbon minimization plans, for new areas and alternatives for functioning, and also reporting on social responsibility. The European Commission will likely establish a generic DPP design applicable to most materials and products, complemented by sector-specific adjustments to align with the core elements of different product groups. The DPP must also be interoperable with

other systems, as products and materials may pass through various industries and applications over their lifecycle.

Why are Digital Product Passports important?

Digital Product Passports are an important instrument in the worldwide fight against waste and shift to circular economy. Currently, an estimated two billion tons of waste is produced every year, with most products thrown away and likely to end up in a landfill or burnt, thus the need to consider how best to design, consume, and dispose of products. Some companies have developed a circular economy approach however, without detailed information on the life cycle of each product and the supply lines, it is daunting. This is where the concept of the Digital Product Pass comes in handy; it provides useful background data on a particular product combined with ecological impact information. They are therefore indispensable for effecting the required change in direction toward the circular economy.

Digital Product Passports play a central role in the EU's Circular Economy Action Plan (CEAP), which aims to guide Europe's shift towards circularity. Under this plan, companies must provide detailed data on their products' sustainability, and Digital Product Passports serve as a critical tool for collecting and sharing this information. For businesses, these passports are essential to comply with both current and emerging regulations, a topic we'll explore further in this discussion.

However, implementing Digital Product Passports is more insightful than just providing an ability to show compliance with regulations. The contemporary customer is becoming more and more aware of the brand's sustainability practices. In other words, by providing verifiable information backed by Digital Product Passports, companies avoid greenwashing while putting more trust in consumer relationships.

What is the Digital Product Passport?

Digital Product Passports capture three key types of information: product journey, composition, and environmental impact. These elements combined, offer insights into the life cycle of a particular product on the market. The data collected is available to anyone in the supply chain and they can see all that has been done to the product before it gets to them.

The core components of a Digital Product Passport typically include:

- Basic Product Information: Core details like product name, batch, model, and unique identifiers (e.g., barcodes or QR codes).

- Material Information: Information on the quantity, origin, and properties of materials used, including sources of raw materials and suppliers.
- Environmental Sustainability Data: Metrics on resource use, energy consumption, and carbon emissions at each stage of the product lifecycle.
- Substances of Concern (SoC): Information on any hazardous or restricted materials present in the product.
- Use Data: Insights on how the product is used, maintained, and repaired over its lifecycle.
- End-of-Life Information: Guidance on how the product can be reused, recycled, or disposed of in a sustainable way.

To ensure accessibility, each product's unique identifier, such as a QR code, should be visibly present on the product, packaging, or documentation. The data itself must be structured, machine-readable, and searchable. Blockchain technology is often used to meet these requirements, as it ensures the data is transparent, secure, and tamper-proof.

EU Regulations on Digital Product Passports

In recent years, sustainability has become a priority for businesses due to new regulations that mandate environmentally conscious practices. Europe is leading this shift through its Circular Economy Action Plan, which encourages companies to implement Digital Product Passports to enhance product transparency and sustainability.

The Eco-design for Sustainable Products Regulation (ESPR) strongly forms this regulatory framework. Therefore, unlike other directives which only recommend the issue of Digital Product Passports, the ESPR requires that they are issued for compliance, which makes them critical for businesses involving regulated products. By providing this structured data, companies can not only meet regulatory demands but also position themselves as responsible, future-ready brands.

Here's a summary of the main EU regulations fuelling the adoption of Digital Product Passports:

Table 1 - Key European Regulations Supporting the Digital Product Passport (DPP

Regulation Name	Implementation Timeline	Description
Circular Economy Action Plan (CEAP)	In effect	Drives Europe's transition to a circular economy by implementing various regulations. Digital Product Passports are essential for achieving CEAP's circularity goals.
Eco-design for Sustainable Products Regulation (ESPR)	Phased implementation, starting in 2026	Aims to make products more durable, energy-efficient, reusable, and recyclable. Digital Product Passports are required to meet these regulatory standards.
New EU Battery Regulation	Implementation starting in 2026	Focuses on enhancing the sustainability, safety, and recyclability of batteries. Digital Product Passports will provide lifecycle data necessary for compliance.
EU Strategy for Sustainable and Circular Textiles	In effect	Targets improved circularity in textiles across clothing, construction, and automotive industries. Digital Product Passports will support meeting required reporting standards.
Construction Products Regulation	To be confirmed	Aims to ensure construction materials meet circularity and safety criteria, with Digital Product Passports central to meeting circular economy objectives.
Corporate Sustainability Reporting Directive	Phased implementation, starting in 2025	Expands corporate sustainability reporting obligations. Digital Product Passports will help companies supply verified data for compliance with these enhanced standards.

These regulations collectively create a strong demand for Digital Product Passports, as they enable transparency and accountability across various industries, helping businesses meet sustainability and circularity objectives.

DPPs and Eco-design for Sustainable Products Regulation (ESPR)

The Eco-design for Sustainable Products Regulation (ESPR) is an important shift for Europe to circular economy from its previous Eco-design Directive, but with broadened application from energy-only saving specifications. It enforces rules which remit that a product should be made keeping in mind the four Rs, namely, reduce, reuse, repair and recycle. The goal is to design products inherently more circular and more sustainably designed, manufactured and marketed and it seeks to transform products across the continent.

A crucial aspect of ESPR is the mandatory Digital Product Passport. These passports are essential for tracking, collecting, and reporting detailed environmental data across a product's entire life cycle, from production to disposal. Without them, businesses will face significant challenges in meeting ESPR's eco-design requirements. Digital Product Passports not only provide the structured data needed for compliance but also support transparency and accountability in the product's environmental footprint.

Due to their environmental impact and high potential for circularity, ESPR initially focuses on the batteries, textiles, and electronics sectors. By 2026, businesses in these industries must implement Digital Product Passports. Following this, sectors such as construction, packaging, furniture, chemicals, and telecommunications will be phased in, with ESPR eventually covering up to 30 product categories.

For companies in these priority sectors, the need to act is immediate. Implementing systems to gather and manage product data, aligning internal processes with ESPR requirements, and ensuring traceability through Digital Product Passports are critical steps. Early preparation is also vital for businesses in industries that will come under ESPR regulations post-2026, allowing them to adapt smoothly when Digital Product Passports become mandatory.

Overall, ESPR and Digital Product Passports represent a strategic push toward sustainable product design in Europe, making it essential for businesses to integrate these requirements into their operational and product development strategies to remain compliant and competitive.

How will Digital Product Passports affect different industries?

As mentioned, the ESPR regulation's initial focus sectors are batteries, textiles, and electronics. Therefore, these are the first industries that will need to create Digital Product Passports. Let's explore how Digital Product Passports will drive sustainability in these industries.

Fashion: an astounding 92 million tonnes of textile waste is generated each year, and it's only expected to grow. The fashion sector is a significant contributor to textile waste. As the sector wakes up to the role it plays in harm to the environment and issues such as greenwashing and obscurity in supply chains Digital Product Passports shall be of significant value. The Digital Product Passports will provide indispensable material-specific and technology-specific product life cycle data needed to meet the requirements of the EU Strategy for Sustainable and Circular Textiles, ESPR regulation as well as speed up efforts to minimize the environmental impacts of textiles.

Batteries: they are essential to the EU's transition to electric cars and clean energy, face significant environmental challenges throughout their life cycle. With the battery market expected to grow rapidly, reducing their impact becomes more pressing. Digital Product Passports will be essential for companies to meet the new EU Battery Regulation and ESPR requirements. Further, materials generated from these passports will process circularity interventions such as the EU Battery Regulation seeking to provide new lives for electric vehicles' batteries like energy storage.

Electronics: the E-waste, the fastest-growing waste stream worldwide, remains a significant challenge. The regulation ESPR requires Digital Product Passports in electronics in order to increase the transparency of how electronic products are built for easy repair and recycling. The utilization of these Digital Product Passports will increase transparency, drastically decrease e-waste, and lengthen the useful lifespan of electronics.

Benefits of Digital Product Passports

Digital Product Passports are the ultimate source of truth, providing accurate, transparent data about every stage of your product's life.

This level of transparency unlocks a range of benefits for your business, including:

- Data-Driven Strategies**:** be expected to supply comprehensive information on materials and processes of the environment for stages of a product life-cycle. This helps the companies to strategic solutions in the impact assessment and measurement for environmental effects.
- Unlock Circularity Potential: offer basic circularity data such as end-of-life information that will allow companies to upscale circular business models. These data reduce the amount of

waste and thus help to design better products in a way that user, reuse, recycling or even the lifetime of the product should be enhanced.

- Optimized Supply Chains: the DPP with information technology and analytics provide the subject organizations with timely information regarding supply chain processes by increasing efficiency and decreasing the negative impact of the environment on supply chain systems.
- Regulatory Compliance**:** offer the data needed to comply with current and upcoming regulations, helping businesses stay ahead and avoid potential penalties, thereby future proofing the company.
- Market Differentiation**:** early adopters can leverage Digital Product Passports to demonstrate their commitment to sustainability, setting their brand apart in the market. With 46% of consumers seeking transparency around product sourcing, Digital Product Passports can help verify genuine sustainability efforts, fostering trust and customer loyalty.

However, Digital Product Passports aren't just a win for businesses, they're a game-changer for consumers too:

- Consumer Empowerment: provide consumers with clear, verified information about a product's environmental impact, enabling them to make informed choices and support brands that genuinely prioritize sustainability.
- Verification of Green Claims: empower consumers to assess and verify a brand's sustainability claims, reducing the risk of greenwashing. By providing transparent data, these passports build consumer trust, making it easier for customers to choose products that align with their values.

Figure 4 - Benefits of DPP

Challenges of Digital Product Passports

The adoption of Digital Product Passports (DPPs) brings numerous benefits for sustainability and transparency, but it also faces a range of challenges that can slow down their implementation. One of the biggest concerns for many firms implementing a green supply chain program is the availability and processing of data at and across various stages of the supply chain, particularly when dealing with cross- border suppliers. The complexity of obtaining detailed information on materials and components from multiple sources makes the process costly and complicated.

Moreover, the lack of interoperability and international standardization hinders the scalability of DPPs, as the absence of shared standards requires significant investments to ensure compatibility between systems across various sectors. Without a global effort toward standardization, companies may encounter difficulties in managing and interpreting data, necessitating international collaboration to define common formats.

Another significant obstacle is the high cost of digitalization and adaptation. Implementing DPPs requires investments in advanced digital technologies, such as blockchain and traceability systems, with high costs for software, hardware, and human resources. These expenses can be prohibitive, especially for small and medium-sized enterprises, slowing the widespread adoption of DPPs.

The lack of technical and managerial skills within companies is another barrier. The absence of specific expertise in data management and digital technologies hinders DPP adoption and presents a challenge for the effective handling of information and the supply chain. Consequently, companies must invest in training and skills development to fully leverage the potential of DPPs.

Extended implementation times and organizational challenges, especially for companies with complex and global supply chains, present additional difficulties. Internal coordination and the need to align all departments require substantial effort and may delay DPP adoption, necessitating investments in training and changes in operational processes.

Finally, internal resistance to change hinders the adoption of DPPs. As it has long been stated, companies often do not want to reveal certain information about their products because they are afraid of putting important information out on the open or because it may be difficult to adopt a new culture of transparency within their organization. This resistance limits progress toward a more sustainable and transparent business model, reducing the potential benefits of DPPs.

These challenges demonstrate the importance of collaborative efforts among businesses, governments, and industry organizations to overcome these barriers and make Digital Product Passports an effective tool for promoting sustainability.

Where to start: Key Steps and Essential Technologies

To begin implementing Digital Product Passports (DPPs), companies should follow a structured approach that encompasses several key steps and leverages cutting-edge technology.

First, map out the data required, creating a framework that includes product origin, materials, environmental impact, and end-of-life data. This mapping process will clarify the essential information that each Digital Product Passport must contain.

Collaboration across the value chain is also crucial; companies should work closely with suppliers, manufacturers, and logistics partners to ensure consistent, accurate data collection throughout the supply chain. Each stakeholder needs to understand their role and the specific data they must provide to support the DPP.

Embracing appropriate technology is another fundamental step. Implementing data carrier technology, like QR codes, allows companies to attach unique identifiers to each product, linking it to its respective passport. Investing in a digital infrastructure that supports real-time updates, secure data sharing, and standardized data collection is equally essential. Also, testing the DPP system through small-scale pilots can help companies refine their approach before scaling across product lines and supply chains.

Technology has a great value, when it comes to the trustworthiness and protection of the Digital Product Passports. Blockchain for instance can establish an unforgeable record of processing phases of a product right from pent-up raw materials to the final disposal of the product guaranteeing transparency through the block chain data management system in each phase of the life cycle of the product. New technologies of the carriers of information such as higher forms of QR code and NFC tags also facilitate the means of obtaining and updating product information. With such technological advancements in the market, companies can be in a better position to avoid regulatory norms, provide accurate, and robust Digital Product Passports to fit the ever-increasing market demands towards transparency and sustainability.

2.3 DPPs for the Circular Economy[6]

The DPP is designed to shift production and consumption models from the traditional linear approach of "take, make, use, dispose" to a circular system, where resources are managed, reused, and recycled sustainably. The role of the DPP goes beyond simple data sharing; it represents a mechanism to promote transparency and accountability, making the environmental footprint of products visible and measurable. This digital system supports compliance with sustainability standards and facilitates efficient resource recovery, thus helping to reduce waste and greenhouse gas emissions.

The EU's vision for the DPP encompasses broad applicability, with specific adaptations for sectors such as textiles, electronics, and construction. By standardizing sustainability-related information and making it universally accessible, the DPP can stimulate demand for eco-friendly materials, promoting decarbonization within EU industries and reducing dependence on primary raw materials. The DPP represents a crucial step toward a more circular and climate-neutral economy, balancing economic growth with environmental protection.

Improved circularity and CO2 reporting through DPP

In the context of the Digital Product Passport (DPP), advanced circular economy strategies, such as the refurbishment of complex products or high-quality material recycling, rely heavily on the availability of reliable and up-to-date data. Creating a digital information system for the circular economy is therefore a critical step that will enable providers to gain the best results for resources available. DPPs can become the primary data carrier for a product or material, encompassing both essential data (such as product information, manufacturer, composition, substances of concern, toxicity, and sourcing) and new data related to use, modifications, maintenance, and wear. Through this form of digital data management, DPPs could enable near real-time monitoring of the environmental impacts of a product.

Given the high information requirements for a circular economy, DPPs represent a potential central source of data and information. The exchange of data on materials and products among various stakeholders will be essential to scale up DPPs, facilitating better analysis and understanding of product life cycles, and establishing the necessary level of transparency for circular economy strategies. Additionally, data analysis from DPPs could provide valuable insights for stakeholders and policymakers alike, enabling the establishment of measurable, science-based targets.

[6] University of Cambridge Institute for Sustainability Leadership (CISL) & Wuppertal Institute. (2022). *Digital Product Passport: The ticket to achieving a climate neutral and circular European economy?* CLG Europe. Retrieved from https://www.corporateleadersgroup.com/files/cisl_digital_products_passport_report_v6.pdf

For policymakers and public administrators, DPPs could support the implementation of demand-oriented policies for sustainable materials and products, creating a level playing field for the transition to a circular and climate-neutral economy. DPPs could also improve policy evaluation by allowing policymakers to better understand the implications of new or revised sustainable development policies. Finally, DPPs could enhance market surveillance, improving the monitoring and enforcement of compliance for domestically produced and imported goods in Europe.

By enhancing data exchange on product materials and lifecycle information, DPPs not only support circular economy strategies but also unlock new insights that benefit other sectors. This cross-sectoral application of DPPs helps industries streamline resource usage and optimize environmental outcomes, paving the way for sector-specific decarbonization efforts

DPPs, therefore, represent not only an opportunity to increase sectoral sustainability but also a means to promote innovation and resilience across value chains, laying the foundation for a more circular and climate-neutral European economy.

2.3.1 DPPs as an enabler for Circular Economy strategies and beyond

Digital Product Passports (DPP) have the potential to inform manufacturers about the nature and qualities of secondary materials, including details on purity, substances of concern, additives, fillers, and dyes. Clear and reliable information is crucial, particularly when recycled materials need to meet the same performance and safety standards as primary materials. DPPs could support various circular economy strategies by facilitating:

- *Repair and predictive maintenance*: Providing data that enables timely repair and maintenance recommendations.
- *Reuse*: Assessing a product's residual value and other properties, including expected number of rotations, distance travelled, and remaining lifespan.
- *Refurbishment*: Offering insights into product usage, wear, repairability, and identification of spare parts.
- *Remanufacturing*: Determining which components of discarded products are reusable and in what applications.
- *Recycling and material recovery*: Supplying information on product composition, additives, and substances of concern.

- *Environmentally responsible disposal*: Supporting safe and eco-friendly disposal methods for residual waste.
- *Reduction of environmental impacts*: Promoting the use of renewable or recycled materials and enhancing energy and resource efficiency.

The anticipated ability of DPPs to improve transparency and knowledge about product content, attributes, and use will deepen our understanding of the circular economy. DPPs, therefore, not only enable a range of circular economy strategies but also provide insights into the overall status of circular economy practices, which is especially valuable for reuse and refurbishment initiatives. Currently, Europe monitors and reports only recycling rates, primarily through Eurostat, yet broader monitoring through DPPs could lead to more effective circularity policies.

Furthermore, information stored in DPPs could integrate data beyond circular economy strategies in the long term, once transparency about basic components is established. For sector-specific policies, DPPs could include information on greenhouse gas (GHG) emissions, which could support additional measures to promote industry-wide climate neutrality. For instance, data from DPPs could inform carbon border adjustment mechanisms or adherence to chain of custody certificates and supply chain regulations.

It's important to note that DPPs are not an ecolabel or a sustainability claim; rather, they provide foundational information that can substantiate ecolabels and sustainability claims. As currently envisioned, DPPs would target consumers as a key audience, offering a tool for more informed purchasing decisions geared toward sustainability. Consumers might also benefit from repairability information, empowering them to repair broken or malfunctioning products.

Business-Level Decarbonization and the long-term benefits of DPPs

Digital Product Passport (DPP) systems present numerous long-term advantages for businesses, forming a unified foundation for data collection, storage, processing, and application along complex value chains. Enhanced insights from DPPs can optimize product and process management, promoting circularity through improved material sourcing, durability, material efficiency, and recyclability. Furthermore, DPPs can support fully automated predictive and prescriptive strategies for resource efficiency.

Adopting circular business models through DPPs can also lead to higher product quality, durability, and recyclability, enabling innovative product-as-a-service models. Cross-sectoral value chains,

supported by DPPs, can create new market opportunities by clarifying the quality characteristics of secondary products and allowing them to enter diverse value chains.

Benefits of DPPs beyond the Circular Economy

DPP systems also offer benefits beyond circularity by enhancing communication of a product's sustainability attributes to customers, investors, and other stakeholders for reporting and audits, particularly in the context of GHG reporting requirements. DPPs could play a crucial role in the industrial transition to climate neutrality, especially in energy and material intensive sectors like aluminium and cement production.

As climate-neutral products become increasingly essential, DPPs could support automatic CO2 footprint calculations across the value chain, facilitating Scope 3 emissions reporting and enabling businesses to redesign products and value chains for lower emissions. Additionally, DPPs could aid compliance with social governance criteria, including regulations on modern slavery and child labour. By centralizing and passing along this critical data throughout production and usage phases, DPPs could serve as a single point of truth for sustainability and governance metrics across the supply chain.

DDPs in the Reverse Logistics

Digital Product Passports (DPPs) provide critical support for reverse logistics by enabling efficient and sustainable handling of returns, repairs, and end-of-life processes. Through accurate digital record-keeping of a product's history – manufacturing history, usage and maintenance history – DPPs support better operational decisions at every turn of reverse logistics cycles. This functionality fosters waste reduction, resource recovery, and supply chain transparency, making reverse logistics a cornerstone of circular economy strategies.

Key applications of DPPs in reverse logistics include:

- Efficient Returns and Repairs: quick access to product data supports faster assessment of returned items, improving repair processes and customer satisfaction.
- Optimized Refurbishment and Recycling: insights into product condition and composition enable precise refurbishment or recycling decisions, minimizing waste and maximizing resource value.
- Counterfeit Prevention: blockchain-enabled DPPs ensure product authenticity, preventing counterfeit goods from entering reverse logistics channels.

Through fast access to data and improving the decision-making process DPPs transform the reverse logistics from the mere cost factor to the valuable opportunity for environment, customer base and innovation. It helps businesses to realise value in all supply chains whilst also creating a circular and climate-neutral economy.[7]

[7] Ralls, A. (2024, Febbario 9). *Embracing the Future: Digital Product Passports to Open New Doors for the Reverse Logistics Supply Chain*. ASCDI. https://www.ascdi.com/embracing-the-future-digital-product-passports-to-open-new-doors-for-the-reverse-logistics-supply-chain/

2.4 Case studies and Real-world applications of the DPP

This chapter aims to showcase the versatility and impact of DPPs through concrete examples of companies and industries that have successfully adopted this technology. By exploring how leaders in fashion, batteries, and circular design have integrated DPPs into their operations, we can better grasp their role in enhancing sustainability, regulatory compliance, and customer engagement.

The value of practical applications lies in their ability to bridge theory and practice, demonstrating how innovative concepts translate into measurable outcomes. These case studies raise not only the future potentials of DPPs but also stimulate new possibilities for industries interested in implementing the circular economy and corresponding to new market challenges. Through these examples, the chapter underscores the importance of DPPs as a catalyst for sustainable transformation.

2.4.1 Applications in Key Sectors

Fashion and Textile Industry: Marimekko[8] and Kappahl[9]

The fashion and textile industry has been an early adopter of the Digital Product Passport (DPP), leveraging its potential to enhance transparency and sustainability. The two leading firms in this industry: Marimekko and Kappahl have successfully negotiated DPPs as pilot programs covering more than 3000 products. By integrating unique QR codes into their items, these companies enable consumers to access detailed information on the origin, composition, and environmental footprint of their purchases.

For example, Marimekko uses DPPs to provide lifecycle data for their garments, showcasing sustainable production processes and reinforcing consumer trust in their brand. Similarly, Kappahl's adoption of DPPs has improved customer engagement by communicating the environmental attributes of their clothing, fostering loyalty among eco-conscious shoppers. These actions explain how DPPs incorporate other circular economy aspects like the repair and recycling nature of the apparels making these firms champions of sustainability.

[8] *Sustainability—Closed Loop | Marimekko*. (s.d.). da https://www.marimekko.com/no_en/sustainability/closed-loop-pilot
[9] *Kappahl launches pilot with digital product passports together with Trace4Value*. (s.d.), da https://www.kappahl.com/en-us/about-kappahl-group/media--news/news/2024/kappahl-launches-pilot-with-digital-product-passports-together-with-trace4value

Battery Industry: The Open Battery Passport and BATRAW[10]

The battery industry faces unique challenges, such as ensuring sustainability and compliance with increasingly stringent regulations. These negative impacts are avoided by the Open Battery Passport designed by Minespider through offering a blockchain-based method of tracking the lifecycle of a battery. This passport includes critical information about the battery's type, chemistry, performance, and recycling options, supporting a circular approach to resource management.

The BATRAW project further exemplifies DPP implementation in the battery sector. Funded by the European Commission, BATRAW focuses on recovering critical raw materials like lithium, cobalt, and nickel from electric vehicle batteries. Minespider's role in this project involves creating Battery Passports that enhance traceability and transparency, ensuring that recycled materials meet safety and performance standards. These initiatives not only align with EU sustainability goals but also pave the way for innovative approaches to battery reuse and recycling, reducing waste and conserving valuable resources.

Circular Product Design: Niaga[11]

Niaga is a leader in circular product redesign, striving to eliminate waste by creating reusable, repairable, and recyclable products from clean, safe materials. Recognizing the importance of transparency, Niaga has developed the Niaga Tag, a scannable QR code that links to a unique Digital Product Passport (DPP) for each product.

These DPPs detail the composition of products and provide instructions for returning items after use to ensure effective recycling. Designed to be future-proof, the Niaga platform is adaptable to evolving regulatory requirements while protecting intellectual property through tiered access levels. Sensitive information is securely managed, allowing different types of users - such as recyclers, consumers, or suppliers - to access appropriate data.

Currently, Niaga Tags are applied to carpets, mattresses, and furniture panels from sustainability-focused companies. By transforming waste streams into material flows, Niaga demonstrates how the DPP can facilitate transparency, improve recycling rates, and reduce environmental impacts. Their approach underscores the importance of accurate component disclosure for assessing recyclability and its effects on human and environmental health.

[10] *Case Study: Batraw Case Study*. (s.d.), da https://www.minespider.com/case/batraw

[11] *Transparency: A competitive advantage*. (s.d.). Niaga by Covestro A, da https://www.niaga.world/zh/stories/how-ingredient-and-supply-chain-transparency-can-become-a-competitive-advantage

2.4.2 Insights and Lessons from Real-World Applications

The case studies analysed highlight the clear value and potential of Digital Product Passports (DPPs). These tools have proven to be effective in enhancing supply chain transparency, promoting sustainable practices, and strengthening consumer engagement. In the fashion sector, companies such as Marimekko and Kappahl have leveraged DPPs to communicate the environmental attributes of their products more transparently, increasing consumer trust and commitment to sustainability. In the battery industry, the BATRAW project demonstrated how DPPs can support traceability and the recovery of critical raw materials, contributing to waste reduction and the conservation of valuable resources.

A key takeaway is the importance of collaboration among supply chain stakeholders and data standardization, which are essential for ensuring interoperability between digital systems. Additionally, balancing transparency with the protection of intellectual property is a significant but necessary challenge to build and maintain trust among stakeholders. These lessons underscore that the success of DPPs relies on an integrated approach that addresses the needs of all parties involved.

Finally, DPPs stand out as central tools for driving the transition toward circular economy models. Their ability to combine sustainability with digital innovation makes them a strategic asset for companies seeking to remain competitive in a rapidly evolving market. Despite initial challenges, the case studies demonstrate that DPPs represent a practical and advantageous path to promote not only environmental sustainability but also economic resilience, offering a replicable model across a wide range of industries.

2.5 Open questions about DPPs

While much progress has been made in conceptualizing Digital Product Passports (DPPs), several key aspects remain unresolved regarding their content and the functioning of their systems. Current discussions have primarily centered on the conceptual design, potential regulatory frameworks, data infrastructure, and integration with other emerging systems.

Despite numerous publications on the topic, there is still no universally agreed-upon definition of DPPs. It remains uncertain whether specific technological elements, like identifiers, underlying data spaces, and knowledge graphs, will be included in DPPs. Another critical area requiring further clarity is interoperability, both within a DPP system and between DPPs and other digital frameworks, including interface design standards.

The appropriate level of detail for DPPs also remains unclear, as well as the scale at which they should be created. For example, individualized DPPs might be appropriate for complex products like buildings, airplanes, or cars; however, this may be impractical or time-consuming for simpler materials like plastics or chemicals.

It is also uncertain whether DPPs should provide different levels of information based on the intended audience. Consumers, businesses, and public authorities may need distinct data tailored to their needs and levels of understanding, raising the question of whether different versions of DPPs are necessary.

Additionally, questions remain about who will manage these publicly mandated DPP systems and how they will operate. This is especially relevant in the context of intellectual property rights (IPR) and proprietary knowledge, as companies are concerned about protecting sensitive product data to maintain a competitive edge. Regulating access, ensuring anonymity, and safeguarding data privacy are therefore essential issues that will need to be addressed.

Furthermore, as the European Commission leads the development and implementation of DPPs, they are largely seen as a “European” initiative. However, with global supply chains in mind, it is crucial to determine how non-EU stakeholders might participate.

2.6 Delphi and TISM: Methods for Data Analysis on DPP Implementation

In addressing complex challenges such as the implementation of Digital Product Passports (DPPs), analytical methods play a essential role in uncovering insights and providing structured solutions. Among these, the Delphi Method and Total Interpretive Structural Modeling (TISM) stand out for their ability to address multifaceted issues by integrating expert opinions and systematically analysing relationships among factors.

The choice to employ these methods in analysing the DPP implementation stems from the complexity of the subject matter. The introduction of DPPs involves multiple stakeholders, regulatory considerations, and technical challenges, all of which are deeply interrelated. A systematic approach is required not only to identify key factors but also to understand how they influence one another, directly or indirectly. By combining the Delphi Method's consensus-driven identification of factors with TISM's interpretive structuring capabilities, this study seeks to provide a comprehensive understanding of the drivers and barriers to DPP implementation.

This methodological framework is essential for navigating the intricate dynamics of DPP adoption and for laying the groundwork for actionable strategies that align with both theoretical insights and practical needs.

2.6.1 The Delphi Method[12]

The Delphi Method can be understood as a promoted communication technology that was initially introduced as a formal, cooperative academic prognostication tool. It uses a jury of relevant opinion makers to share information or make some judgements regarding certain matter. It has gained usage in many areas such as business prediction, medical practices, health care and studies.

Principles and Process

Delphi Method derives its conceptual basis from the proposition that the forecasts or decisions arising from an appointed panel of experts will be more precise and accurate than those arising from a randomly organized group. The procedure takes place in several rounds, in which the experts complete questionnaires which help to capture their judgments, predictions or opinions. The convergence process keeps cycling until the process reaches certain fixed criteria which may include consensus, maximum results, or realization of a fixed number of iterations.

Key Characteristics of the Delphi Method

[12] Delphi method. (2024). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Delphi_method&oldid=1266110837

1. Anonymity of Participants

Participants' identities are kept anonymous throughout the process, even after its completion. This ensures that no participant’s authority, personality, or reputation influences others. The anonymity also minimizes biases like the "bandwagon effect" or "halo effect," fostering free expression, open critique, and a willingness to revise opinions.

2. Structured Information Flow

Initial contributions from experts are collected via questionnaires. The facilitator organizes and filters the responses, removing irrelevant information. This structured approach avoids the negative effects of face-to-face discussions, such as dominant personalities influencing the group or groupthink.

3. Regular Feedback

The iterative nature of the method allows participants to comment on others' responses, track the panel's progress, and adjust their forecasts in real time. This continuous feedback loop refines the collective output over successive rounds.

4. Role of the Facilitator

The facilitator plays a central role in designing the questionnaires, coordinating communication, and analysing responses. By synthesizing common and conflicting viewpoints, the facilitator helps guide the panel toward consensus. If agreement cannot be reached, the process continues, gradually building a synthesis through thesis and antithesis.

Advantages and Applications

The Delphi Method has certain advantages over other forecasting and decision-making techniques, such as prediction markets:

- It is effective in situations with limited quantitative data, relying instead on expert knowledge.
- It allows for a diverse group of experts to collaborate without direct interaction, reducing group dynamics issues.
- It has been widely applied to generate guidelines, inform policy, and identify challenges or priorities in various domains.

Challenges and Considerations

While the Delphi Method is highly versatile, its validity and reliability depend on careful attention to certain methodological aspects:

- Formulating the questionnaires: poorly designed questions can lead to ambiguous or irrelevant data.
- Selecting experts: the quality of the results hinges on choosing participants with relevant knowledge and expertise.
- Measuring consensus: facilitators must define appropriate thresholds to determine when agreement has been reached.

In summary, the Delphi Method is a robust tool for reaching consensus or generating insights on complex issues. Its iterative, structured approach ensures high-quality outcomes by leveraging collective expertise while minimizing the pitfalls of unstructured group interactions.

2.6.2 Methodology TISM[13]

Total Interpretive Structural Modeling (TISM) builds upon the foundational Interpretive Structural Modeling (ISM) technique, enhancing its explanatory power for theory building and decision-making in complex systems. While ISM focuses on uncovering the structural relationships between elements in a hierarchical framework, TISM extends this by providing detailed interpretations for both nodes and links. This refinement enables a more comprehensive understanding of "what," "how," and "why" elements are interrelated, making TISM an essential tool for disciplines requiring structured conceptualization, such as management science and supply chain research.

Core Principles of TISM

TISM retains ISM's graph-based approach to modelling but integrates interpretive matrices to address ISM's limitations, such as limited explanatory insight into the contextual relationships between elements. By combining qualitative inputs with systematic structuring, TISM offers clarity on the mechanisms through which elements influence one another, an improvement critical for both academic research and practical application.

Key characteristics of TISM include:

[13] Sushil. (2018). Incorporating polarity of relationships in ISM and TISM for theory building in information and organization management. *International Journal of Information Management*, *43*, 38–51. https://doi.org/10.1016/j.ijinfomgt.2018.06.003

1. Interpretive Depth: Relationships between elements are not only mapped but also interpreted in detail, elucidating the contextual basis for their connections.
2. Systematic Structuring: The methodology uses pairwise comparisons and transitivity checks to derive hierarchies and ensure logical consistency.
3. Versatility: Applicable to diverse fields, from information management to sustainability practices, TISM aids in exploring challenges and formulating strategies.

Methodological Steps

TISM employs a step-by-step process that transitions from identifying elements to constructing a fully interpretive structural model. The core stages are:

1. Element Identification and Contextual Relationship Definition: Elements relevant to the study are identified, often through literature reviews or expert consultations, and contextual relationships (e.g., "leads to," "enhances") are defined.
2. Pairwise Comparison and Interpretive Logic Development: Each element is compared to others, and the relationships are recorded in an interpretive matrix. Experts provide insights into how and why elements influence each other.
3. Reachability Matrix and Transitivity Testing: Relationships are formalized in a matrix, with transitivity logic applied to infer indirect relationships.
4. Level Partitioning: Elements are arranged hierarchically based on their influence, identifying driver, linkage, autonomous, and dependent elements.
5. Digraph Construction: The hierarchical structure is visually represented as a directed graph, showcasing relationships and their interpretive meanings.
6. Interpretive Matrix Integration: Explanations of the connections are systematically added to the structural model, forming a Total Interpretive Structural Model.

Applications in Theory Building

TISM's ability to incorporate interpretative insights alongside structural modelling has positioned it as a valuable methodology for:

- Identifying Barriers and Drivers: For instance, studies on deploying circular supply chains have used TISM to categorize and analyse barriers, such as lack of top management

commitment or inadequate recyclability facilities, distinguishing between driving and dependent factors.

- Dynamic Hypothesis Development: By visualizing and interpreting positive and negative feedback loops, TISM facilitates hypothesis generation, such as understanding how policy changes influence organizational outcomes.

Contributions to Literature

In contrast to traditional ISM, TISM's explicit focus on interpretation enhances its theoretical robustness. For example:

- In organizational change management, TISM clarifies the impact of stakeholder awareness on cost and time, revealing nuanced interdependencies and enabling targeted interventions.
- In supply chain studies, TISM elucidates how driving barriers cascade into dependent constraints, providing a clear roadmap for practitioners to prioritize actions.

Advantages of TISM

1. Enhanced Explanatory Power: By interpreting links and nodes, TISM uncovers the rationale behind relationships, enriching the theoretical underpinnings of models.
2. Logical Consistency: The transitivity checks ensure a logically coherent hierarchy, essential for robust theoretical constructs.
3. Practical Utility: TISM is not only a research tool but also a decision-support system, guiding strategic planning and operational optimization.

Limitations and Conclusion

While TISM's strengths lie in its detailed interpretive capabilities, it is resource-intensive, requiring substantial expert involvement and computational effort for transitivity analysis. Further research could focus on:

- Automating aspects of the methodology through advanced algorithms.
- Integrating TISM with other frameworks like System Dynamics for holistic modelling.

In conclusion, TISM represents a significant evolution in interpretive structural modelling, providing a robust framework for analyzing complex systems and building theory. Its detailed interpretative approach and logical rigor make it an indispensable methodology in fields requiring nuanced understanding and actionable insights.

2.7 TISM-Based Proposal for DPP Implementation

The previous section highlighted how Total Interpretive Structural Modelling serves as an effective method for analysing and understanding the relationships between various factors influencing the implementation of complex systems. This is particularly important given that the adoption of DPPs is governed by multiple internal and external factors, within the context of which the proposed methodology can be successfully applied.

The simple enumeration of drivers and barriers is not sufficient, which is why an analytical assessment of these components and how they interdependently work is critical for genesis of effective implementation strategies. TISM plays a key role in this process by enabling the mapping of relationships between various factors, identifying primary drivers, critical barriers, and the complex connections between them.

This chapter examines the main drivers and barriers that promote or hinder the implementation of DPPs. These elements form the foundation for a deeper analysis of their interrelationships, which will be conducted using the TISM methodology.

2.7.1 Drivers for the implementation of the Digital Product Passport

The implementation of the Digital Product Passport (DPP) is driven by a series of strategic factors that underscore its importance for companies and organizations. These factors, referred to as "drivers," represent the primary motivations behind adopting this digital tool, which aims to promote transparency, sustainability, and innovation. The drivers can be categorized into two main types:

- *Internal Drivers*: these pertain to the dynamics and objectives within the company, such as improving operational efficiency and building a competitive advantage.
- *External Drivers*: these arise from regulatory pressures, consumer expectations, and market trends.

Recognizing and understanding these drivers is critical for designing a successful transition to the DPP. Meeting internal and external needs and pressures organizations can devise a strategy that will fulfil not only the mandatory requirements of the regulation but also offer a great gain on economical as well as environmental fields. It thus makes sure that companies are well placed to make profits in a world that is going green at a rapid pace. Expanding upon these drivers highlights the transformative potential of the DPP, not just as a compliance tool, but as a catalyst for long-term innovation and growth.

Drivers of the internal environment

- Push for digitalization of business processes

The Digital Product Passport is a cornerstone of digital transformation for companies. By implementing the DPP, businesses can streamline information management across their entire supply chain, enhancing operational efficiency and promoting greater transparency. The DPP provides a central and standardized information concerning materials, processes & products and the information can be accessed by a variety of supply chain members. It simultaneously avoids mistakes and system interruptions as well as helps implement new technologies, such as AI and predictive analysis, into the organisation. According to research by Cikis Studio[14], the DPP fosters an integrated view of material and product flows, contributing to a modern, agile, and competitive supply chain that can adapt quickly to market changes.

- Gaining competitive advantages

Adopting the DPP places the companies as sustainable, a factor that more consumers consider in their decision making today than before. Due to the increasing importance of sustainability practices in decision making especially when buying a product, the DPP is beneficial to firms since it puts it on a different league from its competitors. Deloitte[15] highlights that the DPP not only enhances corporate reputation but also builds trust among customers who prioritize transparency and sustainable practices. Moreover, the DPP can facilitate access to regulated or incentivized markets driven by sustainability standards, unlocking growth opportunities in strategic sectors. In markets where sustainability is a key selection criterion, the DPP becomes a strategic tool for attracting new customer segments and strengthening loyalty among existing clients.

- Enhancement of corporate reputation

Adopting the DPP underscores a company's commitment to sustainability and transparency, significantly improving its brand image. This tool offers material evidence of the fact that the company is socially responsible – a concept that is becoming more and more valued not only by consumers but by investors and other stakeholders as well. Market analysis also shows how the use of the DPP increases transparency and good-will among strategic partners and customers leading to a positive perception in the industry. Additionally, companies implementing the DPP can earn sustainability certifications and accolades, further boosting their visibility and appeal in the

[14] *Digital product passport: Cos'è e perchè implementarlo*. (s.d.). urly.it/3141n2

[15] *Digital Product Passports are just around the corner | Deloitte UK*. (s.d.). https://www.deloitte.com/uk/en/services/risk-advisory/perspectives/digital-product-passports-are-just-around-the-corner.html

marketplace. This enhanced reputation often translates into a lasting competitive advantage, positively influencing brand equity and customer loyalty.

Drivers of the external environment

- Regulatory pressures for sustainability

European regulations, such as the Green Deal, are accelerating the transition toward sustainable economic models. According to Graphimecc[16], these regulations are pushing companies to comply with increasingly stringent standards, making the Digital Product Passport (DPP) an essential tool for ensuring regulatory compliance and anticipating future requirements. Adopting the DPP is not only necessary to avoid penalties but also represents a significant competitive advantage in an evolving market. By adhering to these standards, companies position themselves as forward-thinking and sustainability-driven, which can attract eco-conscious consumers and investors. The DPP also simplifies the integration of sustainability into operational processes, providing a clear framework for tracking and meeting environmental obligations.

- *Consumer demand for transparency*

The growing demand from consumers for clear information about the origin, composition, and sustainability of products is one of the main drivers for adopting the DPP. As highlighted by GS1[17], sectors such as fashion and electronics are particularly influenced by this trend. Consumers increasingly prefer brands that demonstrate transparency, using it as a key factor in their purchasing decisions. The DPP enables companies to meet these expectations by offering a comprehensive view of a product's lifecycle, including its environmental footprint. This transparency not only fosters customer loyalty but also differentiates brands in competitive markets. By implementing DPPs, businesses can enhance trust and create more personalized and engaging consumer experiences while aligning with broader sustainability goals.

[16] *DPP - Digital Product Passport: Tutto quello che c'è da sapere - Graphimecc*. (2023, settembre 13). https://graphimecc.it/it/dpp-digital-product-passport-tutto-quello-che-ce-da-sapere/

[17] *Digital Product Passport (DPP) e standard GS1*. (s.d.). GS1 Italy. da https://gs1it.org/migliorare-processi/supply-chain-sostenibile/passaporto-digitale-prodotto/

- *Support for the Circular Economy*

The DPP plays a pivotal role in facilitating the transition toward a circular economy by promoting recycling, reuse, and repairability. According to the European Circular Economy Platform[18], adopting the DPP improves end-of-life product management, reducing disposal costs and optimizing the use of raw materials. This approach directly contributes to emission reductions and supports Europe's climate goals. By providing detailed information about materials and components, the DPP enables stakeholders to make informed decisions about how products can be reused or recycled effectively. Furthermore, it supports innovative business models such as product-as-a-service, where companies retain ownership of materials and ensure their efficient recovery. This alignment with circular economy principles not only benefits the environment but also enhances resource efficiency and opens new market opportunities, allowing companies to thrive in a sustainability-focused economy.

In summary, the drivers for the DPP show that the Innovation and Improvement potential of the DPP covers various aspects of business and market development. When the internal aims include effectiveness and competitive advantage as well as the external requirements including legal requirements and customer needs the DPP is no longer simply a reaction to the market forces – but a key weapon. Companies that embrace the DPP not only align with sustainability imperatives but also position themselves as leaders in innovation, transparency, and circular economy practices. In the contexts of growing environmental and social concerns, the DPP is the connector to the next generation of business that helps sift through prospective models for certain industries to become greener, cycle is screened through and the global economies becomes stronger and more sustainable.

2.7.2 Barriers to Implementing the Digital Product Passport (DPP)

As this paper has shown, the proposed DPP anchors numerous opportunities for enhancement, enhancing transparency, enabling the promotion of sustainability, and spurring innovation, the strategic instrument is not without starting challenges. These barriers include internal and external factors that in their combined impact post major hurdles in adoption. In internal context, companies experience concerns about how prepared they are to adopt the solution as well as their technical preparedness and resources, On external context it is characterized by relationship with suppliers, legal requirements, and client resistance. Meeting these challenges is possible only through the

[18] *Digital Product Passport: The ticket to achieving a climate neutral and circular European economy?* (2022, luglio 15). European Circular Economy Stakeholder Platform. https://circulareconomy.europa.eu/platform/en/knowledge/digital-product-passport-ticket-achieving-climate-neutral-and-circular-european-economy

consideration of several major steps toward effective implementation of the DPP into the business environment. In this way, the DPP will be fully embraced and deployed holistically by companies that will effectively align with better and new sustainability goals, regulations, and expectations that come with the future market. Besides approaching these barriers allowing compliance, it helps businesses to become models of transparency and promote new ideas within a competitive global economy.

Barriers of the Internal Environment

- Data Interoperability and Standardization

The lack of uniform international standards significantly hampers the scalability of the DPP. Organizations face difficulties in ensuring interoperability between different systems and industries. This challenge requires substantial investments in standardization efforts, including the development of protocols to harmonize data formats and communication interfaces. As highlighted by studies from the European Union's Digital Transformation Framework[19], the absence of consensus on data standards increases the complexity of cross-border operations and limits collaboration across supply chains. Without addressing this gap, companies risk creating fragmented systems that undermine the effectiveness of the DPP.

- High Costs of Digitalization and Adaptation

The change-over to the DPP requires series of investments in sophisticated digital tools like blockchain, IoT's or traceability. These technologies entail costs on software, hardware and human skills, which most firms including the SMEs cannot afford to incur in their initial stages. According to a report by Deloitte[20], companies may face financial strain from the integration of new systems and the potential need to retrofit existing infrastructures. Balancing these costs with long-term benefits poses a significant challenge, especially in industries with narrow profit margins.

- Lack of Technical and Managerial Skills

The effective implementation of the DPP depends heavily on the availability of skilled personnel with expertise in data management, IT systems, and supply chain coordination. However, many organizations report skill gaps in these critical areas. This deficit limits their ability to manage complex digital systems and capitalize on the DPP's potential. Training programs and capacity-building initiatives are necessary, but they demand time and resources, further complicating the

[19] *Shaping Europe's digital future | Shaping Europe's digital future*. (s.d.), da https://digital-strategy.ec.europa.eu/en

[20] *Deloitte | Audit, Consulting, Financial, Risk Management, Tax Services*. (s.d.), da https://www.deloitte.com/it/it.html

adoption process. Research by McKinsey[21] emphasizes that bridging the skill gap requires a dual focus on technical training and organizational change management.

- Organizational Challenges and Extended Implementation Time

The DPP's integration involves extensive organizational changes, including internal coordination, restructuring processes, and employee training. These adjustments demand significant time and resources, particularly for companies with global or extended supply chains. Moreover, the long implementation timelines can lead to strategic misalignment and reduced momentum. Insights from the World Economic Forum[22] underline that companies often underestimate the complexity of these transformations, leading to delays and suboptimal execution.

Barriers of the External Environment

- Challenges in Data Collection and Management

The comprehensive data required by the DPP, covering materials, components, and production processes, poses significant challenges. Capturing accurate and comprehensive data from suppliers across the world is generally challenging especially when compared to advanced supply chain companies from the developing countries. According to GS1[23] research, these remain a challenge due to the fact that upstream suppliers are often not as transparent thereby posing potential challenges to accuracy and completeness of data.

- Resistance to Change

Internal resistance, including employee scepticism and reluctance to share sensitive product information, represents a major barrier to DPP adoption. Concerns over data security, intellectual property, and potential misuse of shared information contribute to this resistance. As noted by Accenture[24], fostering a culture of openness and demonstrating the strategic value of the DPP are crucial to overcoming these challenges. Without addressing these concerns, companies risk delays in adoption and reduced stakeholder buy-in.

The challenges associated with implementing the Digital Product Passport (DPP) also illustrate the challenges of moving to a more transparent and sustainable operational environment. For skill

[21] *Global management consulting | McKinsey & Company*. (s.d.), da https://www.mckinsey.com/

[22] *The World Economic Forum*. (s.d.), da https://www.weforum.org/

[23] *GS1*. (2024, novembre 5). https://www.gs1.org/

[24] *Accenture | Italia | Let There Be Change*. (s.d.), da https://www.accenture.com/it-it

shortage, resistance to change within organizations, to interoperability and data collection issues, businesses have to handle them all systematically, collectively. These barriers if not addressed hinder the implementation and thus the benefits to be achieved from the DPP in value chain marked by training, standardization, and stakeholder engagement. Coping with these obstacles helps organizations meet and abide by the requirements of standards, as well as become leaders in sustainability and innovation for businesses looking to sustainably reshape the market for outward growth in the context of an ever-evolving global consciousness regarding the environment.

Chapter Three: Method

This chapter describes the strategic approach adopted to identify the opportunities and challenges related to the Digital Product Passport use, commonly known as DPP. It outlines the background of the study, and the methodologies used to accomplish the goals of the study. As this section gives a detailed account of methods used, it plays a critical role of giving an account of how results were arrived at, devoid of which would amount to lack of scientific research integrity. The chosen methods Delphi Method[25] and Total Interpretive Structural Modeling (TISM) were selected due to its advantages over other methods. The Delphi Method enabled iterative consultation with a panel of experts, ensuring robust identification and validation of key factors. In parallel, TISM facilitated the systematic analysis of interdependencies between the identified drivers and barriers, yielding actionable insights. Together, these approaches ensured a comprehensive exploration of the factors influencing DPP implementation, guided by both expert insights and structured analytical techniques.

3.1 Research Approach

The approach of research used in this study is mixed method because, it combines both qualitative and quantitative research approach because the research question posed enables comprehensive research. This approach was chosen because it would integrate the merits of both research methods, in an effort to understand further the factors that enhance or hinder the operations of the Digital Product Passport (DPP). The use of mixed-methods framework enabled different categories of data to be collected and comprehensively compare relations among these factors.

3.1.1 Mixed-Methods Framework

The mixed-methods framework used in this research is based on its ability to address the multi-faceted nature of the DPP implementation process. By integrating qualitative and quantitative methods, the study leverages the strengths of both approaches.

- *Qualitative Methods*: these were employed to gather expert opinions on the barriers and drivers of the DPP. The qualitative phase focused primarily on semi-structured interviews with selected experts, to collect detailed and contextualized insights that contributed to defining the key questions for the subsequent phase.
- *Quantitative Methods*: the quantitative phase utilized structured questionnaires containing both Likert scale questions and questions designed to analyse the relationships between

[25] Azevedo, S. G., Govindan, K., Carvalho, H., & Cruz-Machado, V. (2013). Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain. *Journal of Cleaner Production*, *56*, 131–146. https://doi.org/10.1016/j.jclepro.2012.04.011

barriers and drivers, following the Total Interpretive Structural Modeling (TISM) method. The Likert scale questions were used to assess the level of relevance of each factor, while the TISM-related questions enabled the examination and mapping of interdependencies among the identified elements.

This combination of methodologies ensured a robust and comprehensive exploration of the research problem, providing both depth and breadth in the analysis.

3.1.2 Sequential Research Design

The research was conducted using a sequential design, which organized the study into distinct yet interconnected phases. This design allowed for a systematic progression from expert selection to data collection and analysis, ensuring that insights generated in each phase directly informed the subsequent steps.

Phase One: Selection of the Expert Panel

The first phase concerned the identification and appointment of an expert panel involving professionals from assorted disciplines that could be useful for the DPP implementation, including sustainability, supply chain, and technology. The purpose of this phase was to include participants who had extensive information on the subject matter and who were likely to give both quality and quantity input. These criteria were based on participants' professional/academic affiliation, their involvement in innovative projects involving the DPP or similar topics and diversity of the viewpoints.

Phase Two: Interviews and questionnaires as a tool of data collection

In the second phase, data were collected through semi-structured interviews and a structured questionnaire. The interviews that were used in combination with the questionnaire took between half an hour to forty-five minutes and were conducted through Teams or Zoom. All the experts agreed that all the interviews conducted for the purpose were taped and therefore transcribed in order to make use of the contributions.

- **Semi-Structured Interviews:** All the selected experts were asked to undertake individual interviews to capture their perceived barriers and enablers to the implementation of the DPP. These interviews enabled the obtainment of detailed qualitative information and the subsequent quantitative data were placed into a broader context.

- **Structured Questionnaire:** The subjects were given a close-ended structured questionnaire containing two broad categories**:**

    - The first part, based on a Likert scale, assessed the level of relevance of the drivers and barriers identified during the literature review and the qualitative exploration phase.
    - The second part included questions specifically designed to examine the relationships between barriers and drivers, following the Total Interpretive Structural Modeling (TISM) method. This structure ensured comprehensive data collection aligned with the study's objectives.

Phase Three: Data Analysis

The third phase involved analysing the collected data using two main approaches:

- **Construction of the Likert Scale**: responses related to the Likert scale were analysed to determine the level of relevance of each driver and barrier. This analysis enabled the development of a well-structured and validated scale to measure the importance of the identified factors.
- **Analysis of relationships using TISM**: data related to the relationships between factors were analysed using the Total Interpretive Structural Modeling (TISM) method. This analysis enabled the construction of a hierarchical model that highlighted the interdependencies between drivers and barriers. TISM provided a clear view of the internal dynamics among factors, revealing critical pathways and dependencies.

The sequential nature of the research design ensured a logical and integrated flow between the different phases. Through careful expert panel selection, systematic data collection, and thorough analysis, the study achieved a high level of methodological coherence. Additionally, this design ensured that the results were closely aligned with the research objectives, offering practical recommendations for companies seeking to implement the DPP.

3.2 Expert Selection and Characterization

In qualitative research, the selection of experts is critical as it directly influences the depth and validity of the collected data. This study requires insights from seasoned professionals who are not only versed in their respective fields but also have a broad understanding of the nuances that drive the central research question. Therefore, a systematic approach was adopted to identify and select experts whose experiences and positions enable them to provide valuable perspectives.

The selection process aimed to assemble a panel of experts characterized by both their individual expertise and their collective diversity. This was achieved by setting specific criteria that would not only ensure their ability to contribute relevant knowledge but also encompass a variety of professional and geographical backgrounds. The diversity of the panel is essential for addressing the complex nature of the topic, which requires a multifaceted analysis through the lenses of different industrial practices and cultural viewpoints.

By meticulously defining the selection criteria, the research ensures that the findings are grounded in authoritative and comprehensive expert opinions, thereby enhancing the overall credibility and impact of the study.

3.2.1 Selection Criteria for Participants

Participant selection constitutes an important factor within this type of research in an attempt to achieve an affair and generalizable data needed to respond to the posed research question with help of varied expertise. The criteria used in the selection were a deliberate attempt towards extending the list to admit a very diverse pool of participants in the discussions with a view of having diverse stand which would encompass as many standpoints pertaining to the subject matter as was possible.

Candidates were identified through online searches of articles, publications, and relevant projects. This method allowed the identification of a series of potential experts in various sectors of interest. Although several dozen candidates were contacted, only a third responded, and of these, only nine declared themselves available to collaborate. Among these, seven completed the provided questionnaire. The other two experts, although they did not respond to the questionnaire, still made significant contributions to the research through their interviews, offering valuable knowledge and perspectives based on their experience.

Key Criteria:

Experience in various sectors: it was important to seek input from individuals across sectors in order to afford a precise study. This involved working professionals engaged in battery related industries, European projects, academics, textile industries, consultancy companies, software industries and organizations concerned with advanced research and development for an innovative environment towards a sustainable society.

Involvement in the evolution and implementation of the Digital Product Passport: the selection focused on the professionals currently involved in the construction, development and application of the digital product passport, which is crucial for understanding of technology in the innovation process in their fields.

Diverse perspectives and backgrounds: the presence of the diversity of opinions was necessary. An attempt was made to have distribution across geographical and sectoral categories as well as differences in professional, educational, and methodological backgrounds.

Leadership and influence in the field of expertise: providing details of the samples, it became crucial to employ people who in fact made a difference, as evidenced by leadership roles in projects under study, published papers, and participation in initiatives of the industry.

Communication and dissemination ability: the participants were academics, experts and professionals, to whom it was crucial that their ideas and suggestions were articulated coherently; hearing participants narrate their ideas and opinions, this form of clear communication was necessary for the transcription of the following interviews and for the subsequent analytical work.

These details make very clear the various that is involved and the difficulties faced while selecting participants and show the methodology and methodological rigour of the research.

3.2.2 Characteristics of the Expert Panel

The expert panel includes people with various industrial experiences, rendering valuable knowledge and experience relevant to the study. It is for this reason that anonymity has been ensured by coming up with code names of the experts whereby even their details are generalized as Expert one, two and so on. A summary table by field of type of expertise, number of years, type of industry and role of experts as follows.

Table 2 - Expert profiles and Competencies

Expert ID	Field of Expertise	Years of Experience	Type of Industry	Role in Industry	Country
Expert1	Battery recycling	7+	Research Institution	Researcher	DE
Expert2	Product data standardization and sustainability	3+	Supply Chain standardization and management	Standard Specialist	IT
Expert3	Supply Chain Traceability and Blockchain Solutions for Battery	8+	Battery Supply Chain and Blockchain Technology	Founder and CEO	DE
Expert4	Industrial material recycling and Sustainable Materials	8+	Research and development in Sustainable Technologies	Project manager	SE
Expert5	Sustainability Consulting and Circular Economy Strategies	11+	Professional Services and Risk Advisory	Circular economy and Sustainability specialist	DK
Expert6	Supply Chain data traceability and Digital solutions	5+	Software solutions for Supply Chain Traceability	Technical Sales Specialist	DK
Expert7	Industrial material recycling and Sustainable Materials	4+	Research and development in Sustainable Technologies	Project Manager	SE
Expert8	Blockchain Technologies and Cybersecurity	7+	Technology Research and Development	Blockchain Technologies Researcher	ES
Expert9	Sustainable Design and Transition	4+	Professional Services and Risk Advisory	Strategic sustainability consultant	DK

This way it is ensured that while particular identity is masked, the volume of information is not shaved off. This composition of the expert panel was deliberate in order to capture a range of perspectives on different aspects of DP P implementation. This renders it easy for the panel to come up with a collective proficiency that offers an understanding of drivers and barriers across various industrial settings.

3.3 Data Collection: Questionnaire Design

The data collection process involved the adaptation of a combined questionnaire that incorporated the Delphi method and Total Interpretive Structural Modelling (TISM). The questionnaire was divided into two clear sections because of the methodologies of each part and developed based on an extensive review of scientific literature, which helped identify and refine a comprehensive set of potential drivers and barriers relevant to the implementation of the Digital Product Passport. The first part in which all respondents filled in a Likert-like scale evaluating the importance of the drivers and barriers, mentioned above. The Likert scale was used in order to develop a reliability scale for these drivers and barriers, which allowed for the factors to be easily ranked in terms of importance. The second part was devoted to the TISM method in which the interrelationships and polarity of these factors were studied. The integration of design for both methods made it easy to have common data collection formats when aiming to meet the objectives of both methods.

The questionnaire was created using Google Forms for better access and the same was emailed to the experts during the interview using a secure link. Thereby, it facilitated clarity and simplicity to enhance participation but kept high methodological strings still in check.

3.3.1 Likert Scale Design

The first part of the questionnaire is focused on the Likert Scale. This part of the work aimed at receiving professionals' perceptions about the importance of the drivers and barriers considered in the literature review and during the qualitative part of the study. To measure the factors, the participants were requested to rate each factor based on the Likert scale of 1 to 5.

- **Objective**: to create a scale of importance for the drivers and barriers by calculating the average scores provided by the experts.
- **Structure**: each driver and barrier were presented as a separate item, and participants rated its relevance on a scale of 1 to 5:
    - *1 = Not important*
    - *2 = Slightly important*
    - *3 = Moderately important*
    - *4 = Important*
    - *5 = Very important*

After providing a rating, participants were asked to explain their rating for each factor. For example: *"Please explain in a sentence why you rated the importance of 'High costs of digitalization and adaptation' as you did."*

- Example Questions:
    - *"How important do you consider 'Regulatory pressures for sustainability' as a driver to the adoption of the Digital Product Passport (DPP)?"*
    - *"How important do you consider 'High costs of digitalization and adaptation' as a barrier to the adoption of the Digital Product Passport (DPP)?"*

The responses in the form of Likert scale produced numerical responses of the perceived importance of the factors while the qualitative data supplemented the numbers with context. This approach helped making use of the idea of the average score and develop a scale of the significance of elements that contributed to the implementation process of DPP and extend the findings of the first stage.

3.3.2 Relationship Analysis

The second part of the research involved a set of questions that addressed the TISM, Total Interpretive Structural Modeling technique[26]. This section sought to establish the relationships between the various drivers and barriers while focusing on polarity, that is, how, the relation affects the DPP positively or negatively.

*Objective***:** to analyse the directional relationships and polarities between pairs of factors, revealing critical interdependencies and pathways.

- Structure**:** this section was divided into two components:
    1. **Relationship Assessment:** participants were asked to determine if a relationship existed between specific pairs of factors and, if so, indicate the direction of influence.
        - Possible responses:
            - *Bidirectional (Factor A ↔ Factor B)*
            - *Forward direction (Factor A → Factor B)*
            - *Backward direction (Factor B → Factor A)*

[26] Sushil. (2018a). Incorporating polarity of relationships in ISM and TISM for theory building in information and organization management. *International Journal of Information Management*, *43*, 38–51. https://doi.org/10.1016/j.ijinfomgt.2018.06.003

        - *No relationship*

2. **Polarity Analysis:** for each identified relationship, participants evaluated its effect as either positive or negative.
    - Possible responses:
        - *Positive (facilitates DPP implementation)*
        - *Negative (hinders DPP implementation)*

- Example Questions:
    - *"Is there a relationship between Regulatory pressures for sustainability and Resistance to change?"*
    - *"What is the polarity of the relationship between Regulatory pressures for sustainability and Challenges in data collection and management?"*

This structured approach enabled a detailed examination of how drivers and barriers interact within the DPP framework, providing the data necessary to construct the TISM hierarchy.

This integrated design ensured that the Delphi and TISM methodologies were effectively combined into a single, streamlined data collection process, minimizing redundancy and maximizing coherence. The clear segmentation of the questionnaire facilitated the collection of both relevance scores and interdependency data, enabling a comprehensive analysis of the factors influencing DPP implementation.

3.4 Data Analysis Techniques

In this section, the attention is paid to the organization and analysis of the data received while completing the given questionnaire. The previous section highlighted the general procedures, method of the study and the design of the questionnaire, this part gives a detailed elaboration of the procedures used in the analysis of the data for Likert Scale and TISM.

3.4.1 Validation of Drivers and Barriers

The analysis of the first part of the questionnaire, based on the Likert Scale, involved the following steps:

1. *Calculation of averages:*
    - The ratings given by the experts for each driver and barrier were averaged to determine their overall importance.
    - This provided a numerical measure for ranking the factors.
2. *Ranking:*
    - Based on the calculated averages, a ranked list of drivers and barriers was created, ordered by their perceived importance.
3. *Qualitative Context:*
    - For each driver and barrier, one expert comment was selected to complement the quantitative ranking. The chosen comment reflected the general sentiment of the scores and provided deeper insight into why that factor received its rating

3.4.2 Relationship analysis using TISM

The second part of the analysis focused on the relationships between pairs of drivers and barriers, as per the TISM methodology. The steps included:

1. *Identifying Relationships:*
    - For each pair of drivers and barriers, the relationship was determined based on the majority vote of the experts.
    - Possible relationships included:
        - No relationship.

- A unidirectional relationship (e.g., Driver A influences Barrier B or vice versa).
- A bidirectional relationship (e.g., Driver A ↔ Barrier B).

2. *Determining Polarity:*
    - The polarity of each relationship (positive, negative, or neutral) was assigned based on the majority vote of the experts who identified the relationship.
3. *Matrix Creation:*
    - A matrix was developed where each cell represented a specific pair of drivers and barriers.
    - Each cell included:
        - The type of relationship (indicated by a distinct color for clarity).
        - The polarity of the relationship, represented as +1 (positive), -1 (negative), or 0 (neutral).
4. *Driving Power and Dependence Analysis:*
    - The driving power of each driver and the dependence of each barrier were calculated to assess their influence and vulnerability in the system.
    - A distinction was made between positive relationships (ve^{+}) and negative relationships (ve^{-}) to provide a nuanced understanding of how each factor operated within the framework.

The structured analysis ensured a comprehensive understanding of the factors influencing the implementation of the Digital Product Passport (DPP). The Likert Scale analysis provided a ranked importance of drivers and barriers, enriched by qualitative insights, while the TISM analysis revealed the intricate web of interdependencies and polarities. Together, these findings offer a robust basis for strategic decision-making in the DPP implementation process.

3.4.3 How to interpret the Tables

The following legend shows descriptions of drivers and barriers used in the analysis: Such information will enable us to provide some background and set the relationships, polarities and interdependencies described in the above tables into perspective.

Table 3 - Definitions of Drivers and Barriers

ID	Description
Driver1	Regulatory pressures for sustainability
Driver2	Consumer demand for transparency
Driver3	Support for circular economy
Driver4	Push for digitalization of business processes
Driver5	Gaining competitive advantages
Driver6	Enhancement of corporate reputation
Barrier1	High costs of digitalization and adaptation
Barrier2	Lack of technical and managerial skills
Barrier3	Resistance to change
Barrier4	Challenges in data collection and management
Barrier5	Data interoperability and standardization
Barrier6	Organizational challenges and extended implementation time

The next part of the work will also contain a brief explanation of the symbols, terms and values which have been used in the study. The following legend explains the meaning of the symbol and the notations needed to read the relationships and polarities of the drivers and barriers. As it will be illustrated later, this framework will be employed consistently throughout the entire analysis.

Table 4 - Definitions of the Symbols

Symbol	Meaning
↔	Bidirectional
→	Forward direction
←	Backward direction
/	No relationship
1	Positive polarity
-1	Negative polarity
0	Neutral polarity

Explanation:

Relationships (↔, →, ←, /): These symbols represent the directional interactions between drivers and barriers. For example:

- ↔ indicates that the relationship is bidirectional, with mutual influence.
- → indicates a unidirectional influence from the driver to the barrier.

- ← indicates a reverse influence from the barrier to the driver.
- / indicates no direct relationship between the two factors.

Polarity (+1, -1, 0): These values reflect the nature of the influence:

- +1: Positive or favourable influence.
- -1: Negative or obstructive influence.
- 0: Neutral, with no significant positive or negative effect.

These legends act as elaborate maps that give a clear and coherent approach to the later tables of data.

3.5 Ethical Considerations

For any given study, ethical issues are a crucial factor in the processes of studying, and safeguarding the interests of everybody concerned. The ethical standard was adhered to in this study in order to respect, confidentiality and to be transparent. In this section, actions considered to address major ethical issues including consent, anonymity and confidentiality, and security of participants' data are highlighted.

3.5.1 Participant Consent and Anonymity

All the subjects in this study provided their consent to participate in the study as well as understanding the research objectives, the study topics to be used as well as the possible consequences of the research. Each participant received a descriptions of research goals, methods, and their rights. "Oral consent was obtained to secure participants for the study, ensuring that they could withdraw from the study at any time without facing any repercussions.

In an effort to maintain the confidentiality of the participants, code numbers were used to identify them during the interviews and in this report, they are referred to as: Expert1, Expert2 and so on. That way, individual identities were suppressed during data collection, analysis and report writing. In addition, effort was made, while replicating descriptive data, to keep specificity of studied subjects intact and, at the same time, to ensure that exclusion of the possibility of identification could be achieved.

3.5.2 Data Confidentiality and Protection

The confidentiality of participant data was a key priority in this study. All data were stored securely in electronic format, with access limited to the researchers involved in the project.

During the analysis, identifying information was removed, and only aggregated data were used to minimize the risk of identification. Any sharing of data, if necessary, adhered to ethical guidelines and complied with relevant data privacy regulations, such as GDPR. The study ensured that participant identity was protected, fostering trust and upholding the integrity of the research process.

Chapter Four: Results

4.1 Introduction to the Results

This chapter discusses the drivers and barriers to the implementation of the Digital Product Passport (DPP). The purpose of this section is to describe an elaborate analysis of the data gathered and examined based on the approaches described in the previous chapter. This chapter attempts to identify key patterns, relationships and business strategies concerned with organisations engaged in the DPP utilising quantitative data from the Likert Scale and qualitative information from the expert interviews.

The derived results are organised in a manner that provides more focus on the main enablers and constraints; thus, presenting a clearer picture of what they are, how they fit in the scheme of things and their contributions and effects when it comes to DPP implementation. These findings not only contribute to understanding the processes that influence the implementation of the DPP but also create the theoretical and practical framework for strategic decision-making.

The chapter is organized as follows:

1. The first section introduces the results from the Likert Scale analysis, focusing on the average ratings assigned to drivers and barriers by experts. Patterns and trends are identified to understand the perceived importance and relevance of each factor. Expert comments are also integrated to enrich the interpretation of the data.
2. The second section delves into the TISM Relationship Analysis, mapping the directional relationships and polarities between drivers and barriers. This hierarchical approach affords a conceptual framework for the different interconnections extant in the system that can help businesses and policymakers identify key leverage points for DPP adoption.
3. The last part focuses on strategic implications and recommendations for the businesses. Based on the analysis of drivers and barriers, strategies are proposed to address challenges and capitalize on opportunities related to the DPP. This includes guidance on how to manage critical barriers, enhance impactful drivers, and integrate the DPP effectively into organizational processes.

Through this structure, the chapter aims to provide both a robust understanding of the results and practical recommendations that businesses can apply to navigate the challenges and opportunities associated with the DPP.

4.2 Results and Interpretation of Likert Scale Data: Drivers

This section gives a presentation on the Likert Scale results that were analysed based on the identified drivers in this study. The Likert Scale values were obtained through interviews with experts, who rated each driver on a scale from 1 to 5 based on its perceived significance, influence, and relationships within the system.

By doing so, clearer patterns or trends have been identified with regard to each driver in terms of its understanding by respondents and its relative importance or significance**.** These findings provide a foundation for deeper interpretation, linking the expert evaluations to strategic decision-making and the theoretical framework of this study.

In the following table, the results from the Likert Scale analysis are summarized, detailing the expert responses associated with each driver. This data serves as a basis for the subsequent discussion, where observed trends and significant findings will be explored.

Table 5 - Expert evaluation of Drivers

Drivers	Average	Comments from the Experts
Regulatory pressures for sustainability	*4,14*	*"This is currently a key driver for DPP, it is essential to maintain focus on it"* (Expert9)
Support for circular economy	*4*	*"DPP could serve as the "digital backbone" for a future circular economy in products across EU-27 and globally. DPP will enable many new circular economy business models and activities"* (Expert5)
Push for digitalization of business processes	*3,29*	*"This is more important than ever in an increasingly digital world – DPP is driving this change significantly across many organisations and I believe it's a significant motivator for early adoption of DPP"* (Expert6)
Gaining competitive advantages	*3,29*	*"Moderately important but of course much more important for those companies that aim at going beyond the minimum compliance with the DPP/ESPR requirements in order to redevelop their business models and improve competitive advantage among decision-makers ready to embrace the DPP advantages"* (Expert4)

Consumer demand for transparency	*3,14*	*"As a side benefit it is acceptable, but it does not serve as the main driver"* (Expert1)
Enhancement of corporate reputation	*3*	*"DPP will potentially improve the amount of clarity with products and might be utilised by firms to back up their green products, increasing a firm's green image"* (Expert7)

4.2.1 Analysis of Drivers

In this section, the drivers identified through the Likert Scale analysis are examined in detail. Each driver is discussed based on its average rating, highlighting its perceived importance and role within the system. Also, practical suggestions are given for businesses, regarding specific directions to manage, improve, or exploit each driver to advance business objectives. All the considerations provided here come from the main ideas of expert opinions regarding assessment and can be viewed as actionable recommendations. Below is the list:

1. **Regulatory Pressures for Sustainability (4.14):** this is the main driver selected by the experts, as regulations are pushing companies to comply. The recent changes to the regulatory environment entail the firm to adopt solution such as the DPP to enhance the disclosure of sustainability standards. Beyond avoiding penalties, this compliance can represent an opportunity for companies to anticipate future regulatory obligations and improve their competitive position in the market.

   The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Be in constant consultation with the regulators to be able to know future expectations.
   - Use the DPP not only to comply but also to anticipate regulatory changes.

2. **Support for Circular Economy (4):** this is considered one of the main drivers for DPP implementation because it allows companies to align with sustainability objectives which are becoming increasingly critical. The DPP is a mechanism aimed at enabling the tracking, reuse, and recycling of products in the course of their life cycle; and these are key endpoints on the principles of the circular economy system. Experts recognize that DPP provides the transparency and data traceability needed to optimize resource management, reduce

environmental impact and comply with current and future regulations. In addition, the practical implementation of circular economy activities creates opportunities for companies to undertake innovation, adjust their understandings of material and energy consumption costs, and increase the competitiveness of their business in the context of a sustainability-centered market environment.

The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

- Incorporate the DPP into business models, in order to eliminate unnecessary wastage and increase efficiency.
- Collaborate with suppliers and customers to promote circularity.

3. **Push for Digitalization of Business Processes (3.29):** this is seen as an important driver for DPP implementation, as it aligns with the broader need for digital transformation in today's business environment. While not the top priority, the DPP enables companies to streamline processes, improve data management, and enhance collaboration across supply chains, supporting their shift toward a more efficient and automated operational model.

   The following suggestion is based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Use the DPP as a lever to digitalize the entire organization, improving operational efficiency.

4. **Gaining Competitive Advantages (3.29):** this driver is considered important for companies that see the DPP as an opportunity to go beyond simple regulatory compliance. By leveraging the DPP, businesses can differentiate themselves from competitors, improve product offerings, and innovate their business models. The firms that will adopt DPP earlier will get competitive advantage, as it caters to the markets interested in sustainability and decision-makers seeking more long-term value.

   The following suggestion is based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

- Develop strategies to leverage the DPP as a distinctive element, improving products and services.

5. **Consumer Demand for Transparency (3.14):** this is recognized as a secondary benefit rather than a primary driver for DPP implementation. While consumers increasingly value detailed and reliable information about product origins, sustainability, and lifecycle, this demand alone is not strong enough to drive adoption. However, it adds the value of trust and brand loyalty among the customers while satisfying the expectation of sustainable customers.

   The following suggestion is based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Utilize the DPP to provide detailed and transparent information about products, increasing consumer trust.

6. **Enhancement of Corporate Reputation (3):** this driver, rated the lowest on the scale, is seen as a potential but less significant benefit for implementing the DPP. While improving a company's "green" reputation can enhance brand perception and appeal to sustainability-conscious stakeholders, experts consider it insufficient on its own to justify DPP adoption. Nevertheless, for companies already committed to sustainability, the DPP can provide credible data to back up environmental claims, reinforcing their reputation and fostering trust

   The following suggestion is based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Actively communicate the results achieved through the DPP to strengthen the company's image.

4.3 Results and Interpretation of Likert Scale Data: Barriers

This section gives a presentation on the Likert Scale results that were analysed based on the identified barriers in this study. The Likert Scale values were obtained through interviews with experts, who rated each barrier on a scale from 1 to 5 based on its perceived significance, influence and relationships within the system.

By doing so, clearer patterns or trends have been identified with regard to each barrier in terms of its understanding by respondents and its relative importance or significance**.** These findings provide a foundation for deeper interpretation, linking the expert evaluations to strategic decision-making and the theoretical framework of this study.

In the following table, the results from the Likert Scale analysis are summarized, detailing the expert responses associated with each barrier. This data serves as a basis for the subsequent discussion, where observed trends and significant findings will be explored.

Table 6 - Expert evaluation of Barriers

Barriers	Average	Comments from Experts
Challenges in data collection and management	*4,71*	*"In complex supply chains, where multiple actors of varying sizes are involved, efficiently acquiring high-quality data is often a challenge"* (Expert2)
High costs of digitalization and adaptation	*4,43*	*"Especially for small businesses, the costs of digitalization to comply with the requirements of the ESPR regulation can be very high. These costs include acquiring the necessary skills, staff training/external consultancy, implementation of new processes, as well as software and digital infrastructure"* (Expert2)
Data interoperability and standardization	*3,86*	*"Without standards and interoperability, DPPs will be completely useless and incapable of sharing the necessary data between different stakeholders and systems"* (Expert6)
Lack of technical and managerial skills	*3,71*	*"The new regulatory requirements demand skills and roles that were previously absent within companies. This inevitably involves acquiring new skills or hiring new personnel with appropriate qualifications, training internal staff, or seeking external consultancy"* (Expert2)

Organizational challenges and extended implementation time	*3,29*	*"Collecting data from suppliers will be time consuming. Designing and implementing DPP for companies with a broad range of SKUs in scope will be time consuming"*(Expert5)
Resistance to change	*2,71*	*"If the benefits and reasons for implementing the DPP are clearly explained and well-justified, resistance to change will be minimal" (*Expert1)

4.3.1 Analysis of Barriers

In this section, the barriers identified through the Likert Scale analysis are examined in detail. Each barrier is discussed based on its average rating, highlighting its perceived importance and role within the system. Also, practical suggestions are given for businesses, regarding specific directions to manage, improve, or exploit each barrier to advance business objectives. All the considerations provided here come from the main ideas of expert opinions regarding assessment and can be viewed as actionable recommendations. Below is the list:

1. **Challenges in Data Collection and Management (4.71):** this is the most significant barrier according to experts, highlighting how complex supply chains and lack of quality data are critical obstacles. If data is inconsistent, out of date or incomplete then the DPP can become less efficient and more error prone. Failure of all these is likely to deny organizations the intended benefits of DPP due to inadequate flow of reliable information for meeting regulatory needs and engaging stakeholders.

   The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Invest in advanced data collection technologies, such as IoT sensors and supply chain management software.
   - Create partnerships among different supply chain actors to share resources and data collection infrastructures.

2. **High Costs of Digitalization and Adaptation (4.43):** this is particularly challenging for large companies but also for small companies that struggle to afford the costs of software, infrastructure and training. Such costs can also be initial costs accompanied by recurrent costs

such as the costs of maintaining the system, updating it and hiring specialized personnel an aspect that can put a toll on the small organizations.

The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

- Access public funding or tax incentives to support initial costs.
- Develop shared platforms to reduce costs through economies of scale.

3. **Data Interoperability and Standardization (3.86):** this is important because the absence of such standards creates a future challenge to DPP by crossing out the chances for the interoperability between the involved parties and their systems. Without interoperability, the integration of diverse digital systems becomes complex and inefficient, leading to fragmentation that undermines the effectiveness of the DPP in achieving its objectives.

   The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Promote collaboration at the industry level to establish common standards.
   - Participate in international initiatives working on systems interoperability

4. **Lack of Technical and Managerial Skills (3.71):** this requires investments in training or new hires, increasing costs. Many companies, also the smaller ones, may lack the internal expertise to navigate the technical and strategic requirements of DPP implementation. This gap can slow down adoption and lead to dependency on external consultants or service providers, further driving up costs and creating challenges in maintaining long-term sustainability and knowledge retention within the organization.

   The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Implement continuous training programs for internal staff.
   - Collaborate with universities or research centers to develop the necessary skills.

5. **Organizational Challenges and Extended Implementation Time (3.29):** the organizational complexity and the time required for implementation may discourage companies. Adopting the DPP requires thorough planning, restructuring internal processes, and significant efforts in data collection and management. This can be particularly challenging for companies with a wide range of SKUs or a complex organizational structure, making the process seem burdensome and impractical.

   The following suggestions are based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Plan small-scale pilot projects to identify best practices.
   - Develop a clear roadmap to gradually implement the DPP.

6. **Resistance to Change (2.71):** considered less significant, it reduces substantially with clear communication of the benefits. When employees and stakeholders understand how the DPP will positively impact the organization, their roles, and overall outcomes, resistance tends to diminish. Providing training, addressing concerns proactively, and demonstrating early success stories can further ease the transition and foster acceptance.

   The following suggestion is based on insights derived from expert interviews, supported by findings from the literature and the researcher's analysis of the study's results:

   - Engage employees from the beginning and communicate the positive impact of DPP on their work.

4.4 Results and Interpretation from the TISM Methodology

This section presents the results of the TISM (Total Interpretive Structural Modeling) analysis, focusing on the relationships and interdependencies between the identified drivers and barriers in this study. The TISM method was applied to evaluate the directional influences and polarities within the system, offering a hierarchical understanding of how these factors interact and shape the implementation of the Digital Product Passport (DPP).

By utilizing the TISM approach, key patterns and trends have been identified, revealing which drivers hold the most significant influence and how barriers are impacted. The analysis provides a structured framework to map out causal relationships, highlighting the dominant drivers and critical barriers within the system. These findings not only deepen the understanding of the dynamics surrounding the DPP but also serve as a basis for actionable strategies and decision-making.

In the following sections, the results from the TISM analysis are summarized, detailing the expert-validated relationships and directional influences between drivers and barriers. This data will form the basis for a discussion of significant trends, interdependencies, and their implications for businesses and policymakers.

4.4.1 Analysis of Relationships and Polarity

This section examines the relationships and polarities between drivers and barriers, highlighting the directional interactions and the nature of their influence within the system. The analysis is structured into two parts: Relationships and Polarity.

1. The following table provide a breakdown of the direction of relationships between drive and barrier factors:

Table 7 - Directional Relationships between Drivers and Barriers

ID	Barrier1	Barrier2	Barrier3	Barrier4	Barrier5	Barrier6
Driver1	↔	→	→	↔	↔	→
Driver2	↔	/	↔	←	↔	/
Driver3	↔	/	↔	→	→	/
Driver4	↔	↔	←	→	→	↔
Driver5	→	↔	/	→	←	/
Driver6	/	/	↔	↔	/	/

Key Message from the analysis:

Regulatory pressures for sustainability (Driver1) exhibit a strong influence across the system, with bidirectional relationships with high costs of digitalization and adaptation (Barrier1) and forward impacts on lack of technical and managerial skills (Barrier2), resistance to change (Barrier3), and organizational challenges and extended implementation time (Barrier6). This positions regulatory pressures as a key enabler for addressing multiple barriers.

Consumer demand for transparency (Driver2) demonstrates bidirectional relationships with high costs of digitalization (Barrier1) and data interoperability and standardization (Barrier5), but a reverse influence (←) from challenges in data collection and management (Barrier4). This reflects its role as both an enabler and a constraint, depending on the context.

Support for the circular economy (Driver3) shows a consistent forward influence on challenges in data collection and management (Barrier4) and data interoperability and standardization (Barrier5), reinforcing its potential to streamline resource management and reduce systemic inefficiencies.

Push for digitalization (Driver4) emerges as the most influential driver, with bidirectional or forward relationships with nearly all barriers. Its impact spans technical and managerial skill gaps (Barrier2), data challenges (Barrier4 and Barrier5), and organizational challenges (Barrier6), marking it as a central force in enabling systemic change.

Gaining competitive advantages (Driver5) has more limited but focused relationships, with forward influences on organizational challenges (Barrier6) and data interoperability (Barrier5). This indicates its role in addressing specific systemic bottlenecks tied to competitiveness.

Enhancement of corporate reputation (Driver6) plays a more peripheral role, with bidirectional relationships with resistance to change (Barrier3) and challenges in data collection (Barrier4). Its influence is localized, suggesting it is less central in driving widespread change.

These findings underscore the critical role of regulatory pressures, digitalization and circular economy support as primary drivers, while barriers like high costs of digitalization, data challenges and organizational issues represent key areas requiring targeted intervention to enable successful DPP implementation.

2. The next one is the polarity table that provides insights into the nature of the relationships between drivers and barriers.

Table 8 - Polarity of Relationships between Drivers and Barriers

ID	Barrier1	Barrier2	Barrier3	Barrier4	Barrier5	Barrier6
Driver1	-1	0	0	+1	+1	+1
Driver2	+1	/	+1	0	+1	/
Driver3	-1	/	+1	+1	+1	/
Driver4	+1	+1	-1	+1	+1	+1
Driver5	0	-1	/	+1	-1	/
Driver6	/	/	-1	-1	/	/

Some observations include:

- Driver2 shows strong positive relationships (+1) with Barrier1, Barrier3 and Barrier5, but has neutral interactions (0) or no relationship (/) with others.
- Driver4 stands out as having consistent positive influences (+1) across nearly all barriers, except for Barrier3, where it shows a negative polarity (-1).

The directional relationships give use information on how drivers and barriers are related but the polarity analysis gives information on how these relations are positive, negative or neutral.

4.4.2 Analysis of Driving Power and Dependence

This section extends the previous analysis by incorporating the Driving Power (ve^+) and Dependence (ve^-) values into the evaluation of relationships between drivers and barriers. Driving Power determines a level of impact of each driver or barrier on the system while Dependence considers a level of impact that each driver or barrier is subjected to by others.

The inclusion of these metrics provides a deeper understanding of the hierarchical structure within the system. By identifying drivers with high Driving Power and low Dependence, this analysis highlights the key drivers that act as pivotal forces for change. Similarly, barriers with high Dependence and low Driving Power are identified as critical obstacles, requiring focused intervention.

The results are summarized in the following table, which integrates the directional relationships, polarities, and Driving Power and Dependence scores for each driver and barrier. The findings are presented in a tabular form to underscore the main patterns and trends to demonstrate the ratio of the role of each factor in the system.

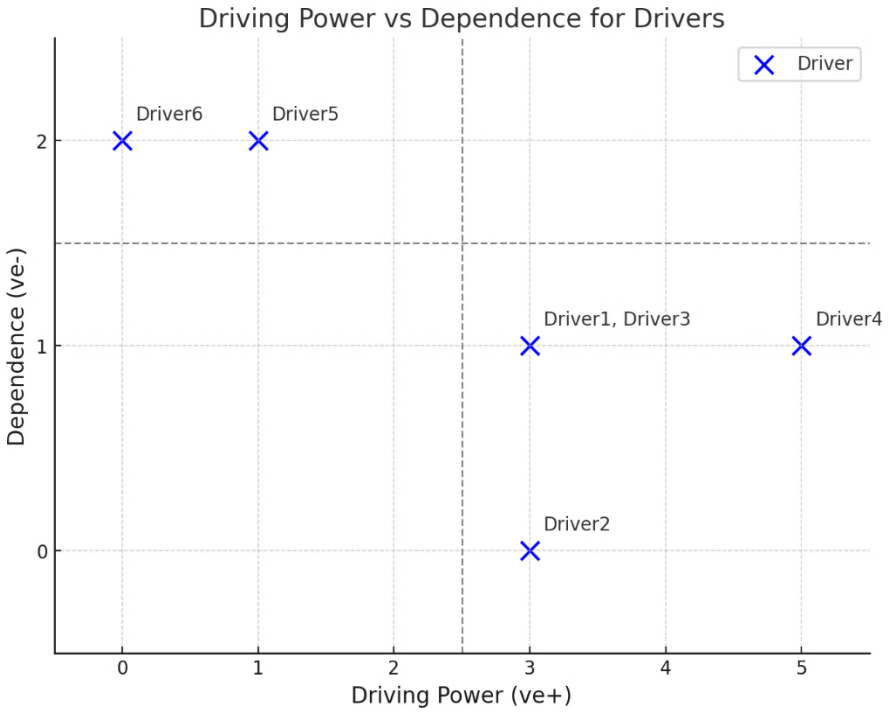
Table 9 - Integration of Driving Power and Dependence Analysis

ID	Barrier1	Barrier2	Barrier3	Barrier4	Barrier5	Barrier6	ve+	ve-
Driver1	-1	0	0	+1	+1	+1	3	1
Driver2	+1	/	+1	0	+1	/	3	0
Driver3	-1	/	+1	+1	+1	/	3	1
Driver4	+1	+1	-1	+1	+1	+1	5	1
Driver5	0	-1	/	+1	-1	/	1	2
Driver6	/	/	-1	-1	/	/	0	2
ve+	2	1	2	4	4	2		
ve-	2	1	2	1	1	0		

4.4.3 Strategic Analysis of Drivers: Influence and Dependence

This section examines the six identified drivers based on their Driving Power (ve^+) and Dependence (ve^-) values. Each driver's position in the system is interpreted to highlight its role as either a key influencer or a reactive element, providing a framework for strategic prioritization.

Table 10 - Scatter Plot: Driving Power vs Dependence for Drivers



The graph illustrates the distribution of drivers based on their Driving Power (ve^+) and Dependence (ve^-) metrics. Each driver is represented as a point, and its position in the indicated quadrants demonstrates the level of its impact and demand in the system.

Quadrant Significance:

- The lower-right quadrant represents drivers with high influence (high ve^+) and low dependence (low ve^-), marking them as key drivers.
- The upper-left quadrant highlights drivers with low influence (low ve^+) and high dependence (high ve^-), indicating reactive elements that require external support.

Driver4: The Dominant Driver

Driver4 represents the push for digitalization of business processes, identified as the most influential factor in the system ($ve^+ = 5$, $ve^- = 1$). It plays a central role in facilitating systemic change by driving innovation, streamlining operations, and improving data management across the value chain. Its high Driving Power and low Dependence indicate that it acts as a pivotal force with minimal reliance on other factors. Driver4 should be prioritized in strategies aimed at accelerating digital transformation and addressing systemic barriers such as data interoperability and organizational challenges.

Drivers1, 2 and 3: Moderately High Influential Drivers

Driver1: represents regulatory pressures for sustainability, a key factor pushing businesses to comply with environmental standards and adopt tools like the DPP to meet these requirements.

Driver2: refers to consumer demand for transparency, emphasizing the need for businesses to provide clear, verifiable information about product lifecycle and sustainability.

Driver3: reflects support for the circular economy, a driver encouraging resource efficiency, recycling and the development of sustainable business models.

These drivers share moderate-high Driving Power and low Dependence, making them critical in supporting the digitalization efforts led by Driver4. They align closely with sustainability goals, suggesting a complementary relationship. For example, regulatory pressures (Driver1) and circular economy support (Driver3) both reinforce the push for digitalization by promoting compliance and innovation. Similarly, consumer demand for transparency (Driver2) benefits from digital tools that enhance traceability and data accessibility

Drivers5 and 6: Low-Influence Drivers

Driver5: represents gaining competitive advantages, which focuses on businesses differentiating themselves through early adoption of sustainability tools like the DPP.

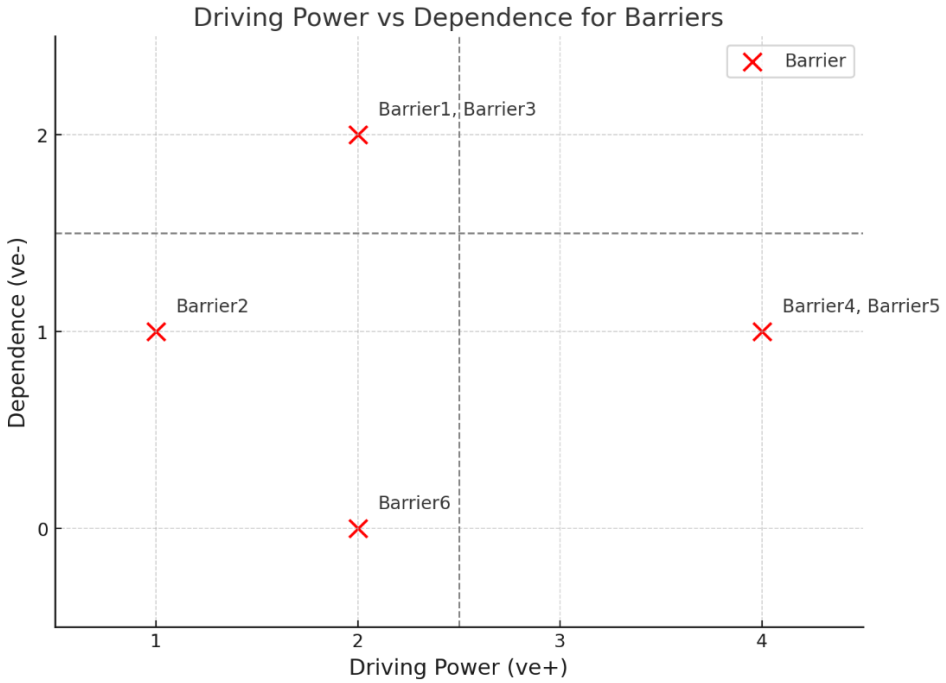
Driver6: reflects enhancement of corporate reputation, emphasizing the potential for businesses to improve their brand image by demonstrating leadership in sustainability and transparency.

Both drivers have low Driving Power ($ve^+ = 1$ and 0, respectively) and high Dependence ($ve^- = 2$), positioning them as reactive elements in the system. They are influenced heavily by higher-impact drivers like regulatory pressures (Driver1) and the push for digitalization (Driver4). These drivers function more as effects of systemic change rather than primary causes, indicating they rely on broader systemic shifts to generate impact.

4.4.4 Strategic Analysis of Barriers: Influence and Dependence

This section examines the six identified barriers based on their Driving Power (ve^+) and Dependence (ve^-) values. Each barrier's position in the system is interpreted to highlight its role as either a key influencer or a reactive element, providing a framework for strategic prioritization.

Table 11 - Scatter Plot: Driving Power vs Dependence for Drivers



The graph illustrates the distribution of barriers based on their Driving Power (ve^+) and Dependence (ve^-) metrics. Each barrier is represented as a point, and its position in the indicated quadrants demonstrates the level of its impact and demand in the system.

Quadrant Significance:

- The lower-right quadrant represents barriers with high influence (high ve^+) and low dependence (low ve^-), marking them as key barriers that should be prioritized for intervention.
- The upper-left quadrant highlights barriers with low influence and high dependence indicating reactive elements that are highly impacted by other factors and require systemic support

Barrier4 and Barrier5: The Key Barriers

Barrier4 (Challenges in Data Collection and Management) and Barrier5 (Data Interoperability and Standardization) stand out as the most influential barriers in the system, both with $ve^+ = 4$ and $ve^- = 1$. Their high Driving Power and low Dependence indicate that these barriers exert significant influence over the system while being relatively unaffected by external factors. These barriers are interconnected: barriers with data collection (Barrier4) impact the approach towards achieving standard and interoperation (Barrier5). Both belong to data related challenges and they are underlining the necessity of better connection and data exchanging opportunities provided by digital technologies. Addressing these barriers will unlock significant opportunities for systemic improvements.

Barrier1 and Barrier3: Dependent Barriers

Barrier1 (High Costs of Digitalization and Adaptation) and Barrier3 (Resistance to Change) are characterized by moderate Driving Power but high Dependence. These barriers are critical because they are both moderately influential and highly impacted by other drivers and barriers within the system. Their high Dependence makes them vulnerable, meaning that effective solutions require a systemic approach, addressing the factors that heavily influence them.

Moreover, these two barriers are interlinked. Resistance to change (Barrier3) can amplify the perceived or actual costs of digitalization (Barrier1), particularly in organizations hesitant to adopt new technologies. Both barriers fall under the broader category of organizational and financial challenges, suggesting that addressing cultural resistance may also reduce financial burdens.

Barrier2 and Barrier6: Secondary Barriers

Barrier2 (Lack of Technical and Managerial Skills) and Barrier6 (Organizational Challenges and Extended Implementation Time) have the same low Driving Power, with $ve^+ = 1$ and $ve^- = 1$ for Barrier2, and $ve^+ = 1$ and $ve^- = 0$ for Barrier6. These barriers are less influential in shaping the system and less impacted by external factors.

However, Barrier6 is particularly notable for its zero Dependence, making it entirely independent. This independence suggests that addressing this barrier can be done in isolation without significant systemic adjustments, making it a secondary priority. Despite their low influence, these two barriers are thematically linked under capacity-related issues, as they both reflect limitations in skills, time, and organizational readiness.

4.4.5 Integrated Analysis of Drivers, Barriers and their Interconnections

This section integrates the analysis of relationships, polarity, Driving Power (ve^+), and Dependence (ve^-) into a single comprehensive framework. The elements synthesized in this way allow us to get a complete picture of the processes occurring in the system and determine the position and relations of the drivers and barriers. The section includes a table that consolidates the data on relationships, polarities, Driving Power and Dependence, providing a detailed overview of the interactions between drivers and barriers, as well as a graph that visually represents these relationships and their corresponding colors, making it easier to identify key patterns and influences within the system.

Before presenting the integrated table, it is essential to understand the types of relationships and their corresponding visual representations. The following legend outlines the color coding used to represent the nature of the relationships between drivers and barriers:

Table 12 - Types of Relationships and corresponding colors

Type of relationship	Color
Bidirectional	
Forward direction	
Backward direction	
No relationship	

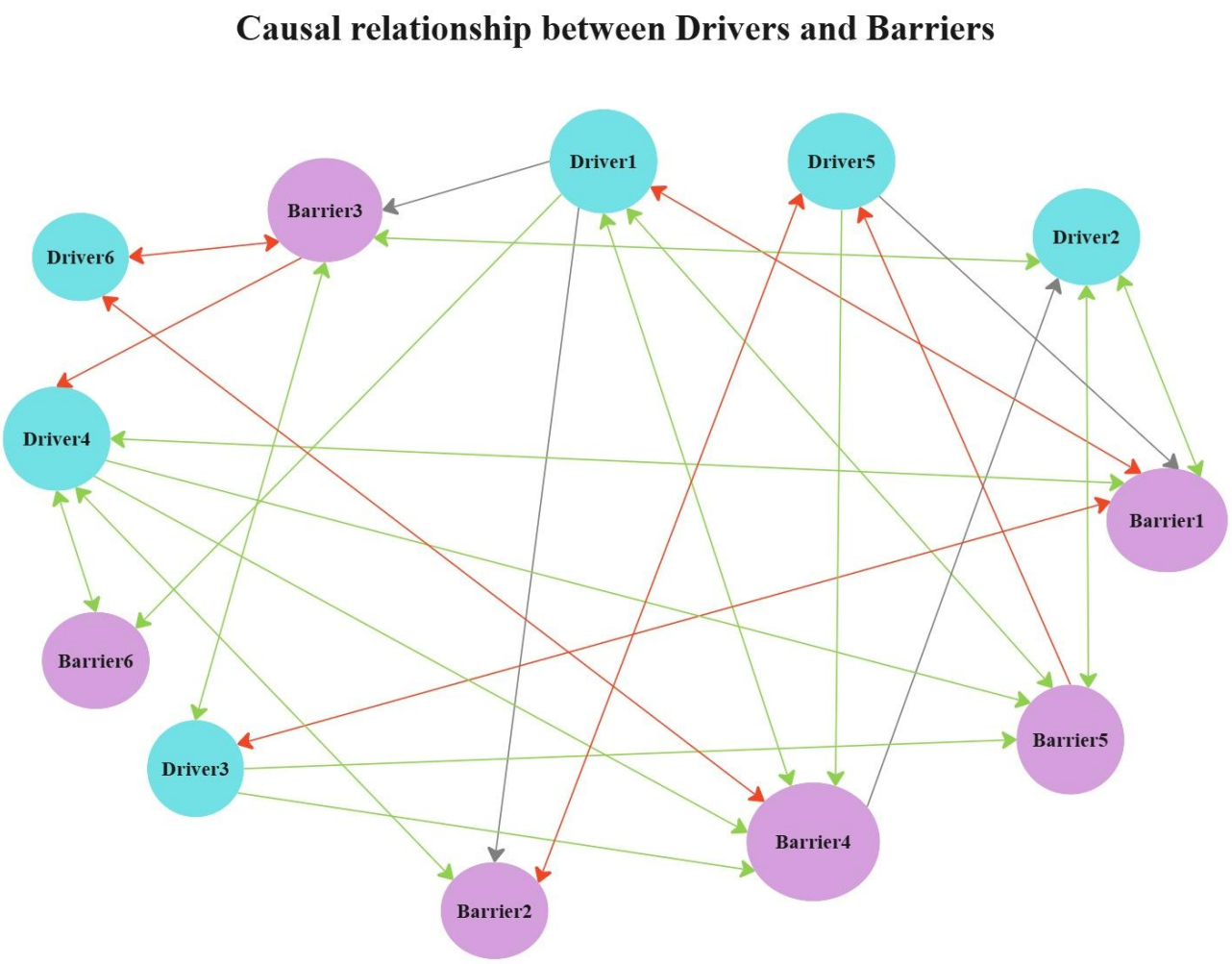
The following table provides a summary of the data, incorporating directional relationships, polarity, and the Driving Power and Dependence metrics for each driver and barrier

Table 13 - Comprehensive Analysis of Relationships, Polarity, Driving Power and Dependence

ID	Barrier1	Barrier2	Barrier3	Barrier4	Barrier5	Barrier6	ve+	ve-
Driver1	-1	0	0	+1	+1	+1	3	1
Driver2	+1	/	+1	0	+1	/	3	0
Driver3	-1	/	+1	+1	+1	/	3	1
Driver4	+1	+1	-1	+1	+1	+1	5	1
Driver5	0	-1	/	+1	-1	/	1	2
Driver6	/	/	-1	-1	/	/	0	2
ve+	2	1	2	4	4	2		
ve-	2	1	2	1	1	0		

The next graph provides a visual representation of the relationships between drivers and barriers, highlighting the type of influence and its corresponding color. The drivers and barriers are shown as nodes and the relationships as directed arcs. Green represent positive polarity, ed represents the negative polarity and gray means the polarity is neutral. Additionally, the arrows which are placed on the edges indicate the direction of the relationship, providing clarity on whether the influence is forward, backward or bidirectional.

Figure 5 - Visual Network of Drivers and Barriers Interconnections



This visual representation simple and effective whereby it becomes easy to understand the relationships between a driver and a barrier as depicted below. It converts what is represented by the table into something more familiar and hence enable the viewer to easily figure out which of the drivers is most influential or which of the barriers is most impacted. Through the direction of arrows, the graph also shows how the values change from one variable to another, and through the use of colours, a positive, negative or null influence can be observed 'behind' the figures. For instance, it

becomes easier to identify higher level of dominating drivers with relatively higher positive polarity or stems that are significantly influenced by multiple drivers, but with negative forms of relationship.

Additionally, this visual tool is particularly effective for identifying clusters of interconnections or outliers, enabling a deeper analysis of systemic behaviour. Such a representation is invaluable for decision-making, as it allows stakeholders to prioritize actions based on the most critical drivers and barriers within the system.

Key Findings from the Visual Representation

The graph highlights several important insights about the relationships between drivers and barriers in the system:

Central Role of Driver4 (Push for Digitalization): it emerges as a dominant driver, with strong positive influences (green arrows) on multiple barriers, particularly Barrier4 (Challenges in Data Collection and Management) and Barrier5 (Data Interoperability and Standardization). This finding reinforces its importance as a systemic enabler that can address core challenges related to data and connectivity.

Interconnection of Data-Related Barriers (Barrier4 and Barrier5): the strong connection between these two barriers, influenced by several drivers, highlights their interdependence. Addressing data collection (Barrier4) is critical for achieving interoperability and standardization (Barrier5), suggesting that a dual approach to tackling these challenges could be more effective than isolated efforts.

Regulatory Pressures as a Double-Edged Sword: Driver1 (Regulatory Pressures for Sustainability) has mixed influences, with both positive and neutral relationships depending on the barrier. For instance, while it drives improvements in interoperability (Barrier5), it also indirectly contributes to financial burdens (Barrier1). This duality underscores the need for balancing regulatory compliance with cost management.

Peripheral Role of Certain Drivers and Barriers: Driver6 (Enhancement of Corporate Reputation) and Barrier6 (Organizational Challenges and Extended Implementation Time) play more localized roles in the system, with limited but specific impacts. This suggests that while they are less central, addressing them could still provide targeted improvements in certain areas.

This graph provides not only a clear overview of the systemic relationships but also reveals interdependencies and unexpected dynamics. Key drivers like Driver4 and Driver1 should be

prioritized in strategic interventions, while the interconnected nature of data-related barriers suggests the need for integrated solutions. By focusing on these insights, businesses can develop targeted strategies that address both the systemic and localized challenges within the system.

4.5 Comparative Insights from Likert Scale and TISM Analyses

The findings from the Likert Scale and TISM analyses presents two parallel views on what factors may enable or hinder the implementation of the Digital Product Passport (DPP). While the above study using Likert Scale provides a positional importance of individual factors as perceived by experts in terms of quantitative value, the TISM analysis investigates the system hierarchy along with interconnectivity of the system.

Key Findings from the Likert Scale Analysis

- Drivers: Regulatory pressures (4.14) and support for the circular economy (4.00) emerged as the most critical enablers, highlighting the alignment of these factors with overarching sustainability goals.
- Barriers: Challenges in data collection (4.71) and high digitalization costs (4.43) were identified as the most significant obstacles, reflecting the tangible difficulties businesses face in adopting the DPP.

Key Insights from the TISM Analysis

- High-Driving-Power Drivers: Factors such as the Push for Digitalization (Driver4) exert significant influence across multiple barriers, positioning them as catalysts for systemic change.
- High-Dependence Barriers: Barriers like High Costs of Digitalization (Barrier1) are heavily influenced by multiple drivers, necessitating targeted interventions to mitigate their impact and unlock progress.

4.5.1 Convergence Between the Two Analyses

Both the Likert Scale and TISM analyses converge on the importance of regulatory pressures and digitalization as central forces shaping the successful implementation of the Digital Product Passport (DPP). Regulatory pressures, such as sustainability goals and compliance requirements, act as external motivators, pushing companies to adopt tools like the DPP. Similarly, digitalization emerges as a pivotal enabler that drives systemic improvements by facilitating data collection, interoperability and process automation.

Both analyses also emphasize the structural nature of data-related constraints as critical barriers. Difficulties in data collection, data integration and data repartition are recognized as systematic problems that involve multi-level actions at organizational and industry levels. These constraints raise

awareness of important areas of investment that business must undertake to improve infrastructural development, inter-agency cooperation, and technological advancement.

The convergence of these findings underscores the interconnectedness of drivers and barriers in the DPP's implementation. Regulatory pressures create the external framework within which digitalization efforts operate, while data-related challenges serve as both obstacles and opportunities for systemic change. Addressing these areas effectively will not only facilitate DPP adoption but also position businesses as leaders in sustainability and digital innovation.

Despite having areas of common concern and focus, the two analyses also present viewership from different lenses that expose different aspects of challenges and enablers for DPP implementation.

4.5.2 Divergence Between the Two Analyses

The Likert Scale and TISM analyses present distinct yet complementary perspectives on the factors influencing the implementation of the Digital Product Passport (DPP). The Likert Scale emphasizes operational and financial constraints as immediate challenges, focusing on barriers like high costs and data collection difficulties that require direct attention. Conversely, the TISM analysis highlights systemic and structural issues, such as data standardization and interoperability, which are critical for long-term success and systemic change.

In terms of drivers, the Likert Scale reflects external pressures, such as regulatory compliance and sustainability goals, as the primary motivators for DPP adoption. In contrast, the TISM analysis underscores the importance of internal capabilities, particularly digitalization, as the central enabler for addressing systemic barriers and driving transformation. These differences provide a clear indication that short-term solutions need to be coupled with strategies that leverage both external drivers and internal enablers. By addressing immediate challenges while simultaneously building on embedded capabilities, businesses can develop strategic responses that are not only effective in the present but also sustainable in the long term.

The integration of these analyses highlights how combining multiple perspectives is essential to creating effective policies. While the Likert Scale captures expert perceptions of immediate priorities, the TISM framework reveals the systemic structure and interrelationships that underpin those priorities. Together, these approaches provide a comprehensive framework for crafting coordinated strategies to eliminate obstacles, harness key enablers, and ensure the successful implementation of the DPP.

The findings derived from these analyses directly inform the business strategies presented in the next section. By leveraging these insights, companies can address priority issues effectively while building a foundation for long-term success in an increasingly digital and sustainable economy.

4.6 Strategic Business Approaches for the DPP Implementation

The integration of the Digital Product Passport (DPP) is a major leap in the change of management and operational models and their intersection with sustainability and digitalisation. Nonetheless, its application calls for the identification of certain strategic issues and factors for its optimal advancement.

Drawing from the combination of Likert Scale and TISM analysis presented in this research, this section provides a clear elucidation of strategies that businesses can adopt to fully harness on the opportunities and minimize on the risks which are associated with actualization of DPP. These strategies work in cooperation with the key success drivers while managing the important barriers, as mentioned in the analyses, to foster a successful roadmap.

This chapter uses a comprehensive approach based on the combination of two approaches, which are based on the relative contribution of individual factors and the interaction between them. By implementing the ideas based on such analyses, businesses can guarantee a successful transition, compliance with the requirements of the DPP, as well as gaining a competitive edge when incorporating the rule into organizational processes.

The following strategies translate these insights into actionable recommendations, addressing both the opportunities presented by key drivers and the challenges posed by critical barriers. Each strategy is designed to align with the findings of the Likert Scale and TISM analyses, providing businesses with a clear path to successful DPP implementation

1. Invest in Digital Infrastructure and Skills Development

The high-driving power of Driver4 (Push for Digitalization), as identified in the TISM analysis, highlights the need to invest in advanced digital infrastructure to unlock systemic improvements. Similarly, the Lack of Technical and Managerial Skills barrier, emphasized in the Likert Scale findings, underscores the importance of capacity-building initiatives.

Based on the identified challenges, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Invest in advanced digital technologies, such as IoT sensors, blockchain, and AI-driven tools, to enhance data collection, interoperability and supply chain transparency.

- Launch continuous training programs to build internal expertise, reduce reliance on external consultants and ensure long-term knowledge retention.
- Foster collaborations with universities and research centres to develop innovative solutions tailored to industry needs.

Benefits: these actions will enhance operational efficiency, improve data quality, and position businesses as leaders in digital transformation.

2. Develop Scalable Pilot Projects

Pilot programs provide a controlled environment to test DPP implementation, aligning with TISM findings that emphasize gradual, system-wide adaptation to overcome barriers such as High Costs of Digitalization (Barrier1).

Based on the identified challenges, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Focus pilots on specific product categories or supply chain segments to identify best practices and refine processes before scaling.
- Use pilot results to demonstrate the tangible benefits of the DPP to stakeholders, reducing resistance to change.

Benefits: Pilot projects reduce risks, build confidence among stakeholders, and provide actionable insights for broader implementation.

3. Establish Industry-Wide Standards and Practice

The systemic nature of data-related barriers, such as Challenges in Data Collection and Interoperability, was underscored in both the Likert Scale and TISM analyses.

Based on the identified challenge, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Participate in industry consortia to develop and adopt common data standards and protocols.

- Collaborate with regulators and industry leaders to create a unified framework that facilitates seamless data exchange across supply chains.

Benefits: Standardization reduces fragmentation, ensures compatibility across systems, and accelerates DPP adoption.

4. Promote Cost-Sharing Initiative

The high financial burden associated with Barrier1 (High Costs of Digitalization) can be alleviated through collaborative approaches.

Based on the identified challenge, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Develop shared platforms for data collection and management, leveraging economies of scale to reduce individual costs.
- Advocate for public funding or tax incentives to support DPP adoption and infrastructure development.

Benefits: Cost-sharing initiatives make DPP adoption more accessible, also for small and medium enterprises, while fostering industry-wide collaboration.

5. Leverage Regulatory Pressures as Opportunities

The Likert Scale findings identified Regulatory Pressures (Driver1) as the most critical enabler for DPP implementation.

Based on the identified challenge, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Position the DPP as a competitive advantage by exceeding minimum compliance requirements and showcasing leadership in sustainability.
- Use the DPP to enhance transparency in reporting and to build trust with regulators, consumers, and investors.

Benefits: Leveraging regulatory pressures not only ensures compliance but also strengthens market positioning and stakeholder trust.

6. Demonstrate Tangible Benefits to Stakeholders

Resistance to change, as highlighted in both analyses, often stems from a lack of understanding of the DPP's advantages.

Based on the identified challenge, businesses should consider the following recommendations, which are grounded in insights derived from the analyses, expert interviews, relevant literature on digital transformation and organizational change, and the researcher's reflections within the study context:

- Share success stories and data-driven results to illustrate the DPP's impact on efficiency, cost savings, and sustainability.
- Engage stakeholders early in the process, addressing concerns and incorporating their feedback into implementation plans.

Benefits: Building trust and showcasing benefits increases stakeholder commitment and reduces implementation barriers.

Altogether the defined strategies provide a contingency plan on how business organizations can successfully implement DPP to increase innovation, sustainability and control over competition forces. Digital transformation and collaboration coupled with regulatory changes and market forces provide companies with an opportunity to road map a transition into the new sustainability revolution. The key message about the Digital Product Passport is not that it is a 'compliance tool', it is significantly more than that: It becomes a lever for change. When effectively implemented the business world will be able to reposition companies with regards to sustainable development frameworks of the world, enhance resource consumption efficiencies and promptly address changing consumer consent. Finally, implementing the DPP will assure that the companies will be ready for the future in which sustainability and digitalisation are not the extra add-ons but the critical success factors.

Chapter Five: Conclusion

This thesis dealt with the Digital Product Passport as a management instrument for a more circular and climate-neutral economy. In a global context marked by pressing environmental challenges and the need for sustainable resource management, the DPP has proven to be a strong support tool in enhancing transparency, accountability of the production and consumption processes.

The research results highlighted how the successful implementation of the DPP is influenced by a combination of enabling factors and obstacles. Key drivers include regulatory pressure for sustainability, support for the digitalization of business processes, and the DPP's contribution to fostering a circular economy. At the same time, significant barriers were identified including high digitalization costs, a lack of technical and managerial skills and challenges related to data standardization and interoperability. The analysis of these dynamics and relationships, conducted using the Delphi method and Total Interpretive Structural Modeling (TISM), enabled the mapping of interconnections among the various factors and the identification of strategic intervention points. Specifically, the Delphi method facilitated the prioritization of drivers and barriers by leveraging the expertise and perspectives of the panel of nine experts, offering a clear ranking of key factors such as regulatory pressures and data-related challenges. This method provided a structured and consensus-driven approach to identifying the most critical elements influencing the DPP's implementation, such as the role of regulatory frameworks in driving adoption, the necessity of standardized data protocols to ensure interoperability, and the importance of addressing high digitalization costs to enable broader accessibility for small and medium-sized enterprises.

On the other hand, the TISM analysis provided a systemic view of the interdependencies among these factors, uncovering how certain drivers, such as the push for digitalization, exert a cascading influence across multiple barriers. This systemic perspective was essential in identifying not just the importance of individual factors but also their role within the broader network of relationships. For instance, TISM highlighted the pivotal role of data interoperability as a barrier that is both influenced by and influences other key factors, making it a critical point of intervention for businesses.

By combining these two approaches, the study was able to offer both a prioritized view of challenges and opportunities and a deeper understanding of their interconnections, ultimately guiding the development of actionable and comprehensive recommendations. The main conclusions were that fostering regulatory alignment, investing in digital infrastructure, and developing pilot projects are essential steps to overcome barriers and leverage drivers effectively. Additionally, the study

emphasized the critical need for stakeholder collaboration to harmonize standards and improve data interoperability, ensuring the successful integration of the DPP into diverse industries.

This work makes a significant contribution to both academic debate and practical applications. On the one hand, it provides a robust theoretical basis for understanding the challenges and opportunities linked to the DPP. On the other hand, it offers concrete recommendations for businesses and policymakers. These include investing in advanced digital infrastructure, such as IoT, blockchain and AI-driven tools, to enhance data collection, interoperability and transparency across supply chains. Additionally, developing scalable pilot projects is a practical approach to test the implementation of the Digital Product Passport in controlled environments, allowing businesses to refine processes and demonstrate tangible benefits before scaling. Another critical strategy is the adoption of common standards for data management, ensuring interoperability and harmonization across industries, which facilitates seamless collaboration and data exchange between stakeholders.

Despite the results achieved, the research has certain limitations. Firstly, the research has been conducted in the European context indicating that research examining the relevance of the DPP in other geographic and sectoral contexts should be conducted in the future. Secondly, the type of methodology championed was a qualitative one; therefore, chief reliance was made on the 'perception' of a fairly reduced number of practitioners /experts involved in a fairly restricted range of situations.

Additionally, the questionnaire used, being quite long and detailed, may have limited the sample size and influenced participation. These aspects could be addressed in future studies by involving a larger number of experts and industries and utilizing more streamlined data collection tools.

In conclusion, the DPP is not merely a regulatory compliance tool but a true catalyst for change toward a more sustainable and resilient economic system. Its adoption, though complex, offers companies numerous benefits, such as the opportunity to differentiate themselves in the market, enhance supply chain transparency and optimize resource management through better tracking of product lifecycles. Additionally, it allows businesses to significantly contribute to global sustainability goals by reducing waste, promoting recycling and aligning with consumer demand for greater accountability.

With coordinated efforts among businesses, institutions and consumers, the DPP can become a cornerstone for the future of the circular economy, fostering innovation and collaboration across industries to build a more efficient and sustainable economic framework.

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Appendix: Questionnaire submitted to the experts

This appendix includes the questionnaire used to collect data from experts. The questionnaire is divided into two main sections:

1. *Likert Scale*: to assess the importance of drivers and barriers for the implementation of the Digital Product Passport (DPP).
2. *TISM Methodology*: to explore the relationships and polarities between pairs of drivers and barriers.

The questionnaire was developed using Google Forms to ensure accessibility and easy sharing. The link to the questionnaire is available here: https://forms.gle/2RzmrxKh7wXs8CZE6.

Section 1: Likert Scale

How important do you consider ' High costs of digitalization and adaptation ' as a barrier to the adoption of the Digital Product Passport (DPP)? (1 = Not Important, 5 = Very Important)

Please explain in a sentence why you rated the importance of ' High costs of digitalization and adaptation ' as you did

How important do you consider the ' Lack of technical and managerial skills ' as a barrier to the adoption of the Digital Product Passport (DPP)?

Please explain in a sentence why you rated the importance of ' Lack of technical and managerial skills ' as you did

How important do you consider the 'Resistance to change' as a barrier to the adoption of the Digital Product Passport (DPP)?

Please explain in a sentence why you rated the importance of 'Resistance to change' as you did

How important do you consider 'Challenges in data collection and management' as a barrier to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of ' Challenges in data collection and management ' as you did

How important do you consider 'Data interoperability and standardization' as a barrier to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of 'Data interoperability and standardization' as you did

How important do you consider ' Organizational challenges and extended implementation time ' as a barrier to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of ' Time and organizational difficulties for implementation ' as you did

How important do you consider ' Regulatory pressures for sustainability' as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of ' Regulatory pressures for sustainability' as you did

How important do you consider ' Consumer demand for transparency ' as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of ' Consumer demand for transparency ' as you did

How important do you consider 'Support for circular economy ' as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of 'Support for circular economy ' as you did

How important do you consider 'Push for digitalization of business processes 'as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of 'Push for digitalization of business processes ' as you did

How important do you consider 'Gaining competitive advantages ' as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of 'Gaining competitive advantages 'as you did

How important do you consider 'Enhancement of corporate reputation ' as a driver to the adoption of the Digital Product Passport (DPP)?

Please explain why you rated the importance of 'Enhancement of corporate reputation ' as you did

Section 2: TISM Methodology

Is there a relationship between Regulatory pressures for sustainability and Data interoperability and standardization?

What is the polarity of the relationship between Regulatory pressures for sustainability and Data interoperability and standardization?

Is there a relationship between Regulatory pressures for sustainability and High costs of digitalization and adaptation?

What is the polarity of the relationship between Regulatory pressures for sustainability and High costs of digitalization and adaptation?

Is there a relationship between Regulatory pressures for sustainability and Lack of technical and managerial skills?

What is the polarity of the relationship between Regulatory pressures for sustainability and Lack of technical and managerial skills?

Is there a relationship between Regulatory pressures for sustainability and Challenges in data collection and management?

What is the polarity of the relationship between Regulatory pressures for sustainability and Challenges in data collection and management?

Is there a relationship between Regulatory pressures for sustainability and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Regulatory pressures for sustainability and Organizational challenges and extended implementation time?

Is there a relationship between Regulatory pressures for sustainability and Resistance to change?

What is the polarity of the relationship between Regulatory pressures for sustainability and Resistance to change?

Is there a relationship between Consumer demand for transparency and Data interoperability and standardization?

What is the polarity of the relationship between Consumer demand for transparency and Data interoperability and standardization?

Is there a relationship between Consumer demand for transparency and High costs of digitalization and adaptation?

What is the polarity of the relationship between Consumer demand for transparency and High costs of digitalization and adaptation?

Is there a relationship between Consumer demand for transparency and Lack of technical and managerial skills?

What is the polarity of the relationship between Consumer demand for transparency and Lack of technical and managerial skills?

Is there a relationship between Consumer demand for transparency and Challenges in data collection and management?

What is the polarity of the relationship between Consumer demand for transparency and Challenges in data collection and management?

Is there a relationship between Consumer demand for transparency and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Consumer demand for transparency and Organizational challenges and extended implementation time?

Is there a relationship between Consumer demand for transparency and Resistance to change?

What is the polarity of the relationship between Consumer demand for transparency and Resistance to change?

Is there a relationship between Support for the Circular Economy and Data interoperability and standardization?

What is the polarity of the relationship between Support for the Circular Economy and Data interoperability and standardization?

Is there a relationship between Support for the Circular Economy and High costs of digitalization and adaptation?

What is the polarity of the relationship between Support for the Circular Economy and High costs of digitalization and adaptation?

Is there a relationship between Support for the Circular Economy and Lack of technical and managerial skills?

What is the polarity of the relationship between Support for the Circular Economy and Lack of technical and managerial skills?

Is there a relationship between Support for the Circular Economy and Challenges in data collection and management?

What is the polarity of the relationship between Support for the Circular Economy and Challenges in data collection and management?

Is there a relationship between Support for the Circular Economy and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Support for the Circular Economy and Organizational challenges and extended implementation time?

Is there a relationship between Support for the Circular Economy and Resistance to change?

What is the polarity of the relationship between Support for the Circular Economy and Resistance to change?

Is there a relationship between Push for digitalization of business processes and Data interoperability and standardization?

What is the polarity of the relationship between Push for digitalization of business processes and Data interoperability and standardization?

Is there a relationship between Push for digitalization of business processes and High costs of digitalization and adaptation?

What is the polarity of the relationship between Push for digitalization of business processes and High costs of digitalization and adaptation?

Is there a relationship between Push for digitalization of business processes and Lack of technical and managerial skills?

What is the polarity of the relationship between Push for digitalization of business processes and Lack of technical and managerial skills?

Is there a relationship between Push for digitalization of business processes and Challenges in data collection and management?

What is the polarity of the relationship between Push for digitalization of business processes and Challenges in data collection and management?

Is there a relationship between Push for digitalization of business processes and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Push for digitalization of business processes and Organizational challenges and extended implementation time?

Is there a relationship between Push for digitalization of business processes and Resistance to change?

What is the polarity of the relationship between Push for digitalization of business processes and Resistance to change?

Is there a relationship between Gaining competitive advantages and Data interoperability and standardization?

What is the polarity of the relationship between Gaining competitive advantages and Data interoperability and standardization?

Is there a relationship between Gaining competitive advantages and High costs of digitalization and adaptation?

What is the polarity of the relationship between Gaining competitive advantages and High costs of digitalization and adaptation?

Is there a relationship between Gaining competitive advantages and Lack of technical and managerial skills?

What is the polarity of the relationship between Gaining competitive advantages and Lack of technical and managerial skills?

Is there a relationship between Gaining competitive advantages and Challenges in data collection and management?

What is the polarity of the relationship between Gaining competitive advantages and Challenges in data collection and management?

Is there a relationship between Gaining competitive advantages and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Gaining competitive advantages and Organizational challenges and extended implementation time?

Is there a relationship between Gaining competitive advantages and Resistance to change?

What is the polarity of the relationship between Gaining competitive advantages and Resistance to change?

Is there a relationship between Enhancement of corporate reputation and Data interoperability and standardization?

What is the polarity of the relationship between Enhancement of corporate reputation and Data interoperability and standardization?

Is there a relationship between Enhancement of corporate reputation and High costs of digitalization and adaptation?

What is the polarity of the relationship between Enhancement of corporate reputation and High costs of digitalization and adaptation?

Is there a relationship between Enhancement of corporate reputation and Lack of technical and managerial skills?

What is the polarity of the relationship between Enhancement of corporate reputation and Lack of technical and managerial skills?

Is there a relationship between Enhancement of corporate reputation and Challenges in data collection and management?

What is the polarity of the relationship between Enhancement of corporate reputation and Challenges in data collection and management?

Is there a relationship between Enhancement of corporate reputation and Organizational challenges and extended implementation time?

What is the polarity of the relationship between Enhancement of corporate reputation and Organizational challenges and extended implementation time?

Is there a relationship between Enhancement of corporate reputation and Resistance to change?

What is the polarity of the relationship between Enhancement of corporate reputation and Resistance to change?