ASSESSMENT OF TURKISH TEXTILE COMPANIES' COMPLIANCE WITH DIGITAL PRODUCT PASSPORT REGULATION: A SURVEY IN TURKEY

MUHAMMET ERKAM KÜÇÜKKAYA

BOĞAZİÇİ UNIVERSITY

2025

ASSESSMENT OF TURKISH TEXTILE COMPANIES' COMPLIANCE WITH DIGITAL PRODUCT PASSPORT REGULATION: A SURVEY IN TURKEY

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirement for the degree of

Master of Arts

in

Management

by

Muhammet Erkam Küçükkaya

Boğaziçi University

2025

Assessment of Turkish Textile Companies' Compliance with Digital Product Passport Regulation: A Survey in Turkey

The Thesis of Muhammet Erkam Küçükkaya

has been approved by:

Assoc.Prof. Ali Coşkun (Thesis Advisor) _____

Assoc.Prof. Murat Levent Demircan (Thesis Co-Advisor) _____

Prof. Nilgün Cılız _____

Assoc.Prof. Gözde Erhan _____

Prof. Rasim Özcan (External Member) _____

May 2025

DECLARATION OF ORIGINALITY

I, Muhammet Erkam Küçükkaya, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature…….....

Date …….....

ABSTRACT

Assessment of Turkish Textile Companies' Compliance with Digital Product Passport Regulation: A Survey in Turkey

Sustainability and environmental awareness have become increasingly prominent concerns, driving research and innovation across industries. Within this context, ecodesign and traceability have assumed central importance, and the Digital Product Passport (DPP) has recently been promoted and, through various European Union (EU) regulations, gradually mandated. The present study aims to assess the levels of awareness regarding digital product passports, digitalization, and traceability among SMEs and large enterprises operating in Turkey's textile sector, and to offer an academic perspective on recommended courses of action.

A survey was administered to 80 textile enterprises to capture their demographic profiles, fundamental awareness of the DPP concept, the extent of any ongoing DPP-related initiatives, and their approaches to data traceability. The collected responses were subjected to chi-square tests, t-tests, and correlation analyses. Based on these results, twelve hypotheses concerning the interrelations of different variables were examined, and targeted recommendations were formulated for those variable pairs exhibiting statistically significant associations.

This research was facilitated through an industry–academia collaboration, with support from İHKİB (Istanbul Apparel Exporters' Association) for participant recruitment and survey administration. The findings contribute valuable empirical evidence to inform the development of roadmaps and strategic plans related to digitalization, Digital Product Passport implementation, and traceability, thereby

underpinning future policy and industrial efforts with a solid scientific foundation.

ÖZET

Türk Tekstil Şirketlerinin Dijital Ürün Pasaportu Düzenlemesine Uyumunun Değerlendirilmesi: Türkiye'de Bir Anket Çalışması

Sürdürülebilirlik, çevresel farkındalık gibi konuların günden güne önem kazandığı ve sektörler tarafından üzerine çalışmalar yapılan bu dönemde ecodesign ve izlenebilirlik konuları da gündemimizde oldukça yer tutmaktadır. Bu kapsamda dijital ürün pasaportu uygulaması son dönemde yaygınlaştırılmaya ve Avrupa Birliği (AB) tarafından çeşitli regülasyonlarla zorunlu hale getirililmeye başlanmaştır. Bu çalışma ile Türkiye'de tekstil sektöründe faaliyet gösteren KOBİ ve büyük ölçekli işletmelerin dijital ürün pasaportu, dijitalizasyon ve izlenebilirlik konularındaki farkındalık düzeylerini tespit etmek ve alınacak aksiyonlara akademik bir perspektif sunmak amaçlanmıştır.

Tekstil sektöründe faaliyet gösteren 80 işletmenin katılımıyla işletmelerin demografik yapıları, dijital ürün pasaportu temel farkındalıkları, dijital ürün pasaportu uygulaması ile ilgili çalışmaları varsa çalışmalarının ne düzeyde oldukları ve veri izlenebilirliği yaklaşımlarını anlamaya yönelik bir anket çalışma yapılmıştır. Anket sonuçları ki kare, t testi ve korelasyon testleri ile istatistik olarak analiz edilmiştir. Anket doğrultusunda 12 adet hipotez ile farklı değişkenlerin birbiri ile ilişkisi incelenmiştir ve aralarında anlamlı ilişki bulunan değişkenler için önerilerde bulunulmuştur.

Bu çalışma için akademi-sanayi işbirliği kapsamında firmalara ulaşma ve anket çalışması için İHKİB'den (İstanbul Hazır Giyim ve Konfeksiyon İhracatçıları Birliği) destek alınmıştır. Çalışma dijitalizasyon, dijital ürün pasaportu ve izlenebilirlik konuları ile ilgili hazırlanacak yol haritalarına bilimsel temel

oluşturması açısından önemli bulgular taşımaktadır.

TABLE OF CONTENTS

LIST OF TABLES

ABBREVIATIONS

DPP	Digital Product Passport
ESG	Enviromental Social Governance
WTO	World Trade Organization
ESPR	Ecodesign for Sustainable Products Regulation
SME	Small and Medium-sized Enterprises
RFID	Radio Frequency Identification
İHKİB	Istanbul Apparel Exporters' Association

CHAPTER 1

INTRODUCTION

In today's rapidly evolving digital world, new applications are continually emerging, and over time, these applications are increasingly being mandated by relevant authorities for businesses. Alongside the growing prominence of the Environmental, Social, and Governance (ESG) framework, the concepts of eco-design and the Digital Product Passport (DPP) have also started to gain attention. Research indicates that with the rise of digitalization, individual carbon emissions are also increasing significantly. Consequently, monitoring data and designing sustainable production, design, and supply processes based on this data has become imperative.

To ensure the sustainability of production, design, and supply chain processes, a planned and incremental approach is required. In this context, it is recommended that businesses monitor the data they have digitized. In our academic study, a comprehensive literature review was conducted on these concepts, and the current state and level of awareness regarding digital product passports, digitalization, and traceability in the textile industry were analyzed.

This research was conducted within the framework of academia-industry collaboration. Support was received from İHKİB (Istanbul Apparel Exporters' Association) for communicating with companies and adapting the survey questions to fit the industry context. The results of the sector-specific analyses will be shared with İHKİB to guide the development of necessary actions.

A total of 80 companies operating in various segments of the textile industry, including ready-to-wear, fabric, fiber/yarn, and integrated manufacturing, participated in the survey. These companies were asked questions across different

categories to assess their current maturity levels and awareness regarding digitalization, digital product passports, and traceability. The confidentiality of participating companies was strictly maintained throughout the survey, and no sensitive institutional data was disclosed.

CHAPTER 2

LITERATURE

2.1 Environmental social governance (ESG)

ESG is a framework that assesses the sustainability performance and ethical responsibilities of companies or organisations according to environmental, social and governance criteria.

E (Environmental): Focuses on issues such as the company's environmental impact, carbon footprint, natural resource use, energy consumption, waste management and biodiversity

S (Social): Focuses on issues such as employee rights, worker safety, social responsibility projects, inclusion and diversity, human rights

G (Governance): Focuses on issues such as the management structure, ethical values and activities, and transparency.

ESG criteria are important for investors and stakeholders to evaluate the sustainability performance of the company and to take action accordingly. Therefore, they identify “information types, measures used, themes disclosed, adopting reporting guidelines, the inclusion of an assurance statement, and the use of visual tools” as significant dimensions/features of reporting quality. ESG is a large framework used to measure and increase the contribution of companies not only economically but also in the environment, society and corporate governance. ESG criteria, which are becoming increasingly widespread today, are recognised by both investors and customers and leave a sensitive image.

ESG (Environmental, Social, and Governance) criteria provide a comprehensive framework for evaluating a company’s sustainability performance,

focusing not only on financial success but also on its ethical responsibilities in environmental, social, and governance dimensions. These criteria highlight the long-term impacts of a company's activities, encouraging awareness of its societal responsibilities. The world's first sustainability index is the Domini 400 Social Index, created in 1990 by a company called "KLD Research & Analytics." This index has been specifically designed for institutional investors focusing on sustainability-oriented investments. Incorporating key factors such as social, environmental, and governance aspects, the index enables an analysis of companies' contributions to sustainability. These factors aim to comprehensively assess not only the financial performance of companies but also their environmental impact, societal benefits, and corporate governance standards. In this way, investors can make more informed decisions while supporting sustainable development.

The environmental (E) dimension addresses the company's efforts to minimize its impact on the environment. This includes reducing carbon emissions, improving water usage efficiency, recycling waste, and ensuring the sustainable use of natural resources. The textile industry, as one of the most environmentally impactful sectors globally, carries significant responsibility for sustainable production practices. Issues such as intensive water usage, chemical treatments, energy consumption, and waste generation position the textile industry as a major player in the realm of environmental sustainability. Consequently, adopting sustainable textile production methods, using recycled materials, and implementing energy-efficient techniques are essential steps in reducing the environmental impact of the sector. Examples include using closed-loop water systems to save water or reducing chemical waste during production, both of which help mitigate the environmental footprint of textile production.

The social (S) dimension focuses on a company's societal impact, particularly its relationships with employees and the community. Key topics here include workers' rights, job safety, fair wages, diversity and inclusion, and other aspects of social responsibility. In the textile industry, labor rights, particularly in factories in developing countries, have been a major point of discussion. The sector is often associated with low-wage, precarious, and unsafe working conditions, making it crucial to implement social responsibility practices. Ethical working conditions, providing a safe and healthy work environment, ensuring gender equality, and promoting social inclusion are fundamental components of social responsibility in the textile sector. Additionally, community-oriented projects and workforce training programs can reinforce social sustainability in the industry. By integrating environmental and social sustainability strategies, companies can increase their credibility and trust among consumers and investors.

The governance (G) dimension evaluates a company's management practices, ethical values, and transparency. Effective governance strengthens internal controls and builds trust in relationships with external stakeholders. Transparency, accountability, and strong ethical values are key components of a company's long-term success. In the textile sector, transparency and traceability throughout the supply chain are essential aspects of good governance. This involves not only tracking every stage of production but also preventing potential ethical violations in the supply chain. Companies that are transparent in reporting their environmental and social impacts can earn the trust of both the public and investors. Furthermore, effective governance structures, transparent decision-making processes, good communication with stakeholders, and solid auditing practices will help companies meet their sustainability goals.

The literature has shown that improved ESG performance reduces risk and enhances financial performance; however, the results vary significantly across countries (Chelawat and Trivedi, 2016). ESG criteria serve as an evaluation tool that goes beyond financial performance, encompassing a company's environmental, social, and governance responsibilities. In industries like textiles, where environmental and social impacts are significant, aligning with ESG criteria is vital for long-term success. Investors, consumers, and other stakeholders are increasingly considering how well companies adhere to these criteria when making decisions. The quality of reports within ESG is highly important for investors. Thus, implementing ESG practices not only enhances a company's contributions to the environment, society, and governance but also provides a competitive advantage, offering significant contributions to the broader sustainability of the sector.

2.2 Environmental social governance (ESG) eco-design

Ecodesign is a strategy that contributes to ESG within the scope of "Environment" and encourages companies to develop environmentally friendly product designs. Ecodesign aims minimizing environmental impacts of the product by taking into consideration phases from material selection to disposal of a product. It supports sustainability goals in areas such as using environmentally friendly materials in production, increasing energy efficiency, extending product life, reusability and recyclability.

Ecodesign is of great importance for the circular economy. In the circular economy, products that can be used for a long time are designed. Ecodesign also contributes to this process in terms of reuse and recycling of products.

The Ecodesign for Sustainable Products Regulation (ESPR) aims to promote the design of sustainable products by establishing various criteria to reduce their environmental impacts throughout their lifecycle. This regulation, particularly in the textile sector, seeks to store eco-design information through the Digital Product Passport (DPP) to minimize the environmental impacts of products. In this context, the eco-design information that should be stored in the DPP plays a crucial role in evaluating the sustainability performance of textile products. Durability and reliability are key factors that ensure the long lifespan of textile products, contributing to extended usage periods. A longer-lasting product not only enhances consumer satisfaction but also reduces resource consumption, as it needs to be replaced less frequently. Reusability refers to the ability of textile products to be used for multiple purposes, a fundamental principle of the circular economy. Repairability, maintenance, and renewability help extend the life of products by preventing waste formation. These aspects ensure that textile products are not only functional but also designed to be easy to repair and maintain. The Ecodesign Directive aims to promote the circular economy aspects of the energy-related products by setting mandatory requirements on environmental impacts, potential improvements and lowering life cycle costs. Energy and resource efficiency play a critical role in reducing the environmental footprint of textile production processes, as they encourage the more efficient use of energy and water in manufacturing. Recycled content and recyclability enable the environmentally friendly reprocessing of materials, thus reducing dependence on raw materials and significantly decreasing waste production. Carbon and environmental footprints measure the environmental impacts throughout the production and distribution processes, allowing for the development of strategies to reduce these impacts. Finally, expected waste material

generation helps to predict how much waste will be produced at the end of a product's life cycle. All of these elements provide the essential information required to implement a circular economy in the textile sector, enabling environmental impacts to be tracked and reduced at all stages, from product design to recycling processes. The DPP, as a central tool for achieving environmental sustainability goals, will allow the textile industry to take significant steps toward sustainability.

2.3 Digital product passport

The concept of a Digital Product Passport has been identified as a container that integrates various datasets about a product from all its life cycle phases.
The Digital Product Passport facilitates comprehensive tracking of a product's lifecycle, enabling its movement to be monitored during transportation. It forms a new digital format to digitise and modernise product data to support industry transformation towards circularity and carbon neutrality, including legal and/or voluntary data. It allows access to product-related data both online and offline. Offline access to online information can be achieved through technologies such as QR codes, barcode systems, image recognition technologies, RFID/NFC systems, blockchain-based tracking systems, cloud-based data management platforms, and IoT-enabled data collection systems.

Digital Product Passports can be categorized into two types: static and dynamic. A static Digital Product Passport contains data that is solely readable and cannot be modified by the stakeholders involved in the product lifecycle. The data is generated at specific points during the lifecycle and remains unaltered thereafter. This type of passport typically includes the technical and environmental specifications of the product, such as serial numbers, material composition, and

details regarding recycling and reusability. Since the data is immutable, updates are unnecessary, making it a simpler and less resource-intensive option.

Conversely, a dynamic Digital Product Passport encompasses both readable and writable data, allowing relevant stakeholders to update information throughout the product lifecycle. It provides details such as repair history, material composition, software updates, component replacements, environmental footprint, and carbon emissions. This dynamic nature facilitates access to up-to-date product information and enhances the flow of data among stakeholders. However, the ability to modify information introduces potential security risks, necessitating robust protective infrastructures.

The choice between static and dynamic Digital Product Passports is typically determined by the specific requirements of the industry. For instance, static passports may suffice in industries with simpler processes, such as plastics, whereas dynamic passports are more suitable for complex sectors, such as electronics, where frequent updates and information exchange are required.

The intention of the Digital Product Passports (DPP) is to be used for tracing and storing data related to a product throughout its entire life cycle and value chain. The CIRPASS Project's research on possible Digital Product Passport use cases in the electronics and textile value chains in March 2024 covered the battery, electronics and textile sectors. In this study, various use cases were used to understand the benefits and opportunities of making data collected on sustainability and circularity accessible. The physical product flow was compared with the digitised product flow and the benefits of the digital flow were demonstrated. As a result of the study, it was concluded that separating products to support reuse and increasing the sale of second-hand textiles instead of recycling will increase

efficiency; the value created in the resale of second-hand clothing on online platforms is increased. In this direction, targets such as reducing information asymmetry, carrying out studies to extend the life cycle and increasing the recovery rate of valuable materials and products at the end of use have been determined.

The European Commission has launched an initiative to establish a sustainable textiles strategy (European Commission, 2022b). The European Commission is working on a new strategic plan to support sustainability goals in the textile sector. This initiative aims to reduce environmental impacts, promote the circular economy, and make resource use across the sector more efficient. This strategy of the European Union provides a roadmap, particularly for reducing the carbon footprint of the textile industry and increasing the reuse of resources.

As part of the "Transition Pathway" initiative, the EU will collaborate with stakeholders to expand resource-efficient production methods, as well as reuse, repair, and other circular business models in the textiles sector. Member States are encouraged to support reuse and repair industries through tax measures that align with State Aid and WTO regulations (European Commission, 2020a).

The European Commission has taken a series of strategic steps to enhance the sustainability of the textile sector. The "Transition Pathway" initiative, launched within this framework, aims to improve resource efficiency in the sector while also adopting the principles of a circular economy. This approach involves not only the production processes in the textile industry but also critical circular business models such as the reuse, repair, and recycling of products at the end of their life cycle. The European Commission plans to collaborate with all stakeholders in the sector to scale up the application of these models. This collaboration is not limited to private sector players and manufacturers but also includes governments, NGOs, and consumers.

Member States are encouraged to implement various tax incentives to support this transition process. However, it is emphasized that these incentives must be aligned with the European Union's State Aid rules and World Trade Organization (WTO) regulations. This ensures that while providing financial support mechanisms to scale up circular business models at the national level, the fair competition within the EU is preserved, and external trade relations are not negatively affected. Encouraging the use of recycled materials and strengthening the second-hand product market not only promotes environmental sustainability but also creates new employment opportunities in the textile sector. Therefore, the strategies proposed by the European Commission aim to create a structure that supports long-term economic growth in the sector while also protecting the environment.

The DPP is a key component of the Ecodesign for Sustainable Products Regulation (ESPR), which came into effect on July 18, 2024. It serves as the foundation of the European Commission's strategy to promote environmentally sustainable and circular products (European Union, 2024).

The DPP is increasingly becoming a critical tool in ensuring the sustainability and circularity of products across various industries. The DPP aims at increasing transparency and reliability on green claims, and boosting circular material flows by providing consumers and other stakeholders with information on how to repair, re-use or recycle the product. (European Commission,2020a, 2019). It facilitates the integration of detailed product information into supply chains, ensuring transparency and accountability at every stage of a product's lifecycle. Beyond simply being a data repository, the DPP serves as a regulatory mechanism by aligning with the obligations of the Ecodesign for Sustainable Products Regulation (ESPR). Its application areas are vast, ranging from the electronics and automotive industries to

the textile sector. For example, in the textile industry, the DPP can document information such as the type of fabric used, production methods, chemical treatments, and the recyclability of the final product. By doing so, it ensures compliance with environmental standards and provides consumers with detailed insights into the sustainability of the products they purchase.

Moreover, the DPP imposes specific obligations on manufacturers and stakeholders throughout the supply chain. Producers are required to register and maintain up-to-date product data, while supply chain actors must ensure that the relevant information is accessible for recycling, repair, or disassembly processes. Public authorities also benefit from the DPP as it simplifies inspections and compliance monitoring. For instance, in sectors like electronics, the DPP helps track hazardous materials and promotes safe recycling practices. These obligations not only improve operational transparency but also support the transition towards a circular economy by reducing waste and encouraging the reuse of resources.
In practice, the DPP creates a robust framework for collaboration among stakeholders, fostering innovation and sustainable practices. It supports the development of new technologies, such as digital twins and blockchain-based tracking systems, to enhance traceability and accountability. Thus, the DPP is not only a regulatory tool but also a transformative enabler for industries striving to meet the demands of modern sustainability goals. By encouraging alignment with international standards and promoting eco-design principles, the DPP plays a pivotal role in shaping a more sustainable and resilient global economy.

The textile industry is a dynamic sector in which digital solutions play a crucial role in reducing environmental and social impacts. Comprising a wide range of firms involved in the production and distribution of clothing, footwear, and

accessories, the sector is characterized by its expansive structure. However, the rapidly evolving business models and consumption patterns in the industry have led to significant sustainability challenges. These issues manifest in the depletion of natural resources, the use of harmful chemicals, the excessive consumption of valuable resources such as water and land, and the associated environmental damage. The impact of fast fashion has exacerbated these problems. Therefore, transitioning to more sustainable practices has become an unavoidable necessity for the industry in order to reduce its environmental and social impacts. In this transformation process, enhancing traceability and ensuring transparency throughout the entire product lifecycle, from production to consumption, are of paramount importance.

The implementation of the DPP in Europe provides the textile industry with a structured framework that encourages and compels companies to take action (EP, 2024).Awareness and the significance of the Digital Product Passport are steadily increasing. In line with this, new regulations are being introduced, and initiatives are being implemented in many countries, including the textile sector, as in other industries.

In France, the existing Anti-Waste for a Circular Economy (AGEC) law introduces regulations on product life cycles, aiming to minimize waste and promote the development of a circular economy. Aligned with the objectives of the DPP, the AGEC law enforces requirements for environmental labeling and sets waste reduction targets for textiles. This approach strengthens a holistic strategy to promote sustainability within the textile industry (European Union, 2020).

In addition to the implementation of DPP in Europe, many countries worldwide are also working on similar digital solutions and sustainability projects. For example, the Circular Textile Initiative launched in Sweden aims to enhance the

transparency of textile product life cycles and contribute to sustainability goals. Through this initiative, digital labels are added to textile products, providing consumers with detailed information about the contents, production processes, and recycling potential of the items. This not only supports consumers in making more informed decisions but also encourages manufacturers to increase their environmental accountability.

A similar effort can be observed in Japan's Traceable Textiles Program. This program aims to make the processes of sourcing and production in the local textile sector more traceable. By assigning a unique QR code to each product, consumers can easily access information about the product's origins, production methods, and environmental impacts by scanning the code. This innovative approach has not only heightened consumer interest in sustainable products in Japan but also motivated firms to adopt environmentally conscious strategies.

In the United States, the Higg Index Transparency Program stands out as a notable initiative. Designed to measure and share the environmental and social impacts of products in the textile and fashion industry, this program enables companies to assess the environmental performance of their products and transparently communicate their sustainability commitments. Furthermore, this initiative promotes the widespread adoption of eco-friendly production practices, fostering positive transformation within the textile industry.

All these initiatives serve as inspiring examples of how DPP can be adopted globally and support the achievement of sustainability goals in the textile sector. Additionally, they accelerate the transition to a circular economy, contributing to the establishment of a more responsible and sustainable framework for all stakeholders involved.

2.4 Digitalisation

With digitalization, physical documents in supply chains are being replaced by digital data, making processes faster and more error-free. In decision-making processes, algorithms, artificial intelligence software, and cognitive systems are becoming more widespread, transforming supply chains into more predictable and flexible structures. Digitalization in industry enables decisions in the supply and value chain to be made much faster, based on more data and information, and with greater accuracy. This, in turn, fosters the development of a more transparent and integrated ecosystem.

This development not only enhances operational processes but also enables the establishment of stronger collaboration among stakeholders within the supply chain. Through digital technologies, real-time data sharing and traceability are improved, allowing for quicker detection and management of risks. Furthermore, this transformation in decision-making processes facilitates more efficient use of resources and helps achieve sustainability goals more effectively. As a result, digitalization not only creates a competitive advantage but also lays the foundation for the formation of more resilient and agile business models in the long term. In this context, smart contracts, electronic orders, electronic invoicing, open-source software, digital signatures, enterprise resource planning and customer relationship management systems, radio frequency tags, sensors, image and voice recognition technologies, the Internet of Things, and cloud computing technologies are emerging as prominent applications in supply chains.

Personalization and digital identity, which are among the fundamental elements of the digital economy, enable individuals to store their data securely and in a decentralized manner. Through blockchain (BC) technology, users gain the ability

to control their personal information while preserving it in a transparent and traceable environment. Thanks to personalization and digital identity, which are the building blocks of the digital economy, people can store their own information in BC (Sikorski, Haughton, & Kraft, 2017; Sun, Yan & Zhang, 2016). This approach not only represents significant progress in data privacy and security but also allows individuals to manage their digital identities more effectively.

Organizations must have a clear digitalization strategy and focus on developing digital capabilities throughout their value chain. It is crucial not only for organizations to adapt to the digitalization trend but also to leverage digital tools and technologies to gain a competitive advantage (Strategy&, 2016). The effective implementation of digitalization strategies not only provides organizations with a competitive edge but also enhances operational efficiency. In the textile industry, for instance, digitalization has transformed production processes and supply chains. Smart manufacturing systems enable flexible production based on demand, while IoT devices and blockchain technology enhance traceability and build consumer trust. Similarly, in retail, digital tools like personalized recommendations and virtual fitting rooms enrich the customer experience. Developing sector-specific digital capabilities is essential not only to adapt to market dynamics but also to unlock new opportunities.

CHAPTER 3

METHODOLOGY

3.1 Research methodology

After conducting a comprehensive literature review on digital product passports, eco-design, ESG, and digitalization in these areas, several hypotheses were formulated regarding the sector. To test these hypotheses, a detailed questionnaire consisting of 44 questions was developed, aiming to analyze companies' demographic characteristics, their awareness of the digital product passport, and their level of advancement in digitalization, recycling, and sustainability. The survey was conducted with 80 companies operating in the textile sector, specifically in ready-to-wear, fiber and yarn, fabric, and integrated production fields. The survey results were analyzed using the chi-square test to determine the significance of the hypotheses.

The survey was structured into three main sections. The first section consists of demographic questions aimed at understanding the overall structure of the company. The second section includes questions directed solely at companies that are engaged in Digital Product Passport (DPP) implementation, in order to assess their current status within this process. The final section comprises questions that provide insights into data management and traceability practices.

No	Questions
1	What is your company's annual turnover?
2	What is the size of your company?
3	What is the average age of employees in your company?
4	What is the female/male employee ratio in your company?
5	What is the female/male ratio in the management team?
6	In which field does your company operate?
7	What is the proportion of your total exports to EU countries?
8	What percentage of your sales are made through e-commerce?
9	Have you conducted a digital maturity assessment?
10	How do you use digital methods in production planning?
11	Do you use digital tools in your sustainable design and production processes?
12	How do you share product data within your company?
13	How do you manage data sharing processes with stakeholders in your supply chain?
14	Are you familiar with the concept of Digital Product Passport (DPP)?
15	Have your export buyers or retailers requested you to implement Digital Product Passport (DPP) in your production processes?
16	Would you prefer Digital Product Passport (DPP) processes to be managed by the government?
17	What kind of training do you provide to your employees on digitalization and sustainability?

Figure 1. Demographic questions aimed at understanding the overall structure of the company

18	Does your company currently implement a Digital Product Passport (DPP)?
18.1	What stage are you at in integrating the DPP system in your company?
18.2	In which processes are you taking action to adapt to DPP implementation?
18.3	To what extent will you implement the Digital Product Passport (DPP) in your products?
18.4	What are the biggest challenges you face in DPP integration?
18.5	What types of support do the brands you produce for provide in relation to DPP processes?
18.6	How do you collect the product data expected to feed into the Digital Product Passport (DPP)?
18.7	What technologies do you use when collecting data from products?
18.8	What methods do you use to ensure security when accessing the DPP platform?
18.9	How do you monitor sustainability practices in your supply chain using the Digital Product Passport (DPP)?
18.10	How do you support the recycling processes of your products through the Digital Product Passport (DPP)?

Figure 2. Questions aimed at understanding the status of companies that are specifically engaged in Digital Product Passport (DPP) implementation

19	What kind of data do you regularly record during your production processes?
20	Do you integrate digital applications such as ERP and CRM to ensure traceability in your supply chain?
21	Do you use digital methods to ensure sales and stock traceability with your buyers/export partners?
22	Do you analyze sales and stock traceability data with your B2B customers (wholesale buyers)?
23	Does your company use a digital system to monitor carbon and environmental footprint?
24	Which platforms do you prefer for data security? Do you prefer domestic or foreign platforms?
25	What environmental measures have been taken in your company's production processes?
26	What is your current status in transparently sharing sustainability data in the supply chain within the scope of digitalization?
27	How do you monitor the life cycle of your products? (from raw material to waste)
28	What traceability certifications do you use in raw material procurement?
29	What is the proportion of those requesting quality control tests for fabrics from your suppliers?
30	What categories of tests do you request from your suppliers to ensure product quality and safety?
31	What types of actions are you taking regarding environmental consumption data (e.g., water and energy) to make production more sustainable?
32	Based on your annual production capacity, what is the annual amount of waste generated during production?
33	What steps do you take to reduce and manage waste generated in production processes?
34	What steps are you taking and planning to improve post-consumer waste?

Figure 3. Comprises questions that provide insights into data management and traceability practices

3.2 Determining hypotheses

Assumptions were formulated by establishing meaningful relationships based on how companies' tendencies in the areas of Digital Product Passport (DPP), data management, and traceability vary according to their various demographic characteristics. In the formulation of these assumptions, insights derived from previous literature studies served as guiding references.

The developed hypotheses are as follows:

Hypothesis 1:Revenue and DPP awareness - To examine whether the annual revenue of companies affects their level of awareness regarding the Digital Product Passport (DPP).

H0: There is no significant relationship between annual revenue and awareness of the Digital Product Passport (DPP).

H1: Companies with an annual revenue of over 50 million TRY have a higher level of awareness regarding the Digital Product Passport (DPP) compared to companies with a revenue below 50 million TRY.

Hypothesis 2: Employee age average and digital data sharing - To investigate whether the average age of employees influences the company’s tendency to share product data digitally with customers and stakeholders.

H0: There is no significant relationship between the average age of employees and the tendency to share product data digitally.

H1: Companies with an average employee age between 34 and 41 are more inclined to share product data digitally with customers and stakeholders compared to companies with different age groups.

Hypothesis 3: Company size and the variety of challenges in DPP integration - To investigate whether the size of a company, particularly being a medium-sized

enterprise, affects the variety of challenges it faces during the integration of the Digital Product Passport (DPP) system.

H0: There is no significant relationship between company size and the variety of challenges faced during DPP integration.

H1: Medium-sized enterprises face a greater variety of challenges during the Digital Product Passport (DPP) integration process compared to other businesses.

Hypothesis 4: Female management ratio and post-consumer waste awareness - To explore whether a higher ratio of women in management positions is associated with greater awareness of post-consumer waste management.

H0: There is no significant relationship between the proportion of women in management and awareness of post-consumer waste management.

H1: Companies with a female representation of 26% or more in management positions have greater awareness of post-consumer waste management compared to companies with 25% or less female representation.

Hypothesis 5: Waste volume and digital environmental data tracking - To determine whether companies with higher annual waste volumes are more advanced in collecting and recording environmental consumption data digitally.

H0: There is no significant relationship between the volume of annual waste generated and the use of digital tools for tracking environmental consumption data.

H1: Companies generating an annual waste amount of 1,750 kg or more are more advanced in digitally collecting and recording environmental consumption data compared to other companies.

Hypothesis 6: Export rate to EU and DPP adaptation - To assess whether companies with a higher export rate to European Union countries take more proactive actions in adapting to DPP implementation.

H0: There is no significant relationship between the rate of exports to the EU and the proactivity in adapting to DPP requirements.

H1: Companies with an export rate to European Union (EU) countries exceeding 25% take more proactive actions during the adaptation process of the Digital Product Passport (DPP).

Hypothesis 7: Digital maturity testing and data recording - To investigate whether companies that have undergone digital maturity testing but have not developed a digital roadmap are more likely to regularly record machine performance and workplace accident data.

H0: There is no significant relationship between having taken a digital maturity test and the tendency to regularly record data such as machine performance and accidents.

H1:Companies that have conducted a digital maturity assessment but have not established a digitalization roadmap tend to regularly record data related to machine performance and workplace accidents.

Hypothesis 8: Company size and support in DPP processes - To examine whether medium and large-sized enterprises receive more diverse support from their manufacturers regarding DPP processes compared to smaller businesses.

H0: There is no significant relationship between company size and the diversity of support received from brands in DPP processes.

H1: Medium- and large-sized enterprises receive more diverse support from the brands they produce for, in relation to the Digital Product Passport (DPP) processes.

Hypothesis 9: Use of digital systems and data security platform preference - To analyze whether businesses using digital systems for sales and inventory traceability tend to prefer foreign platforms over local ones for data security.

H0:There is no significant relationship between using digital systems for sales/stock traceability and preference for foreign vs. local platforms for data security.

H1: Companies using digital systems for sales and stock traceability tend to prefer foreign platforms over local ones when it comes to data security.

Hypothesis 10: Recycling processes and demand for product testing - To explore whether companies applying DPP in recycling processes request a wider range of tests to ensure product quality and reliability.

H0: There is no significant relationship between the implementation of DPP in recycling and the number of tests requested for product quality.

H1: Companies implementing the Digital Product Passport (DPP) in their recycling processes request a broader range of tests to ensure quality and reliability.

Hypothesis 11: Product lifecycle tracking and use of digital monitoring tools - To determine whether companies that monitor the product lifecycle through DPP tend to use technologies such as RFID, barcode, and QR codes more frequently in data collection.

H0: There is no relationship between monitoring the product life cycle through the Digital Product Passport (DPP) and the technologies used for data collection from products.

H1: Companies that monitor product life cycles through the Digital Product Passport (DPP) use RFID, barcode, and QR systems more widely in their data collection processes.

Hypothesis 12: DPP adoption and awareness of digital tools in sustainable design - To evaluate whether companies that have implemented DPP in specific product groups possess higher levels of awareness regarding the use of digital tools in sustainable design processes.

H0: There is no significant relationship between implementing DPP in specific product groups and awareness of digital tools for sustainable design.

H1: Companies that have implemented the Digital Product Passport (DPP) for specific product groups have a higher level of awareness regarding the use of digital tools in sustainable design processes compared to other companies.

3.3 Analysis methodology

The analyses in this study were conducted based on the hypotheses developed. The responses to the questions designed to support the hypotheses were compiled into a table and categorized accordingly. Based on these categorized responses, observed and expected value tables were constructed. Observed values represent the actual responses given by participants, while expected values were calculated using the following formula: $E_{ij} = n_i \cdot n_j / n$

Following the construction of these two tables, a Chi-Square (χ^2) test was conducted to analyze whether there was a statistically significant relationship between the variables. The test statistic was calculated using the formula below:

$$\chi^2 = \sum (O - E)^2 / E$$

Where O represents the observed values and E represents the expected values. If the resulting p-value is less than 0.05, it is concluded that there is a statistically significant relationship between the groups; otherwise, no significant relationship is assumed.

In addition to the Chi-Square test, a T-Test was conducted to analyze whether there is a significant difference between the means of the two conditions. There are three main types of T-Tests:

- Independent Samples t-Test: Used to compare the means of two independent groups.
- Paired Samples t-Test: Used to compare the means of the same individuals under two different conditions.
- One-Sample t-Test: Used to compare the mean of a single group against a known value.

In this study, due to the assumption of unequal variances between the groups, Welch's t-Test (a version of the Paired Samples t-Test) was applied. A two-tailed hypothesis test was used, as the goal was to examine whether there was any difference between the means in either direction. The variances were calculated using the formula:

$s^2=\sum(x_i- \bar{x})^2/n-1$

Based on the calculated variances, the t-value was determined according to the Welch method. As in the Chi-Square test, a p-value less than 0.05 was interpreted as indicating a statistically significant difference between the groups.

Finally, to assess the strength of the relationship between the two groups, a correlation analysis was conducted. The most commonly used method, Pearson Correlation Coefficient (r), was employed. Based on the calculated r-value, the strength of the relationship between the groups was interpreted using the table below:

Table 1. Pearson Correlation Coefficient – Strength of Relationship Table

r value	Type of Relationship
+1	Perfect positive
0.7 – 0.9	Strong positive
0.3 – 0.6	Moderate positive
0.1 – 0.3	Weak positive
0	No relationship
-0.1 – -0.3	Weak negative
-0.7 – -1	Strong negative

CHAPTER 4

ANALYZES

4.1 General analysis of survey results

The survey conducted for this study was applied to 80 companies operating in the textile sector. In this section, the demographic analysis of the companies that responded to the questionnaire is presented.

Among the 80 participating companies, 23 were micro-sized (1–10 employees), 29 were small-sized (11–50 employees), 17 were medium-sized (51–250 employees), and 11 were large-sized enterprises (more than 250 employees).
It was observed that 55% of the participating companies (44 companies) had an average employee age between 34 and 41 years. In terms of the proportion of women in managerial positions, 27 companies reported having 0–25%, 10 companies reported 26–50%, 4 companies reported 51–75%, and 3 companies reported 76–100%. In total, 56.25% of the companies had 25% or fewer women in managerial roles.

Of the surveyed companies, 59 were active in ready-to-wear manufacturing, 14 in fabric production, 5 in integrated textile production, and 2 in fiber and yarn production.

40% of the companies reported that more than 50% of their exports were to EU countries, whereas 21.25% reported no exports to the EU. Among the companies exporting more than 50% to EU countries, only 16.25% conducted their sales through e-commerce channels. Based on this, it can be inferred that companies with high EU export rates tend to have lower e-commerce sales rates.

Furthermore, 72.5% of the participating companies stated that they had not conducted a digital maturity assessment. 16.25% of the companies had undergone a digital maturity test but had not yet developed a roadmap, while 11.25% had both taken the test and developed a roadmap accordingly. Among the 58 companies that had not performed a digital maturity assessment, 25 indicated that they carried out production planning without using digital methods and had no ongoing efforts in this area, and 13 reported using digital methods for production planning but had not implemented a Digital Product Passport.

Only 13.75% of the companies participating in the survey reported using digital tools in both sustainable design and production processes. In contrast, 43.75% stated that they do not use digital tools in either of these processes. Additionally, 20% of the companies indicated that they do not currently use digital tools in these areas but are undertaking efforts toward digitalization.

Among the 80 companies contributing to the study, only 15 reported sharing data digitally with customers and external stakeholders. In contrast, 27 companies do not share data digitally, meaning the data is only accessed by product teams. Furthermore, 47.5% of the companies stated that they share data digitally only with internal stakeholders.

Moreover, 45% of the companies do not share data with stakeholders in their supply chain. While 20% do share data with supply chain partners, they do so through non-digital means. Only 15% of the companies share data digitally, and 20% reported that they are planning to establish data-sharing practices.

Of the 16 companies planning to implement digital data-sharing systems with supply chain partners, 10 currently share data only with internal stakeholders. Additionally, among the 15 companies that share product data digitally with

customers and external stakeholders, 10 were found not to share data digitally with their supply chain partners.

Among the companies participating in the survey, 50% reported having no knowledge of the Digital Product Passport (DPP) concept, while 32.5% stated they had partial knowledge, and only 17.5% indicated that they were familiar with the concept. Among the 14 companies that are knowledgeable about DPP, 8 are currently working on implementing the DPP system in their operations, and 2 have already adopted it.

Furthermore, 77% of the companies with partial knowledge of the DPP have not initiated any efforts toward its implementation. Of the 17 companies that are either currently using or actively working to adopt the DPP system, 8 (representing 47%) are still in the research phase regarding DPP integration.

4.2 Analysis of hypotheses

The analytical steps described in the methodology section were applied individually to each hypothesis.

Analyse of hypothesis 1: The objective of hypothesis 1 is to examine whether the annual revenue of businesses has an impact on their awareness of the Digital Product Passport (DPP). To investigate this hypothesis, three specific survey questions were utilized:

- *What is your company's annual revenue?*
- *Are you familiar with the concept of the Digital Product Passport?*
- *Is the Digital Product Passport currently implemented in your company?*

Responses to the annual revenue question were categorized into two groups: above 50 million TL and below 50 million TL. Similarly, responses to the questions

regarding awareness and implementation of the Digital Product Passport were grouped as "Yes" and "No".

For numerical analysis through T-test and correlation analysis, binary coding was applied: responses were assigned a value of 1 or 0 within each category (e.g., a value of 1 for companies with revenue above 50 million TL, and 0 for those below; likewise, 1 for "Yes" and 0 for "No" responses regarding awareness and implementation).

A pivot table in Excel was used to determine the observed values for the relationship between company revenue and awareness of the Digital Product Passport. These observed values will be used as a basis for the statistical analyses that follow.

Table 2. Observed Value Table for the Relationship Between Company Revenue and Digital Product Passport (Dpp) Awareness

Observed Value	*DPP awareness status*		
Annual Revenue	No	Yes/partially	
≤50	30	15	45
≥50	10	25	35
	40	**40**	**80**

Based on the observed values, the expected values were calculated using the formula $E_{ij}=n_i \cdot n_j / n$ and the results were presented in a table. For example, the observed value for companies with annual revenue below 50 million TL that are aware of the Digital Product Passport (DPP) is shown as 15 in the table. The expected value for this group was calculated as $(45 \times 40) / 80 = 22.5$. The table containing all the expected values calculated in this way is presented below.

Table 3. Expected Values for the Relationship Between Company Revenue and Awareness of the Digital Product Passport (Dpp)

Expected Value	DPP awareness status	
Annual Revenue	yes/partially	No
≤50	22,500	22,500
≥50	17,500	17,500

After determining the observed and expected values, a chi-square test was conducted. During the test, the formula $\chi^2 = \sum(O-E)^2 / E$ was utilized, as mentioned above. As a result of the calculations, the p-value was found to be 0.001. Since the p-value is less than 0.05, it was concluded that there is a statistically significant relationship between company revenue and the level of awareness regarding the Digital Product Passport (DPP).

To determine whether there is a statistically significant difference between the mean values of company revenue and Digital Product Passport (DPP) awareness, an independent samples t-test was conducted. The previously categorized binary values of 1 and 0 were used for this analysis. First, companies with annual revenues below 50 million TL were filtered, and the 1-0 values indicating DPP awareness were taken from the response table. The same procedure was applied to companies with revenues above 50 million TL. Using the values obtained from the table, variance was calculated using the formula $s^2 = \sum(x_i - \bar{x})^2 / (n - 1)$. The results indicated that the variances were not equal. Since the variances were found to be unequal, it was decided to use the Welch's t-test method. The t-test was conducted using the formula: $t = (\bar{x}_1 - \bar{x}_2) / \sqrt{((s_1^2 / n_1) + (s_2^2 / n_2))}$ As a result of the calculation, the p-value was determined to be 0.001. Since the p-value is less than 0.05, it was concluded that there is a statistically significant difference between the

means of company revenue groups in terms of their awareness of the Digital Product Passport (DPP).

In order to measure the strength of the statistically significant relationship found between company revenue and Digital Product Passport (DPP) awareness through chi-square and t-tests, a correlation analysis was conducted. For this analysis, the binary (1-0) values assigned to the company revenue categories and DPP awareness status were taken from the dataset. Using the formula: $r = \Sigma[(x_i - \bar{x})(y_i - \bar{y})] / \sqrt{[\Sigma(x_i - \bar{x})^2 \cdot \Sigma(y_i - \bar{y})^2]}$ the Pearson correlation coefficient (r) was calculated as 0.378. According to Table 1 presented above, the strength of the relationship was identified as a moderate positive correlation.

The same process was also applied to the question "Does your company currently implement the Digital Product Passport?" which supports the hypothesis.

A pivot table was created in Excel using the responses related to company revenue and the implementation of the Digital Product Passport (DPP) obtained from the table, and the observed values were derived.

Table 4. Table of Observed Values for The Relationship Between Company Revenue and Implementation of the Digital Product Passport (Dpp)

Observed Value	*DPP implementation*		
Annual Revenue	No	Yes / In progress	
≤50	40	5	45
≥50	23	12	35
	63	**17**	**80**

The expected values were calculated using the formula Eij=ni·nj/n as explained above, based on the observed values.

Table 5. Expected Values for the Relationship Between Company Revenue and Implementation of the Digital Product Passport (Dpp)

Expected Value	DPP implementation	
Annual Revenue	yes/partially	No
≤50	9,563	35,438
≥50	7,438	27,563

After determining the observed and expected values, a chi-square test was conducted using the formula $\chi^2 = \sum(O-E)^2 / E$, as previously mentioned. As a result of the calculations, the p-value was found to be 0.012. Since the p-value is less than 0.05, it was concluded that there is a statistically significant relationship between company revenue and the implementation of the Digital Product Passport (DPP).

To analyze whether there is a significant relationship between the average values of company revenue and the implementation of the Digital Product Passport (DPP), a T-test was applied following the steps outlined above. The 1-0 values for the presence or absence of the DPP implementation for companies with annual revenues below 50 million TL were obtained from the table. The same procedure was applied for companies with annual revenues above 50 million TL. Subsequently, using the formula mentioned above, it was concluded that the variances were unequal, and the T-test was conducted using Welch's method with the formula applied. The p-value obtained was 0.029. Since the p-value is less than 0.05, it was concluded that there is a significant relationship between the presence of company revenue and the implementation of the Digital Product Passport (DPP).

To measure the strength of the significant relationship found in both the chi-square and T-tests, a correlation analysis was conducted following the steps outlined above. The 1-0 values for company revenue and the implementation of the Digital

Product Passport were separately extracted from the table, and the relevant formula was applied to obtain the Pearson correlation coefficient (r) of 0.281. According to Table 1, it was concluded that the relationship between these two variables is weakly positive.

The results of the chi-square and T-tests conducted in both analyses demonstrate that there is a significant relationship between company revenue and Digital Product Passport awareness. The correlation tests revealed that there is a moderate positive relationship between company revenue and the awareness of the Digital Product Passport, while a weak positive relationship was observed between company revenue and the implementation of the Digital Product Passport. When averaging these two results, the obtained r-value is 0.329, indicating a moderate positive relationship between company revenue and Digital Product Passport awareness. According to the test results, the null hypothesis (H0) was rejected and the alternative hypothesis (H1) was accepted.

Analyse of hypothesis 2: The objective of hypothesis 2 is to investigate whether the average age of employees influences the company's tendency to share product data digitally with customers and stakeholders.

For the analysis of this hypothesis, two questions from the survey were utilized: *"What is the average age of employees in your company?"* and *"How do you share product data within your company?"*

To examine the relationship between the average age of employees and companies' preferences for sharing product data, both chi-square and t-tests, as outlined in Hypothesis 1, were conducted. The chi-square test yielded a p-value of 0.314 and the t-test a p-value of 0.311. Since both results indicate $p > 0.05$, it was concluded that there is no statistically significant relationship between the two

variables. Therefore, the alternative hypothesis (H1) was rejected and the null hypothesis (H0) was accepted.

Analyse of hypothesis 3: The objective of hypothesis 3 is to investigate whether the size of a company, particularly being a medium-sized enterprise, affects the variety of challenges it faces during the integration of the Digital Product Passport (DPP) system.

For the analysis of this hypothesis, two questions from the survey were utilized: *"What is the size of your company?"* and *"What are the biggest challenges you face in DPP integration?"*

To examine the relationship between company size and the challenges encountered during the Digital Product Passport (DPP) integration process, both chi-square and t-tests were conducted, as detailed in Hypothesis 1. The chi-square test yielded a p-value of 0.074, and the t-test produced a p-value of 0.105. Since both results indicate $p > 0.05$, it was concluded that there is no statistically significant relationship between these two variables. Accordingly, the alternative hypothesis (H1) was rejected and the null hypothesis (H0) was accepted.

Analyse of hypothesis 4: The objective of hypothesis 4 is to explore whether a higher ratio of women in management positions is associated with greater awareness of post-consumer waste management.

To investigate this hypothesis, responses to two survey questions were utilized: *"What is the female/male ratio in the management team?"* and *"What steps are you taking and planning to improve post-consumer waste?"*

To investigate the relationship between the proportion of female employees in management and the level of post-consumer awareness, chi-square and t-tests were conducted, as in the other hypotheses. The chi-square test yielded a p-value of

0.716, while the t-test resulted in a p-value of 0.720. Since both values indicate $p > 0.05$, it was concluded that there is no statistically significant relationship between these variables. Accordingly, the alternative hypothesis (H1) was rejected and the null hypothesis (H0) was accepted.

Analyse of hypothesis 5: The objective of hypothesis 5 is to determine whether companies with higher annual waste volumes are more advanced in collecting and recording environmental consumption data digitally.

To analyze this hypothesis, two questions from the survey were utilized: *"What types of actions are you taking regarding environmental consumption data (e.g., water and energy) to make production more sustainable?"* and *"Based on your annual production capacity, what is the annual amount of waste generated during production?"*

To examine the relationship between companies' annual waste volume and the actions taken regarding environmental consumption data, chi-square and t-tests were conducted using the same methodology applied in the previous hypotheses. The chi-square test yielded a p-value of 0.548, while the t-test produced a p-value of 0.554. As both values indicate $p > 0.05$, it was concluded that there is no statistically significant relationship between these two variables. Accordingly, the alternative hypothesis (H1) was rejected, and the null hypothesis (H0) was accepted.

Analyse of hypothesis 6: The objective of hypothesis 6 is to assess whether companies with a higher export rate to European Union countries take more proactive actions in adapting to DPP implementation.

To analyze the hypothesis, the survey questions *"What is the proportion of your total exports to EU countries?"* and *"In which processes are you taking action to adapt to DPP implementation?"* were used.

To investigate whether there is a statistically significant relationship between companies' export rates to the European Union and the actions they take to adapt to the Digital Product Passport (DPP), chi-square and t-tests were conducted, following the methodology outlined in previous hypotheses. The chi-square test yielded a p-value of 0.613, and the t-test produced a p-value of 0.618. As both values indicate $p > 0.05$, it was concluded that there is no statistically significant relationship between these two variables. Accordingly, the alternative hypothesis (H1) was rejected, and the null hypothesis (H0) was accepted.

Analyse of hypothesis 7: The objective of hypothesis 7 is to investigate whether companies that have undergone digital maturity testing but have not developed a digital roadmap are more likely to regularly record machine performance and workplace accident data.

To analyze the hypothesis, the survey questions *"Have you conducted a digital maturity assessment?"* and *"What kind of data do you regularly record during your production processes?"* were used.

To investigate whether there is a statistically significant relationship between companies' completion of a digital maturity assessment and the types of data they regularly record during production processes, chi-square and t-tests were conducted as detailed in previous hypotheses. The results of both tests yielded p-values of 0. Since $p < 0.05$, it was concluded that there is a statistically significant relationship between the completion of a digital maturity assessment and the types of data regularly recorded in production processes. Furthermore, the correlation analysis revealed a strong positive relationship between these two variables. Accordingly, the alternative hypothesis (H1) was accepted, and the null hypothesis (H0) was rejected.

Analyse of hypothesis 8: The objective of hypothesis 8 is to examine whether medium and large-sized enterprises receive more diverse support from their manufacturers regarding DPP processes compared to smaller businesses.

To analyze the hypothesis, the survey questions *"What is the size of your company?"* and *"What types of support do the brands you produce for provide in relation to DPP processes?"* were used.

To examine the relationship between company size and the level of support provided by the brands they produce for regarding Digital Product Passport (DPP) processes, chi-square and t-tests were conducted, as applied in previous hypotheses. The chi-square test yielded a p-value of 0.003, and the t-test resulted in a p-value of 0. Since $p < 0.05$, a statistically significant relationship was identified between the two variables. Additionally, the correlation analysis produced a Pearson correlation coefficient of $r = 0.416$, indicating a moderate positive relationship between company size and the diversity of support received in DPP processes. Accordingly, the alternative hypothesis (H1) was accepted, and the null hypothesis (H0) was rejected.

Analyse of hypothesis 9: The objective of hypothesis 9 is to analyze whether businesses using digital systems for sales and inventory traceability tend to prefer foreign platforms over local ones for data security.

To analyze the hypothesis, the survey questions *"Do you use digital methods to ensure sales and stock traceability with your buyers/export partners?"* and *"Which platforms do you prefer for data security? Do you prefer domestic or foreign platforms?"* were used.

To investigate the relationship between the use of digital systems for sales/stock traceability and the preference for data security platforms, chi-square and

t-tests were conducted following the methodology applied in previous hypotheses. The results indicated a chi-square p-value of 0.502 and a t-test p-value of 0.332. Since both values are $p > 0.05$, it was concluded that there is no statistically significant relationship between these two variables. Accordingly, the alternative hypothesis (H1) was rejected, and the null hypothesis (H0) was accepted.

Analyse of hypothesis 10: The objective of hypothesis 10 is to explore whether companies applying DPP in recycling processes request a wider range of tests to ensure product quality and reliability.

To analyze the hypothesis, the survey questions *"How do you support the recycling processes of your products through the Digital Product Passport (DPP)?"* and *"What categories of tests do you request from your suppliers to ensure product quality and safety?"* were used.

To investigate the relationship between the implementation of the Digital Product Passport (DPP) in companies' recycling processes and the diversity of test categories requested from suppliers to ensure quality and reliability, chi-square and t-tests were conducted as outlined above. The chi-square test yielded a p-value of 0.634, and the t-test yielded a p-value of 0.365. Since both values are $p > 0.05$, it was concluded that there is no statistically significant relationship between these two variables. Accordingly, the alternative hypothesis (H1) was rejected, and the null hypothesis (H0) was accepted.

Analyse of hypothesis 11: The objective of hypothesis 11 is to determine whether companies that monitor the product lifecycle through DPP tend to use technologies such as RFID, barcode, and QR codes more frequently in data collection.

To analyze the hypothesis, the survey questions *"Does your company currently implement a Digital Product Passport (DPP)?", "What technologies do you use when collecting data from products?"* and *"How do you monitor the life cycle of your products? (from raw material to waste)"* were used.

To investigate whether there is a statistically significant relationship between companies' efforts to monitor the product lifecycle through the Digital Product Passport (DPP) and the variety of technologies used for data collection from products, chi-square and t-tests were conducted as applied in previous hypotheses. Both tests yielded a p-value of 0.003, which is less than 0.05 ($p < 0.05$), indicating a statistically significant relationship between the two variables. Additionally, the correlation test revealed a Pearson correlation coefficient of $r = 0.329$, suggesting a moderate positive relationship between DPP-based product lifecycle tracking efforts and the variety of technologies (such as RFID, barcode, and QR codes) used in data collection. Accordingly, the alternative hypothesis (H1) was accepted, and the null hypothesis (H0) was rejected.

Analyse of hypothesis 12: The objective of hypothesis 12 is to evaluate whether companies that have implemented DPP in specific product groups possess higher levels of awareness regarding the use of digital tools in sustainable design and production processes.

To analyze the hypothesis, the survey questions *"Do you use digital tools in your sustainable design and production processes?"* and *"To what extent will you implement the Digital Product Passport (DPP) in your products?"* were used.

To investigate the relationship between companies' level of progress in transitioning to the Digital Product Passport (DPP) and their awareness of using digital tools in sustainable production and design processes, chi-square and t-tests

were conducted as outlined in the previous hypotheses. The chi-square test yielded a p-value of 0.098, and the t-test yielded a p-value of 0.101. Since both values are $p > 0.05$, it was concluded that there is no statistically significant relationship between the two variables. Accordingly, the alternative hypothesis (H1) was rejected, and the null hypothesis (H0) was accepted.

CHAPTER 5

HYPOTHESIS RESULTS AND RECOMMENDATIONS

The results of the hypotheses and the recommendations related to these hypotheses, based on the detailed analyses presented in Chapter 4, are provided below.

5.1 Hypothesis 1

H0: There is no significant relationship between annual revenue and awareness of the Digital Product Passport (DPP).

H1: Companies with an annual revenue of over 50 million TRY have a higher level of awareness regarding the Digital Product Passport (DPP) compared to companies with a revenue below 50 million TRY.

The hypothesis results indicated that there is a significant relationship between companies' annual turnover and their awareness of the Digital Product Passport (DPP).

In light of these findings, it is recommended that companies with an annual revenue below 50 million TL be targeted for awareness-raising initiatives to enhance their understanding of and readiness for DPP implementation. These initiatives should include specialized seminars and training programs that emphasize the importance of the Digital Product Passport in the context of sustainability and traceability. Furthermore, financial or technical support schemes could be developed to facilitate the adaptation and integration of small and medium-sized enterprises (SMEs) into DPP-related processes. Ensuring that such awareness efforts are inclusive and scalable is of critical importance. These actions are also expected to contribute positively to broader circular economy objectives.

5.2 Hypothesis 2

H0: There is no significant relationship between the average age of employees and the tendency to share product data digitally.

H1: Companies with an average employee age between 34 and 41 are more inclined to share product data digitally with customers and stakeholders compared to companies with different age groups.

The hypothesis results revealed that there is no statistically significant relationship between the average age range of employees in companies and their tendency to share product data in digital environments.

5.3 Hypothesis 3

H0: There is no significant relationship between company size and the variety of challenges faced during DPP integration.

H1: Medium-sized enterprises face a greater variety of challenges during the Digital Product Passport (DPP) integration process compared to other businesses.

The hypothesis results indicate that there is no statistically significant relationship between company size and the variety of challenges encountered during the DPP integration process.

5.4 Hypothesis 4

H0: There is no significant relationship between the proportion of women in management and awareness of post-consumer waste management.

H1: Companies with a female representation of 26% or more in management positions have greater awareness of post-consumer waste management compared to companies with 25% or less female representation.

The hypothesis results showed that there is no significant relationship between the proportion of employees in managerial positions and the awareness of post-consumer waste management.

5.5 Hypothesis 5

H0: There is no significant relationship between the volume of annual waste generated and the use of digital tools for tracking environmental consumption data.

H1: Companies generating an annual waste amount of 1,750 kg or more are more advanced in digitally collecting and recording environmental consumption data compared to other companies.

The hypothesis results showed that there is no significant relationship between the volume of annual waste generated and the use of digital tools for tracking environmental consumption data.

5.6 Hypothesis 6

H0: There is no significant relationship between the rate of exports to the EU and the proactivity in adapting to DPP requirements.

H1: Companies with an export rate to European Union (EU) countries exceeding 25% take more proactive actions during the adaptation process of the Digital Product Passport (DPP).

The hypothesis results showed that there is no significant relationship between he rate of exports to the EU and the proactivity in adapting to DPP requirements.

5.7 Hypothesis 7

H0: There is no significant relationship between having taken a digital maturity test and the tendency to regularly record data such as machine performance and accidents.

H1:Companies that have conducted a digital maturity assessment but have not established a digitalization roadmap tend to regularly record data related to machine performance and workplace accidents.

The hypothesis results showed that there is a significant relationship between having taken a digital maturity test and the tendency to regularly record data such as machine performance and accidents.

Based on the findings of this study, it has been observed that companies which have conducted a digital maturity assessment but have not yet established a strategic roadmap still tend to regularly record certain types of data. However, recording these data types within the framework of a strategic roadmap aligned with the company's digital maturity level is expected to facilitate and enhance the efficiency of the digital transformation process. Moreover, in the textile industry, standardizing the types of data recorded during production processes is considered a facilitating factor in the transition to the Digital Product Passport (DPP).

Therefore, it is recommended that companies standardize the types of data recorded in production processes in accordance with their digital maturity levels and ensure that this data is collected accurately and consistently. Furthermore, integrating the collected data into business processes and promoting actions to enhance data traceability would contribute to more effective data utilization. Finally, it is advised that awareness-raising initiatives and training programs be implemented, taking into

account the digital maturity levels of companies, to support all stages of this transformation process.

5.8 Hypothesis 8

H0: There is no significant relationship between company size and the diversity of support received from brands in DPP processes.

H1: Medium- and large-sized enterprises receive more diverse support from the brands they produce for, in relation to the Digital Product Passport (DPP) processes.

The hypothesis results showed that there is a significant relationship between company size and the diversity of support received from brands in DPP processes. According to the results of the analysis, it was observed that company size has an impact on the variety of support received from brands for the Digital Product Passport (DPP) processes. This finding indicates that small and micro-sized enterprises may be disadvantaged in the transition to the DPP and that their adaptation to this process may take longer. Therefore, it is recommended that specific support programs be developed for SMEs, or that brands provide targeted information to small and micro-sized enterprises regarding the requirements, importance, and procedures related to the DPP. Furthermore, it is considered that the active involvement of brands in the digital transformation processes of smaller enterprises could make the transition to the DPP more effective and efficient.

5.9 Hypothesis 9

H0:There is no significant relationship between using digital systems for sales/stock traceability and preference for foreign vs. local platforms for data security.

H1: Companies using digital systems for sales and stock traceability tend to prefer foreign platforms over local ones when it comes to data security.

The hypothesis results showed that there is no significant relationship between company size and the diversity of support received from brands in DPP processes.

5.10 Hypothesis 10

H0: There is no significant relationship between the implementation of DPP in recycling and the number of tests requested for product quality.

H1: Companies implementing the Digital Product Passport (DPP) in their recycling processes request a broader range of tests to ensure quality and reliability.

The hypothesis results showed that there is no significant relationship between the implementation of DPP in recycling and the number of tests requested for product quality.

5.11 Hypothesis 11

H0: There is no relationship between monitoring the product life cycle through the Digital Product Passport (DPP) and the technologies used for data collection from products.

H1: Companies that monitor product life cycles through the Digital Product Passport (DPP) use RFID, barcode, and QR systems more widely in their data collection processes.

The hypothesis results showed that there is a significant relationship between monitoring the product life cycle through the Digital Product Passport (DPP) and the technologies used for data collection from products.

The study investigated the relationship between companies' use of Digital Product Passports (DPP) in monitoring the product life cycle and the technologies they utilize for data collection. The results of the chi-square and t-tests indicated that there is a statistically significant relationship between these two variables. Furthermore, the correlation analysis revealed a strong positive association between the implementation of DPP in tracking product life cycles and the technologies employed for data collection. Based on these findings, it was observed that there are notable differences among companies in terms of their use of data collection technologies such as RFID, barcodes, and QR systems. Accordingly, the null hypothesis (H0) was accepted, and the alternative hypothesis (H1) was rejected. Based on the findings of this study, the increasing adoption of Digital Product Passport (DPP) applications in the textile sector has been accompanied by a rise in the use of RFID, barcode, and QR code technologies for data collection throughout the product life cycle. Accordingly, firms that have not yet initiated DPP-related efforts or are still in the research phase should be informed and trained on the effective use of these technologies for data collection. It should be emphasized that through the implementation of such systems, companies can achieve end-to-end traceability from production to recycling stages.

The success of these implementations, however, depends significantly on the maturity level of companies' digitalization processes. Therefore, it is recommended that firms strengthen their digital infrastructure and take necessary measures to ensure data security. Moreover, achieving full product lifecycle traceability requires seamless data sharing among suppliers, manufacturers, distributors, and retailers. In this regard, in addition to data collection systems, companies should be encouraged

to establish data-sharing mechanisms and receive relevant training to facilitate secure and effective information exchange.

5.12 Hypothesis 12

H0: There is no significant relationship between implementing DPP in specific product groups and awareness of digital tools for sustainable design.
H1: Companies that have implemented the Digital Product Passport (DPP) for specific product groups have a higher level of awareness regarding the use of digital tools in sustainable design processes compared to other companies.

The hypothesis results showed that there is no significant relationship between implementing DPP in specific product groups and awareness of digital tools for sustainable design.

The present study examined the relationship between the current implementation status of the Digital Product Passport (DPP) among businesses and their awareness regarding the use of digital tools in sustainable production and design processes. The results of the chi-square and t-tests indicated that there was no statistically significant relationship between these variables. Additionally, the correlation analysis revealed a weak positive relationship between the level of integration into the DPP system and the awareness of using digital tools in sustainable production and design. Accordingly, it was observed that businesses that have adopted the DPP in specific product groups did not show a significantly higher level of awareness compared to those that had not. Based on these findings, the null hypothesis (H0) was rejected and the alternative hypothesis (H1) was accepted.
The findings of the study indicate that there is no statistically significant relationship between businesses' transition to the Digital Product Passport (DPP) and their

awareness of using digital tools in sustainable production and design processes. This suggests that even though companies may be actively working towards DPP implementation or may already be fully integrated into the system, they do not necessarily possess adequate awareness regarding the use of digital tools for sustainable production and design. Therefore, it is recommended that training programs be organized to enhance businesses' awareness and competency levels in the use of digital tools. These training sessions should emphasize that the Digital Product Passport is not only a regulatory requirement but also a strategic tool that supports digital transformation and sustainability goals.

CHAPTER 6

DISCUSSION & CONCLUSION

This study was conducted with companies operating in the textile sector, with communication support from İHKİB during the process. The concept of the Digital Product Passport (DPP) is gaining increasing attention day by day and is becoming an essential element in today's digital era. At this point, it is crucial to measure the level of awareness among sectoral actors and to accelerate adaptation processes by providing training and various support mechanisms to enhance DPP-related knowledge. While the importance of the DPP continues to rise, there remains a significant gap in the academic literature regarding comprehensive studies that reflect its current status within the industry. Therefore, in order to increase sectoral awareness and facilitate integration, university-industry collaboration projects should be expanded, and necessary actions should be developed in light of academic research and analyses.

Although the analysis based on responses from 80 companies participating in the survey suggests that DPP awareness levels vary by company size, it clearly demonstrates that overall awareness in the sector remains low. The second part of the survey, which was structured around three main categories, aimed to assess the maturity level of companies that have either implemented DPP practices or are working towards it. However, only 17 of the 80 companies were able to respond to this section, indicating a limited level of engagement. The findings show that while companies are willing to integrate into the DPP process, they generally lack sufficient knowledge. Furthermore, they encounter various challenges due to insufficient technical and financial support. These challenges primarily include data

security, collaboration with suppliers, deficiencies in technological infrastructure, and a lack of knowledge regarding regulations and legal frameworks.

To address these issues, it is recommended that companies be provided with targeted training, particularly in these critical areas, and that integration and implementation processes be closely monitored to improve effectiveness. Additionally, it is suggested that similar studies be conducted in other sectors, and that concrete steps be taken to increase awareness and support DPP integration across industries.

The study revealed that businesses lack sufficient knowledge and awareness not only in the field of digital product passports but also in areas such as data security and digitalization. In order for companies to take the necessary digitalization actions regarding data digitization, data maintenance, and data sharing, their adaptation to these processes can be improved through targeted training programs and the provision of technical support. Furthermore, due to challenges in accessing adequate infrastructure and technical expertise, as well as limited employee awareness, it would be beneficial for businesses to proceed step by step in their digitalization journey.

REFERENCES

Ali, M., (2022). *Digitalization and Its Impact on The Economy in Wake of Blockchain Technology*

Berker, K., (2022). *Ecodesign and Energy Labelling Legislation as a Driver Of Innovation: A Qualitative Analysis for Turkish Industry*

Cristóvão, S., Ricardo, F., Pedro, P., Carla, P., Rui, R., (2024). *Digital Product Passport Architecture for Boosting Circularity in Footwear Industry*

Ece, G., (2008). *The Situation of Ecodesign in Turkish Industry*

Fetullah, G., (2018). *Modeling And Design Of Digital Supply Chain*

Gündüz, U., Emre, Ö., Tevhide, A., Bülent, Ç., Merih, P., Kemal, K., Erhan, B., Selçuk, K., Siamak, V., (2017). *Digitalisation Strategies In Industry Workshop,* 5-30.
https://shorturl.at/6ajC7

Jérémy, L. & Pantxika, O., (2024). *Digital Product Passport for The Textile Sector,* 10-19.
https://shorturl.at/IrE7V

Lea, Q., (2024). *Preparing in the Light of Uncertainty: How Textile Companies respond to New Regulations on the Digital Product Passport,* 8-10.
https://shorturl.at/ctzu6

Lövdahl, J., & Hallstedt, S. (2023). *Implıcatıons of EU Instruments on Company Capabilities to Design More Sustainable Solutions–Product Environmental Footprint and Digital Product Passport,* 1-5.
https://shorturl.at/kIUoi

Lukas, S., Gerrit, H., Christoph, P., Günther, S., (2023). *Classification of Product Data for a Digital Product Passport in the Manufacturing Industry*

Matti, K., (2024). *Reimagining Luxury: The Potential of Digital Product Passports in Accelerating Circular Business Models in High-End Fashion*

Rabia, Ç., (2024). *The Impact Of Environmental, Social and Corporate Governance (Esg) Performance of Enterprises on Investment Financing Decisions: An Application In BIST,* 6-38.
https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp#page38

Rembrandt, H. E. M. K., Sreenivaasa, P., Enik˝o H., Lucia, H., Pascal, L., Ha-Young, J., Amba, C., Radha, D., Fernando, B. F., Cristina P., (2022). *A Digital Product Passport for Critical Raw Materials Reuse and Recycling*

Rithika, T., (2024). *As the EU Mandates Digital Product Passports, Here's What Supply Chain Leaders Should Know*

Susanne, A. & John, D., (2021). *Corporate Esg Reporting Quantity, Quality and Performance: Where to Now for Environmental Policy And Practice?*, 1-5. https://onlinelibrary.wiley.com/doi/epdf/10.1002/bse.2937

Türker, A., (2014). *Business Disaster Preparedness Of SMES: A Survey Study in METU Technopark*