Tampere University of Applied Sciences

Digital Solutions are Integral for Scaling the Circular Economy in the Apparel Industry

Debabrata Paul

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ABSTRACT

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The global apparel industry has been criticized for a long time for its unsustainable practices, which damage the environment, create too much waste, and cause social inequality. In reaction to these problems, the idea of the circular economy has come up as a promising idea and scope. It emphasizes how important it is for the apparel industry to reduce, reuse, and recycle resources. Despite the fact that the Circular Economy (CE) offers a lot of change to the apparel industry, this research looks at how digital technologies like Radio Frequency Identification (RFID), the Internet of Things (IoT), data analytics, and Artificial Intelligence (AI) can make it easier and faster for circular practices to be used in the manufacturing, distribution, consumption, and recycling of apparel.

This thesis shows through a thorough study of the literature, case studies, and empirical analysis that digital solutions could help to develop and solve some of the most important factors in circularity. It includes tracking, designing products with sustainable materials, optimizing the supply chain, recycling, and getting consumers involved. It also shows how digital technologies and circular strategies work together systematically, putting light on how these two can work together to make solutions that can be scaled up and are good for the environment. This study also shows how important it is to use digital technology practices and innovations by looking at the current state of the apparel industry and the problems it faces in becoming circular.

The thesis also talks about the social and environmental effects of using digital technology in the clothing business to support Circular Economy (CE) and sustainability. It ends with practical suggestions for people in the apparel business, policymakers, and researchers, with a focus on how important it is to use digital solutions as a way to grow the circular economy now and in the future. It also helps to look into how digital platforms and openness in the supply chain could be used to encourage circle practices. It looks at successful case studies and points out hurdles to adoption, giving ideas for how to get around these problems.

In the end, this thesis says that digital solutions are needed for the circular economy in the clothing business to reach its full potential. As the demand for clothes around the world continues to grow, the old linear model of the industry must be changed into a sustainable circular model. The results of this study not only show how important digital integration is but also give industry players, policymakers, and consumers a plan for how they can all work together to drive the change toward a more sustainable and circular apparel ecosystem.

Keywords: Circular economy, digital solution, apparel industry, RFID, AI, IoT, sustainability.

CONTENTS

ABBREVIATIONS

AI	Artificial Intelligence
BM	Business Model
BDA	Big Data Analysis
CE	Circular Economy
CEAP	Circular Economy Action Plan
CSC	Circular supply chain
CSCM	Circular Supply Chain Management
EU	European Union
IoT	Internet of Things
RFID	Radio Frequency Identification
RQ	Research Question
T&A	Textile & Apparel
VR	Virtual Reality

1 INTRODUCTION

1.1 Background

The Circular Economy (CE) is a way to encourage people to use resources responsibly in recent years, the Circular economy has been supported as a way to help the earth and the economy at the same time. The CE is considered as an umbrella concept (Homrich et al., 2018) that includes different strategies and principles for reducing the number of materials used and the amount of trash made. It also means that the CE Concept is made up of many different ideas, strategies, and practices that all work together. These tactics and ideas can break the link between linear resource use and economic growth (Pauliuk, 2018). The idea of a circular economy is getting much attention from various sides. Nowadays it uses the main parts of the idea of sustainability. According to Winans et al. (2017), the term "Circular Economy" (CE) refers to a shift away from the conventional "linear" economy (take, make, and throw away) to one that involves closing, slowing down, and tightening the loop of material flows.

Textile waste is one of the biggest global issues right now. Over 15 million tons of textile waste are thought to be dumped in landfills annually, according to the Environmental Protection Agency of the United States (EPA, 2022). Also, the European Commission stated that in Europe, there are 12 million tonnes of textile waste generated per year (European Commission, 2023). The percentage of recycled textiles is rising year after year despite the fact that many of the current methods for separating textiles for recycling include some manual processing. The user can also utilize digital technologies to determine whether a textile has undergone fiber processing in order to identify and measure textile material (Cura et al., 2021). Digital technology can also distinguish between the many fiber types present and calculate the completed textile's relative percentage composition. Utilizing quick acquisition periods and automated analysis, which eliminates the labour-intensive aspects of manual approaches, it is able to acquire precise compositional analyses for textile identification quickly.

The whole world is moving towards sustainability and applying the concept of the CE. One industry where the circular economy paradigm is used is textiles. Digitally enabled solutions with verified data from cases that reduce emissions for customers or supply chain members (Cura et al., 2021). Upstream, Digital trigger (RFID, IoT, AI, etc.) contains information to reduce upstream stock and ensure stock is not wasted or more efficiently shipped to customers/consumers. Usage and resale or reuse, the life of the product, lengthens the lifespan of the product helps or allows it to be used in a more environmentally friendly way. Downstream, the data connected to the trigger allows for the full product to be returned to the correct recycling location, can be sorted more efficiently by reverse logistics, or allows for improved collection and connection to the correct recycling location with the tracking of recycled content post recycling. The EU adopted a new Circular Economy Action Plan (CEAP) in March 2020 and the subsequent initiatives along the entire life cycle of products (Horizon, 2022). It focuses on product design, stimulates circular economy practices, promotes environmentally friendly consumption, and works to prevent waste generation and prolong the useful life of the resources used. Additionally, this strategy strives to make sure that the circular economy benefits people, communities, and cities, completely supports climate neutrality, pollution-free living, resource usage decoupling, and fully utilizes the potential of research, innovation, and digitization.

In recent years, challenges such as climate change, accelerating global population growth, and the increasing scarcity of land and water resources have all escalated. Because of this, the effects of production methods on sustainability, especially in the fashion business, have become more important. In this situation, business model innovation (BM) is required to align incentives and market logic in order to apply circular solutions to benefit from technological advancements that can promote sustainability. (De Pádua Pieroni et al., 2019). In the past few decades, digital technologies like big data analytics and artificial intelligence have been used in the making, selling, and marketing of products. Utilizing these technologies accelerates innovation, research into new techniques, the creation of new goods, and business growth when it comes to digital (Bag et al., 2021). Today, this road is shaped by how fast technology changes, which is faster than it was in the past.

In this case, sustainable business models (BMs) for the fashion industry can be used to connect technological advances with circularity to make the fashion industry more sustainable (Lüdeke-Freund, 2009). The biggest problem is that these BMs have to be made in a way that makes money for the company and also helps people and the world (Schaltegger & Csutora, 2012). CE models push companies to make money and do good for society at the same time. They do this by combining rules, resource contracts, climate concerns, and social forces to give them a competitive edge. This helps the economy grow in a way that uses resources efficiently. (MacArthur, 2013).

In these circumstances, the author looked into how digital innovations can help CE and how they can be used in the apparel business sector (Rosa et al., 2019). These processes slow down and change how resources are used and make them more efficient and effective (Pagoropoulos et al., 2017). This enables the development of new market segments (such as closed-loop and extended life strategies) that generate revenue and give people access to goods that improve their quality of life (Bressanelli et al., 2021). Additionally, transparency and traceability should be offered across the entire life cycle of a product (Schäfer et al., 2021).

1.2 Research objectives and questions

The study looks at how the circular economy is being used in the world, especially in the European clothing industry right now, focused on the practices and strategies that are already in place. It looks at how digital solutions like blockchain, the Internet of Things (IoT), data analytics, RFID, and Artificial Intelligence (AI) can help move us toward a circular economy. The study also looks at the pros and cons of digital options and gives examples of how they have been used successfully. The way stakeholders see the digitally driven circular economy and how they are ready for it. It is suggested to integrate digital solutions into the apparel industry using a complete framework that takes into account technological, operational, and strategic issues. The study also makes predictions about how circular practices in the industry might be able to grow, taking into account things like resource efficiency, reducing waste, and economic success. There are practical suggestions for policymakers and business leaders on how to use the synergy between digital technologies and the ideals of the circular economy. The study

helps make a plan for future research and innovation, pointing out how it could help with things like sustainable development, resource conservation, and the well-being of society.

The above study goals led to the creation of four key research questions (RQs) that need to be looked into. First, need to know why the clothing business needs or wants a circular economy. In long-term, sustainable business, how can CE help to fix the problems caused by the world's excessive use of resources and raw materials, and how are these problems affecting the climate and human life? Next, the study tries to figure out how digital technology helps and works to cut down on these threads and save resources for the future by driving the whole circular economy in the apparel sector. With that, how will it affect producers, consumers, policymakers, and business groups when these things are put into practice? At last, the study looks at the risks that will be added to the system as a whole and how those risks can be managed.

RQ1. How is the circular economy currently used in the European clothing business, and what are the main problems that keep it from being used more widely?

RQ2. What are the most important digital solutions (like blockchain, RFID, IoT, AI, etc.) that the EU apparel industry can use as part of its circular economy practices, and how do they solve specific problems?

RQ3. How do digital solutions offer real and intangible benefits for the European apparel industry, such as scalability and driving circularity among producers, consumers, policymakers, and industry associations?

RQ4. What are the challenges, risks, environmental and social impacts?

1.3 Research structure

The paper is divided into five chapters: an introduction, a review of the literature, methodology and approach, a discussion with results and recommendations for the future, and a conclusion. The essential principles of circular economy and how it is employed or relevant in the garment sectors are covered in the second

chapter's theoretical literature assessments. It also discusses the advantages of CE for society, the economy, and the environment. Additionally, this includes how daily progress in the circular economy is being made via digital solutions. The integration of digital solutions for the circular economy in the garment sectors is emphasized at the chapter's conclusion. The chapters concentrate on critical details on the important topics based on recent scientific research. To provide academically sound and trustworthy results, the data was obtained utilizing databases that have been validated by scientists. The scientific data is supported by articles and publications from organizations that support the circular economy and digitalization.

The paper's methodology is introduced in Chapter 3. The framework approach is introduced at the beginning of the chapter as the foundational reference to be used in the assessment of the findings in chapter four. Through numerous conversations, teamwork, and project work, the planning and conduct of the research are described in relation to the decisions reached. Several case studies will be discussed. As this thesis made on the demand for the company where the author works so much confidential and public data had been collected for analysis. To keep confidentiality for the company and the other companies with whom collaboration was made during this thesis work. Confidential data were not published in this paper but public data has been shown in the data collection section. According to those all kinds of data some tables, graphs, and figures are also included in the data section.

Chapter four includes the core findings of this thesis with an important step that was taken by EU authority, a Digital Product Passport (DPP) to make the apparel industry circular by digital platform. Digital tools are appealing in the textile industry to grow circularity in this sector. This chapter also includes the role of digital tools in supply chain operations for the apparel industry. The apparel sector has many branches, manufacturing, repairing, reselling, and recycling. How digital solutions help in those branches is highlighted here based on the previous chapters. After all, if there is an implementation there must be risks, challenges, privacy and security issues. This chapter also highlighted those in a good manner based on all previous discussions and findings. Combining the results from all study instances, each research issue is examined separately, then the empirical

results are contrasted with the data from the scientific literature. For the purpose of giving the analysis supportive and easily comprehensible data, the results are visually presented.

The last chapter is chapter five, where the research's success is critically reviewed and the research's conclusions are formed. The chapter attempts to produce recommendations that would be advantageous to the research participants as well as significant research information for academic purposes. Additionally, the process-identified limitations and suggestions for additional study are addressed.

2 LITERATURE REVIEW

2.1 Concepts of the circular economy in the apparel sector

CE provides a broad framework that can be used for many different methods, such as product design, waste management, business models, and how consumers act. Under this CE concept, different projects and methods can be used to reach the overall goal of using resources effectively and growing the economy (Homrich et al., 2018). CE is based on the idea that goods that were meant to be thrown away in landfills but are now no longer valid, should be put back into production. A crucial component of the CE idea is that it consists of two parts: the "Circular" part, which emphasizes the technical cycle of materials, and the "Economy" element, which offers the economy and society new opportunities and trends (Nikolaou & Tsagarakis, 2021).

Sustainability problems in the manufacturing sector make it more appealing to switch to a more sustainable economic system. The best way for businesses to solve sustainability problems in the manufacturing sector is to switch to a model based on the circular economy (CE). Businesses are important to this shift because they have more resources and skills. By creating products and designs that benefit the environment, the circular economy (CE) is a sort of industrial economy that seeks to make the earth a better place to live (Ghisellini et al., 2016b). The primary objective of CE is to restore value to tangible objects through a more constrained closed loop of reuse and repair. Compared to recycling and energy recovery, this may be better for the economy and the environment. By developing goods, using production techniques, and using supply networks that keep resources moving in a closed loop, the concept of waste may be decreased in the circular economy (Ashby, 2018). The "single-use" way of life has turned the world into one where people "take, make, use, and throw away." Earth is using up materials 1.5 times faster than it can support (Janssen & Stel, 2017). Because it harms the economy, the environment, and the people, the traditional linear economic model has come under scrutiny. The most recent endeavour to lessen the dangers of the straight economy is the circular economy (CE). For many firms, however, the transition to a CE remains a significant challenge since it necessitates changes throughout the whole value chain, including new collaborations,

product design, closed-loop methods of converting waste into a resource, and innovative business models (Schaltegger et al., 2015).

One industry grappling with these challenges is the textile and garment sector, known for its long supply chain and environmental impact (Franco, 2017). It is additionally regarded as one of the most polluting business sectors globally (Fieldson & Rai, 2009). Making fabric for clothes takes a lot of water and energy. That's why pollution is still an early problem in the textile and clothing industry. Wet processing wastewater has dangerous chemicals in it that can harm the environment if they aren't properly cleaned up before being released. This can happen by contaminating water, gas, and the cloth itself (Alkaya & Demirer, 2014).

By 2050, the demand for clothes is expected to grow at a rate three times faster than it does now and its growth will be driven mainly by emerging countries (MacArthur, 2017). A lot of cotton output has also moved to developing countries, which have a lot of water problems and use half of all insecticides. Because of this, it is important for the fashion industry, especially in developing countries, to switch to CE, which is better for society, the environment, and business. In order to create an eco-friendly label, the fashion industry can alter the way products are made and place more emphasis on using ethically sound materials, fair trade practices, collaborations, value networks, and waste reduction (Henninger et al., 2016). The transition of the fashion industry to CE could be different depending on the country or region, economic level, present clothing consumption trends, obstacles, and laws.

Throughout the entire textile and clothing supply chain, encompassing design, sourcing, fabric and garment production, packaging, shipping, utilization, and disposal, the recurrent challenges are identified (Lorek & Spangenberg, 2014). The impact of the fashion industry's "textile product life cycle" on a global scale is staggering as well (Ramus, 2018). The third largest industrial industry in the world after transportation and technology, it is projected to be valued $1.3 trillion. The manufacture of T&A generates more greenhouse gas emissions than international air and sea travel combined, according to a 2017 analysis by the Ellen MacArthur Foundation. By 2050, the T&A industry will be responsible for one-

fourth of all global carbon emissions if current emissions trends continue (MacArthur, 2017). Additionally, the 3.3 billion tons of CO2 emissions produced annually by the fashion sector are approximately identical to the 3.5 billion tons of CO2 emissions produced annually by the 28 countries and territories that comprise the EU (UK Parliament, 2019).

The idea of a circular supply chain (CSC) refers to a complex, multifaceted system that stands out for its unique ability to create a never-ending circle of reusing and recycling resources and materials (Mangla et al., 2018). This new strategy supports a basic principle of sustainability by promoting a never-ending cycle of resource optimization that is both profitable and kind to the environment. As a key component of Circular Supply Chain Management (CSCM) within the overall circular economy concept (Zhang et al., 2023), the main goal of this strategy is to use as few resources as possible over the whole lifecycle of a product, with a focus on circular remanufacturing methods (Lieder & Rashid, 2016). By adhering to CSCM principles, individuals in different supply networks can interact within an open, connected system, facilitating the easy flow of resources within and between technology and natural material loops.

Realizing that Circular Supply Chain (CSC) and Circular Supply Chain Management (CSCM) have effects extending beyond direct operations is crucial for addressing urgent global problems. This broader impact is particularly significant for mitigating pollution, deciphering complex production and marketing trends, simplifying material use, and even reducing the effects of climate change (Lahane et al., 2020). The main idea is that businesses, by adopting circular models for the flow of resources, trash, and goods, can significantly reduce waste production and minimize the adverse effects their supply chains have on the environment (Tsoulfas & Pappis, 2006).

Utilizing digital technologies in products accelerates the transition from linear to circular economic models (Sariatli, 2017). This shift is driven by business innovations leading to social changes that cater to the needs of the current EU apparel market, from producers to consumers. To achieve these goals, new methods for making goods and processes that are environmentally friendly need to be developed using innovative business models (Sariatli, 2017). This can be facilitated by

technology, ensuring clear and sustainable supply lines. In our contemporary society grappling with challenges like climate change, pollution, and inadequate infrastructure, the creation of such an ecosystem is necessary. However, the use of digital technologies must transcend mere economic efficiency and competitive advantages, focusing on sustainability (George et al., 2020). Although new processes and products have contributed to reducing the negative effects of manufacturing and service processes, a critical mass has not yet been reached (Shahi & Sinha, 2020). The growing interest in circularity in the EU, from customers and shareholders to neighbourhood groups and the government, signals a shift. However, for circularity to succeed, the economic system, especially how companies generate and understand money, must change. This necessitates a rethinking of the current business model (BM) to separate value creation and resource use (Bocken et al., 2014). Therefore, business model innovation toward circularity becomes a crucial strategy for businesses.

The CE has made brands, manufacturers, and customers rethink how they usually buy clothes and how to reuse and recycle clothes (Gupta et al., 2022). Also stresses the significance of eliminating waste and pollution, preserving products and materials, and reviving natural systems. More and more fashion businesses are starting programs to make clothes last longer, encourage reuse and repair, and invest in materials that are good for the environment. But despite these positive steps, the CE still can't reach its full potential because of several problems that make it hard to scale up and spread. Garments are no longer seen as things that can be thrown away. Instead, they are seen as valuable resources that can be reused and recycled, which reduces the environmental impact of the industry and promotes sustainable growth.

The world could alter if a circular supply chain is established, especially when it comes to organizing and harmonizing various practices. The complete CSC framework makes it easier to figure out how to use these practices, taking into account things like the best order to use them and how well they work together. When these things are taken care of properly, they lead to the creation of a circular, lean, and sustainable consumption paradigm that is easy to combine.

An entirely new method of managing resources and ensuring the sustainability of operations is created by the many components of the circular supply chain and circular supply chain management. Their implementation is more complicated than just making things more efficient. It has to do with more general environmental needs and plans for innovation that look to the future.

2.2 Environmental, social, and economic benefits of adopting CE

The traditional cycle of production, consumption, and waste needs to be changed to one of production, consumption, and reuse. This requires producers, consumers, and lawmakers to work together and be committed (Laurenti et al., 2018). The success of this economic model, which is intended to be beneficial for the social life of the community, the economic well-being of the community, and the natural environment, depends in large part on co-creating value amongst these (Yan et al., 2019). According to research that shows the world as a closed, circular system with finite resources, where the economy and the environment should work together, the CE method is based (Yan et al., 2019). As of yet, the CE has largely adhered to traditional economic theory, which views enterprises as beings with the primary objectives of producing money and expanding (Velenturf et al., 2019). The circular economy has placed a strong emphasis on proving how its environmental benefits would lead to financial gains (for example, by increasing sales through trash utilization and/or cutting costs associated with waste management). Meanwhile, the societal advantages (such as the creation of fresh direct and indirect employment opportunities and the promotion of a more healthful living environment) are generally taken as an inherent outcome (Velenturf et al., 2019).

In the context of a circular economy, social aspects can have multiple meanings in business. Although they were viewed from the perspective that both individuals and businesses are economic players in a circular economy, the social characteristics of customers were deemed to be significant (Velenturf & Purnell, 2018). The fundamental critique is that no one has considered how CE can help to improve social and financial equity and access to resources both across and between generations (Murray et al., 2015b) (Schröder et al., 2019). To help businesses deal with environmental and social issues while also assisting in the

achievement of the UN's Sustainable Development Goals, for example, success might be measured against a variety of environmental, social, and economic indicators and incorporated into decision-making (United Nations, 2022). They participate in forming the government and a circular society in addition to running their own businesses (Dyllick & Muff, 2013), developing new business models that incorporate environmental and societal costs and benefits into their value proposition, cost structure, and income stream (Montanati et al., 2017).

The European Commission's 2011 European Circular Economy Plan demonstrates how seriously the EU takes the development of a circular economy (CE). Entrepreneurs are also getting more knowledgeable about the business strategies that the CE can provide (MacArthur, 2013). However, it is advisable to encourage business and economics experts to investigate the profitability and viability of CE strategies and related management approaches for resolving related issues (Khitous et al., 2020). By closing, enlarging, and slowing down material and energy loops, the CE is viewed as a self-renewing system that decreases the number of resources utilized, waste, emissions, and energy loss. Sustainable development is defined as the "harmonious integration of economic, environmental, and social considerations." Researchers have studied the long-term effects of the circular economy (CE) concept on how the natural world functions (Rashid et al., 2013; Bakker et al., 2020). Some experts have examined the CE's broader consequences from a broad perspective, accounting for social and economic effects in addition to environmental ones (Muniz & Cruz, 2015). However, other authors have examined various facets of how the CE affects social dynamics, including how well tax systems function and how consumer behaviour evolves (Webster et al., 2015).

Since the late 1970s, the concept of a circular economy (CE) has been discussed, and many researchers have examined how it impacts economic growth (Trica et al., 2019). By carefully examining publications published between 1950 and January 2016 in the areas of "Sustainability," "Circular Economy," and "Circular Economy and Sustainability," a particular study discovered a direct connection between CE and economic growth (Geissdoerfer et al., 2017). Researchers have examined the CE from small- and large-scale perspectives to see how it affects various phenomena (Haupt & Hellweg, 2019; Ramani et al., 2010). The current

emphasis is on researching how CE influences longevity and economic growth in nations, particularly in the European Union (Moraga et al., 2019). Indicators like production and consumption, waste management, secondary raw materials, competitiveness, and innovation were proposed in a strategy to monitor the advancement of CE on a broader scale across all EU member countries (Mayer et al., 2018).

It's critical to remember that using renewable resources is only one part of achieving sustainability and enhancing the impact of the circular economy on economic growth (Busu & Nedelcu, 2017). This viewpoint is supported by five significant elements taken from the Eurostat database. Like private investment, employment, gross value added related to CE, environmental tax revenues, trade-in of recyclable raw materials, municipal waste recycling rate, and recycling-related patents (Laci & Hysa, 2015).

According to the circular economy, above stated factors include waste management, taxes, investments, innovation, and trade. Economic growth that is tied to sustainability depends on how well different parts of the European market work together (Montanati et al., 2017). The circular economy, which includes both consumers and producers, is built on three pillars: environmental, social, and economic factors. Together, these three pillars make up the triangle of sustainable growth. The figure 1 shows how these five keys affect the environment, society, and the economy for long-term economic growth in CE (Hysa et al., 2020).

TABLE 1. Modeling circular economy in the context of sustainable growth (Hysa et al., 2020).

Sustainable Economic Growth in Circular Economy	
Environmental Impact	Environmental tax revenues
	Recycling rate of municipal waste
Social Impact	Environmental tax revenues
	Private investment,jobs,gross value added related to CE
	Patents related to recycling
Economic Impact	Environmental tax revenues
	Private investment,jobs,gross value added related to CE
	Patents related to recycling
	Trade in recyclable raw materials

2.3 Advancing Circular Economy with Digital Solutions

The ongoing shift toward a circular economy (CE) has become an important strategic goal for companies all over the world. This is a big change from the usual approach of take, make, and throw away. Instead, it focuses on the ideas of regeneration, using things for a long time, making as little waste as possible, and reducing pollution (Chauhan et al., 2022). In this new framework, the old way of thinking about things at their "end-of-life" is replaced by a more complete way of thinking that focuses on reducing, reusing, recycling, and recovering. As organizations try to switch from linear to circle practices, they have trouble getting and integrating data, which can make it hard to make the changes that are needed at both the organizational and ecosystem levels. Scholars say that the change in CE and the trip to digitalization, which is happening at the same time, are closely related. We need to use the power of digital assets that can change the world, like big data, RFID, artificial intelligence (AI), blockchain, the Internet of Things (IoT), and cloud computing, for this link to work. Therefore, the majority of experts concur that the adoption of CE principles is intimately related to developments in digitization. This creates a good setting for predictive analytics, full product lifecycle management, and proactive decision-making support (Chauhan et al., 2019).

How important it is for technology to help move the economy toward a circle model. This job is important for a lot of reasons that have to do with the strategic goals of CE adoption. In particular, these transformative digital tools help bridge the gap between abstract CE ideas and practical practices in the real world (Kintscher et al., 2020). By looking at these new tools through the lens of circularity, it has been seen that they have real benefits. They help people improve their skills and abilities so they can make well-informed decisions based on the circle of life (Mboli et al., 2020). When data-driven insights are used in the planning process, they support circularity by making the best use of resources. This makes things better for the economy and the environment. Using lessons from predictive and prescriptive machine learning, products, their parts, and the processes that go with them can be designed and improved in a way that follows CE principles (Bressanelli et al., 2018). Companies can forecast demand when they combine real-time and historical data, keep track of stock well, and cut down on waste. This helps processes last longer. Also, digital technologies make it easier to find and use best practices, which speeds up the process of remanufacturing and reusing. One great example of how digital innovations and circularity go hand in hand is using AI-powered picture recognition to improve the efficiency of e-waste collection (Wilts et al., 2021).

Radio Frequency Identification (RFID), Artificial Intelligence (AI), and Big Data are all examples of digital tools that can change how traditional business models work. By making it possible to adjust a lot of things at once, these tools give businesses the ability to match sustainable inputs with the changing needs of customers (Bag et al., 2021). At the same time, these technologies are a big part of how predictive maintenance methods help products last longer. This doesn't just make things better for customers as a whole. Organizations on the verge of digital transformation will be able to take advantage of a lot of new opportunities in key areas like production, processing, logistics, and waste management because they will have a better idea of how their complicated supply chain network works. This kind of technological change could help both local and global economies grow, which could lead to long-term business models that are more stable (Bag et al., 2021). Still, mixing CE principles with automation is a complicated process that leads to several problems that need to be looked at in detail. The

way this integration works depends on how different each business is, and the rate of growth in each may be different.

To get the most out of digitalization, businesses need to carefully use enablers to bring about the hoped-for gains in circular performance. It's important to keep in mind that putting CE principles into practice takes a big change in how most businesses work. Because of this, there is more and more writing at the intersection of CE and digitalization. Importantly, digitalization is a key part of giving lawmakers the tools they need to deal with pressing environmental problems, like material flows, by giving them correct and relevant data (Bonilla et al., 2018). This wealth of information makes it easier to make good choices and opens the door to better ways of putting CE into place. At the same time, this study shows how important it is for businesses like clothing to stop narrowly looking at things and start focusing on the whole ecosystem. In this case, technologies like RFID, IoT, and blockchains help create dynamic ecosystem partnerships, which are key to making the circular economy work profitably (Wilts et al., 2021). The two most crucial strategic imperatives for firms today are the transition to a circular economy and the utilization of digital technologies. The change from linear to circle economics is hard because we don't have enough data and it's hard to put everything together. Faced with these problems, digitalization seems to be a force that can help solve them and open up new areas by putting together changing digital assets. Combining CE ideas with data-focused is the next stage of resilient and sustainable economic models (Chauhan et al., 2022). As experts learn more about this convergence, they come up with new ideas that show how CE and digitalization work together to make the economy grow and the environment less stressed. This relationship is a once-in-a-lifetime chance to change how businesses work by combining circularity and digital skills in a way that works well together.

2.4 Advancing Digital Solutions for CE in the apparel sector

It is obvious that the textile and fashion industries will be impacted as the globe undergoes a digital transformation and transitions towards the fourth industrial revolution, known as Industry 4.0 (Machado et al., 2019). Notably, digital tools are used a lot to get clothing buyers and customers interested. Digitalization is

becoming more and more important in the fashion business, especially in the fast fashion sector. Artificial intelligence, virtual reality, and big data analysis are some of the most important technological advances that help predict and analyze fashion trends (Akhtar et al., 2022). The biggest problem with how the fashion industry works now is that it is built on a straight system, and even when it uses sustainable practices, it only cares about the environment (D'Itria & Colombi, 2022). Digital technology has helped improve eco-friendly ways of doing things, which has led to less pollution, waste, and use of energy and resources in business. It has been discussed how radio frequency identification technology can be used to cut down on the amount of fashion trash that ends up in dumps, which cuts down on carbon emissions and greenhouse gas production (Nayak et al., 2022). Above mentioned technologies also give customers personalized suggestions and help them make decisions about what to buy. Designers and manufacturers must employ the above-described technologies in their work if they want to promote the circular economy of the apparel and fashion industry. Cyber-physical systems that are incorporated into industry processes (Machado et al., 2019) which cover manufacturing, transportation, and production, are geared toward producers and can be used to move the circular economy forward. Still, there are some big problems with how the apparel business is adapting to digitalization. These include boosting the mindset of fast fashion and making a feedback loop happen because of better efficiency. Inadvertently, methods that use less material and cost less can speed up production, which adds to the fast fashion trend during the production phase.

Emerging technologies, which are often digital, are used for two reasons. First, they are used to improve working processes and production methods for the apparel industry and make them more efficient and flexible. Second, they are used to make these functions more sustainable (Faria et al., 2020). This increase in efficiency is also seen in the economy, where the improvement of processes leads to a higher level of economic effectiveness (Faria et al., 2020). At its core, Industry 4.0 combines the real parts of the industrial world with the imaginary parts of the digital world. This is made possible by a wide range of digital technologies. These technologies include Artificial Intelligence and machine learning, as well as blockchain, cloud computing, big data use, the Internet of things, and

technologies like virtual reality and augmented reality, as well as radio frequency identification systems (Ghoreishi & Happonen, 2021).

With digitalization, EU apparel businesses can reach a larger audience and offer their goods and services to a wider range of customers. But some problems come with using these tools. To get around in the world of Industry 4.0, makers and producers need to spend a lot of money and know a lot about technology (Machado et al., 2019). One important result of automation is the ability to track products and improve the value chain, which leads to the growth of circular economy practices. Digital tools create mutually beneficial relationships between producers and customers by acting as a platform. This makes it easier for services to be provided and for businesses to work together (Berg et al., 2022)

Intelligent design and prototyping, real-time monitoring, group decision-making, analytical work, warehouse management, marketing, and information exchange are just a few of the numerous domains that digital technologies have an impact on (Ghoreishi & Happonen, 2021). Digital tools increase the efficiency of cutting, stitching, pressing, and packing in the apparel sector (Yadlapalli & Rahman, 2022). By facilitating access to rare materials and replacement components via online platforms and solutions, digitalization can expand the market for repair services (Carmer, 2021). The foundation for e-commerce platforms, virtual fitting rooms that facilitate communication between businesses and customers, and various methods for consumers to resell worn clothing is also laid by industry 4.0 technologies (Faria et al., 2020).

The fusion of digitalization and sustainability stands out as a subject that permeates all stages of production in the larger context of garment production in the EU and the rest of the globe, particularly in the search for models of a circular economy. The circular economy and the sharing economy are being pushed toward by the fashion industry's digitalization (Akhtar et al., 2022). By lowering production risks, the objective of sustainable production also has a social component that benefits the health and well-being of industrial workers and employees. The main goal of sustainable production is to use as little material and energy as possible. This includes efficient waste management, resource conservation, less water use, better use of land, and more energy efficiency (Machado et al., 2019).

Uses of technology are causing a huge change in the fashion supply chain. This change not only makes it easier for the different people and parts of the supply chain to talk to each other, but it also improves the way everyone works together. Integration of tracking systems will bring many benefits. For example, manufacturers will be able to track their goods' journeys and predict how their quantity and value will change (Jia et al., 2020). Traceability and tracking technologies fill in the gaps in past information about a product's lifecycle and where it goes after it is bought. The hope is based on the fact that information and communication technologies are still getting better, which should make it easier to handle and track product lifecycles.

The review discusses the challenges faced by the apparel industry in transitioning to a circular economy, such as changes in business models, collaborations, and closed-loop methods. Further research could explore specific obstacles encountered by companies in different regions, economic levels, and cultural contexts, providing insights into tailored strategies for overcoming these challenges. While the literature emphasizes the importance of digital solutions in advancing the circular economy, there is a need for more in-depth research on the practical integration of digital technologies, such as RFID, AI, blockchain, IoT, and cloud computing, into the circular supply chains of the apparel sector. Investigating how these technologies can be effectively implemented, their challenges, and the impact on overall supply chain efficiency would be valuable. The review mentions the use of digital tools in promoting circularity. However, there is a research gap in evaluating the actual effectiveness of these tools in achieving circular economy goals. Investigating the impact of these technologies on waste reduction, resource optimization, and overall sustainability in the apparel industry would be valuable.

3 METHODOLOGY AND APPROACH

3.1 Framework Introduction

For this thesis, the convergent design framework was chosen since it offers a comprehensive method of problem-solving. Convergent design is a main element of the mix method research (Creswell et al., 2017) which enables the research and incorporation of solutions to the complicated problem of the circular economy in the apparel sector. Diverse stakeholders, including producers, buyers, decision-makers, and environmentalists, are involved in the apparel sector. The integration of these various viewpoints is made possible by the convergent design technique, ensuring a thorough analysis of the problems and potential fixes in the context of circularity and digital solutions. Because CE solutions need to be developed and improved iteratively. This framework makes an iterative approach possible by continuously assessing and settling on the best digital solutions for implementing circular business practices in the apparel sector.

To fully understand complex systems and processes, mixed-methods research is a potent instrument (Fetters et al., 2013). This method, which combines qualitative and quantitative techniques, gains significant power when it is incorporated into a study's design. Sequential exploratory, sequential explanatory, and convergent mixed method designs are the three main categories that stand out. In the convergent design framework, when both qualitative and quantitative data are collected and analyzed at the same time, an interesting combination happens. This parallel journey gives us a chance to use an interactive method, in which the live interaction between collecting data and analyzing, helps to improve methods for collecting data. For example, as the first quantitative ideas come together, they could change the way qualitative data is collected, and vice versa. This method improves the study process by making sure that different data streams work well together. In a study, the qualitative and quantitative results kept feeding back and influencing each other until a coherent story emerged (Crabtree, 2005). This repeated blending of data gives a more complete picture and shows details that might have been hidden otherwise. On the other hand, a popular variation that is easy to do technically is to collect qualitative and quantitative data at the same time. In this case, the merging journey starts after data collection has made

a lot of progress or is finished. Often, these two different kinds of data are analyzed separately before they are put together to make a full tapestry of insights.

In this landscape of mixed methods research, practical knowledge of quantitative and qualitative techniques gives researchers a good summary of the research. When all of these different pieces of data are put together, they form a tapestry that gives a fuller picture of the complicated forces. As study methods change, mixed methods continue to give us new ways to figure out what's going on in the world around us. This model is also used finely as well (Cappetta et al., 2006).

Addressing the circular economy in the apparel industry requires an interdisciplinary approach that spans technology, business, sustainability, and design. Scalability is likewise an important component of circular economy solutions. In order to identify adaptable and scalable digital solutions that can be implemented across different scales of the apparel industry, from individual brands to global supply chains, the convergent design framework encourages collaboration across these disciplines, fostering a well-rounded analysis of the issue and its potential solutions. Convergent design can encourage evidence-based decision-making through data collection and analysis by gathering information on the efficacy of various digital solutions and their effects on the circular economy in the garment sector. Lastly, this framework encourages innovation and creative thinking by allowing for the exploration of unconventional solutions and the integration of new technologies that can drive circular practices in the apparel industry forward by providing a structured methodology for investigating, evaluating, and proposing these solutions to address the industry's sustainability challenges.

3.2 Research Design

The research design is like a map that shows how data will be gathered, analyzed, and interpreted during a study. In this part, there is more detail about the chosen research design along with its rationale and suitability for addressing the research objectives.

Mixed-methods research is used here to give a full picture of digital solutions in scaling the circular economy within the apparel industry. The mixed-methods approach was chosen because it can catch both the context-richness of qualitative data and the statistical rigor of quantitative data. This makes it possible to explore the research problem thoroughly.

For the qualitative part, open discussion and collaboration were done with people who work in the cloth sorting, recycling, and laundry industries. The aim is to gather their experiences, thoughts, and problems when it comes to putting digital solutions into the circular economy through these conversations. The interviewees were chosen carefully, with a focus on people with a lot of experience in the business with sustainable practices and digital technologies.

The quantitative aspect encompasses data collection and data analysis of metrics related to the collaborative project between the company where the author works and a textile recycling entity. Those data were taken into confidential, that's why the author is unable to publish those data. Analyzing quantitative data, like increases in efficiency, decreases in waste, and the best use of resources gives the results of our study a numeric dimension. The triangulation of qualitative and quantitative data is made possible by the mixed-methods design, which gives the study's findings more credibility and depth. It makes sure that the research question is looked at from all angles and lets us learn more about how digital solutions and the scalability of the circular economy work together in the apparel business.

Overall, the complexity of the research problem fits well with a mixed-methods research plan. This makes it possible to do a thorough and nuanced study that uses the best parts of both qualitative and quantitative research.

3.3 Case Studies

The transition towards a circular economy within the apparel industry stands as a formidable yet essential challenge in the face of escalating environmental concerns and resource depletion. As the industry grapples with the imperative to decouple growth from its ecological footprint, innovative strategies become paramount. The integration of Radio Frequency Identification (RFID) and other digital

solutions emerges as a potent contender in redefining textile sorting and recycling practices—a pivotal dimension of the circular apparel economy.

In this chapter, embark on an exploration of case studies that epitomize the synergistic fusion of digital technology and circular economy principles. Each case study unveils a distinct fact of how RFID and digital solutions have revolutionized textile sorting and recycling optimization. From reshaping traditional sorting paradigms to enabling enhanced traceability of recycled materials, these case studies epitomize the transformative potential of technology in driving the circular economy forward. The author has conducted several interviews with personnel from several types of companies which has a different kind of business with textiles. These interviews aid in the study and analysis of the operations of those businesses as well as their potentiality toward the Circular Economy which is driven through digital technologies. All the information that will be provided in the rest of this chapter and the upcoming chapters maintains the confidentiality of those companies' information and data. Only the publicly accessible data and information have been displayed.

3.3.1 Zara's RFID-Enabled Inventory Management

Inditex, the company that owns Zara, is known for using technology to change the fashion industry. To construct smarter dressing rooms and organize shop inventories, for instance, they employ data. To enhance customer service, transform their stores, and enhance their supply chain, they are now employing RAIN RFID (Robshaw, 2016). At the time of production, Inditex attaches plastic security tags with RAIN RFID chips to each item. The plastic case safeguards the RAIN RFID chip and permits the business to reuse the tags after they have been removed from an item at the register. Before the RAIN RFID system was put in place, workers took stock of the whole store by scanning the barcodes of each item one by one. Because this method took so much time, store inventories were only done every six months. The store's management is immediately notified by the RFID when an item is sold, and someone is immediately dispatched to the stockroom to replace it. Each item of clothing in Zara's showcase is available in four sizes: small, medium, large, and extra-large. RFID also makes it easier to monitor how quickly various items are selling in stores and online. The amount of

product and how well that area of the store is selling in comparison to other areas of the store and to the same time last year can be determined via a device that resembles a handgun and moves across the screen.

3.3.2 H&M's Recycling Program

H&M, a well-known international clothing store, started a program to recycle clothes as part of its efforts to be more eco-friendly. The main goal of the program is to get customers to recycle their old and unwanted clothes so that textile waste can be reduced. The whole fashion business is known for creating a lot of waste and pollution, so programs like H&M's clothing recycling program are very important for promoting greener ways of doing things, which is the main principle of sustainability and circularity. In this process of recycling customers can bring their old clothes from any brand to H&M stores to be recycled through the program. The clothes are then put into piles based on how good they are. Clothes that can still be worn are often given to charities or sold as second-hand clothes. Clothes that can't be worn anymore are remade to make new things or materials.

In 2020 H&M announced a recycling system called ‘LOOOP’ (H&M Group,2020) which helps H&M to transform unwanted garments into new garments. This system has a method for taking apart and putting back together old clothes to make new ones. The clothes are cleaned, broken into small pieces, and then turned into new yarn. This yarn is then used to knit new clothes. During the process, some raw material has been added that come from sources that don't harm the environment, they try to keep this amount as small as possible. The system doesn't use any water or chemicals, so it has a much smaller effect on the earth than making clothes from scratch. The main reason for this program is to reduce waste and make the process circular and sustainable.

The whole reuse & recycle process of H&M runs in a closed-loop supply chain system (Guide & Van Wassenhove, 2009) where customers can bring their unwanted items to H&M shops, where H&M’s partners will sort them based on how good or bad, according to the EU waste hierarchy (Egüez, 2021) which puts reuse before recycling. Looper Textile Co. joint venture with H&M garment collecting partner Remondis, which helped collect clothes, at the beginning of 2023. At first,

the company will operate this business in Europe (H&M Group,2022). H&M has shown little progress in those sustainability goals that they set before and there are still so many targets and programs in the pipeline for the future to comply with the sustainability and circular economy

3.3.3 SAKUPE textile service

Sakupe Oy is a textile service business in Finland that focuses on giving its corporate clients safe and effective ways to keep their textiles in good shape. The company sends out about 100,000 different pieces of clothes to customers every day, so it does about 10 million kilograms of laundry every year. Sakupe's service is based on four main ideas: safety, affordability, ease of use, and responsibility. In line with these values, the company provides top-notch textile services that are both high-quality and affordable. These services are suited to the needs of professionals and help them do their jobs. In healthcare sectors, patients' clothes and bed sheets must be carefully cared for and cleaned according to strict standards. Sakupe's focus on maintaining high standards of cleanliness depends on using advanced microfiber textiles, which are known for how well they clean.

RFID technology is used to run a closed-loop supply chain system which is an important part of how they do business. This technology makes it possible to collect a lot of data about clothes from the time they are bought to the time they are thrown away. Sakupe buys clothes from vendors by putting RFID tags on them and entering data into their system. Then, the RFID database is used to manage the whole supply chain. This creates a smooth process aimed at extending the use of textiles until they hit the point where they become textile waste.

The company's major objective is to promote the cyclical usage of textiles. Some affiliate vendors collaborate with Sakupe to gather discarded textiles when a product's lifespan is up. Those textiles which become waste are then recycled in new ways to make new clothes. These clothes are fixed up and sent back to Sakupe. This creates a sustainable circular model that supports the company's approach to responsibly managing textiles.

Sakupe Oy puts a lot of effort into taking care of the environment in all of its service production, while also making sure it follows all laws and regulations very closely. They have a strong commitment to being environmentally friendly, which is a goal for cleanliness and saving the environment. The way they plan the size and make-up of their rental textile collection is already environmentally friendly, and it seems they always try to close an eye on and improve the efficiency of the textile lifecycle all the time. There is a method in place that makes it easy to recycle textiles completely when they are no longer useful so that they can be used again.

3.3.4 SPINNOVA- A sustainable textile material company

Spinnova is a Finland-based textile material company that has developed a technology, that can transform cellulosic fiber into fiber for the textile industry. This transformation is fully done in a mechanical process. Wood pulp and agricultural waste are ground up by their patented machines into microscopic fibers that may be spun into wool and then produced into garment fabric. The method appears to offer advantages over cotton cultivation, as it requires fewer pesticides and less water, which can be especially beneficial in regions facing water scarcity. Because it uses trees that don't require irrigation as they develop, it has been calculated that it uses more than 99% less water than cotton and no hazardous chemicals are used in the procedure. It doesn't utilize chemicals to break down difficult fibers, in contrast to certain other materials that can be manufactured from trees, including viscose. The fabric also avoids the drawbacks of synthetic textiles like polyester, which are frequently created using fossil fuels and can contribute to the accumulation of plastic debris in the ocean when minute strands come loose from clothing during washing into rivers.

The company planned to start its first production in 2023. In terms of technology, the company’s goal is to create clean, bio-based materials that are needed for the textile industry (Spinnova 2020) now a days. With the aid of technology, Spinnova mechanically purifies wood pulp raw material and creates a suspension of fibers that is safe for spinning. Currently, Spinnova is recognized as a pioneering company in the world that has successfully developed the capability to transform cellulose into sustainable textile fiber. The suspension travels through a special

nozzle at high pressure after spinning into the filament (Spinnova 2020). The fibrils spin and align with the flow to form a textile fiber with the proper type of extrusion. After simple drying and collection, the fiber is prepared for spinning into yarn (Spinnova 2020). Spinnova can convert virtually any cellulose biomass into microfibrillars, which are then spun into textile fiber using the pulp processing method. This doesn't call for more technological advancement. Although wood is the primary raw material, other choices include cotton waste, leather waste, and agricultural waste like wheat straw.

In terms of circularity, one of the special characteristics of fiber is that it may be recycled during the process, once more without dissolving or dangerous chemicals. This suggests that in the future, a brand with which can collaborate could potentially retrieve a product from a customer, transport it to the processing facility, and convert it into microfibrils without the need for disassembling the product. The quality of the recycled fiber is equivalent to, if not superior to, that of the original fiber. It can be transformed into new items without the addition of any new fibers. The ambitious innovation project The Collection of Tomorrow is a partnership between the Scottish textile finisher Halley Stevensons, Spinnova, and the outdoor clothing company Bergans from Norway (Spinnova 2020). Together, they are trying to drive the textile sector hard in the direction of a more circular future. It's likely that the first companies globally to achieve the closed-loop transformation of a textile product without the use of toxic chemicals include Spinnova, Bergans, and Halley Stevensons. This is a tiny step for outdoor apparel, but a huge stride for environmentally friendly textile manufacturing. Also, they have collaborated with many textile manufacturing brands to build sustainable textiles together.

3.3.5 TEXAID- A textile sorting company

By collecting, classifying, and recycling discarded textiles in an environmentally friendly manner, TEXAID gives worn-out clothing, shoes, and household textiles a new lease on life. One of the top organizations in Europe for the environmentally friendly gathering, sorting, and recycling of discarded textiles is TEXAID. To consistently provide its partners and consumers with high-quality services and goods, the company uses creative procedures, specialized collection logistics,

and cutting-edge sorting. To keep old textiles as long as possible in the value-added chain, TEXAID blends economics and ecology.

TEXAID collects around 80000 tonnes of used textiles every year (TEXAID, 2023). The whole process of the company runs through a closed-loop supply chain system of collection, sorting & recycling. To run this system textiles are collected through bins in several countries or areas and also in-store collection systems at selected clothing stores. In the sorting facilities, skilled workers inspect each garment by hand and categorize it using about 60 criteria. In the recycling process badly damaged textile items made to cleaning cloths and other textiles are recycled for retailers, second-hand markets, etc.

As one of Europe's leading textile recycling companies, TEXAID is committed to its significant responsibilities toward the community, the environment, and the public. The company's approach involves ongoing enhancements in climate and environmental protection. TEXAID is dedicated to offering sustainable solutions for used textiles and has continually improved its operational methods and quality standards over the years. In order to sustain and advance its environmentally conscious and climate-neutral corporate culture, TEXAID consistently strives to enhance its strategies related to the environment, sustainability, and climate. The company also actively develops and implements long-term strategies to reduce energy consumption. To promote textile recycling, TEXAID collaborates with various stakeholders in the industry.

The company cares about more than just how well it runs. TEXAID has a strong sense of duty to the community and the environment, which drives its efforts to protect the climate and the environment. Their long-term commitment to improving work methods and quality standards shows how much they care about finding long-term answers. TEXAID works hard to create a corporate culture that cares about the environment and isn't affected by climate change. It does this by constantly improving its strategies for environmental, sustainability, and climate goals. Strategies to cut down on energy use over the long term show how effective they are. TEXAID's commitment to circularity is also strengthened by the fact that it works with different players in the textile business. By working with different people, the company is helping to create a closed-loop textile system and making

sure that its actions are in line with larger sustainable goals. For this reason, TEXAID is working on several projects (TEXAID, 2023). To make a high-quality basic product that stays in the textile cycle longer. TEXAID is also working on technology that can tell what a material is made of and how the fibers are separated. A few projects on what TEXAID worked and currently working on, such as Texcircle, Texcysle, Re: Mix, Fibersort, and Dissolving on Demand. TEXAID's huge effect on the circular economy and sustainability is a testament to its creativity, dedication, and never-ending pursuit of a greener, more sustainable future. Through its creative methods, TEXAID turns old textiles into useful resources and sets a good model for other businesses that want to help the environment.

3.4 Data Collection and Analysis

This sub-chapter focuses on research by presenting the methodologies that helped to gather and dissect the empirical data crucial for those above case studies. The synthesis of these methodologies forms the cornerstone of our comprehensive analysis, paving the way for insightful interpretations and conclusions. Those case studies begin with a meticulous process of interviewing and some study as well as of data collection and analysis. This sub-chapter illuminates the strategies employed to acquire relevant data and subsequently transforms raw information into meaningful insights that contribute to a deeper understanding of our research objectives. By going through the case-by-case author will not include confidential data, The data and figures shown in the rest part of this subchapter are available for public use from several sources and analyze those data at the same time.

Considering the first case studies about Zara’s inventory management through RFID. RAIN RFID accelerates the whole inventory management for Zara in Europe as well as in the whole world. Before that Zara’s employee was responsible for managing the inventory by scanning barcode one at a time (Impinj, 2014). Because of the time-consuming process, Zara’s inventory management team can perform this once every six months. For this inventory checking it requires 40 employees and a total of around 5 hours. With the help of RFID, a team of 10 people can do this job within half of that time. In this Zara case, RFID is helping the supply chain process which leads to a part of the CE principle. It also offers

excellent visibility, allowing users to track how each garment is handled and where it is at all times. With the help of RFID Zara can reduce overstocking or stockouts, leading to better demand forecasting and inventory optimization. Inventory management and visibility are a part of the CE model. By managing inventory well, companies like Zara can repair, refurbish, and remanufacture products to make them last longer. This method saves resources, helps take-back programs, and makes it possible for supply lines to be closed. Inventory visibility also makes it easier for people to consume sustainably by letting them know about circular choices. In the end, good inventory methods are in line with circular economy principles because they reduce waste, make better use of resources, and make products last longer.

Considering the recycling program of H&M, the technology they have used with the help of AI, made people more aware of textile waste and pushed people to do the right thing by recycling their old clothes instead of throwing them away. The idea was in line with the circular economy because it aimed to turn recycled linens into new fabrics and materials. This would cut down on the need for new resources. By putting recycling bins in their stores, H&M made it easy and handy for a wide range of customers to recycle. The Figure 2 data below shows how much clothing was gathered by H&M's reuse and recycling program globally from 2013 to 2021 (H&M, 2021).

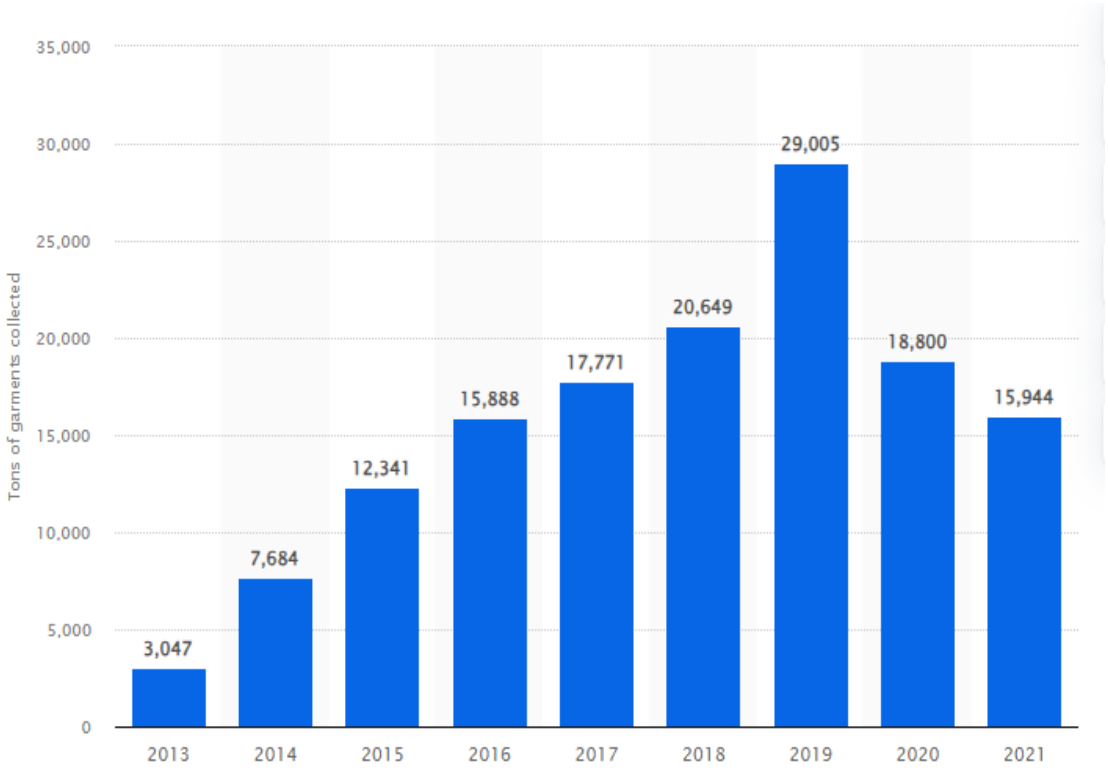

FIGURE 1. Quantity of apparel collected by H&M's reuse and recycling scheme worldwide from 2013 to 2021 (in tons) (H&M, 2021).

From the above statistics it has been seen that the collection of apparel for reuse and recycling gradually increased until 2019. After that, it has reduced due to the Coronavirus pandemic (Covid 19) (Ritchie et al., 2017). By 2030, H&M wants to use only recycled materials that come from sources that are good for the environment in its clothes. Its plan to reach this goal is based on three things: In addition to the Green Machine, it has collaborated with a Swedish textile recycling business. The Green Machine is the world's first technology that can separate blended textiles at scale, without any quality loss. Regarding new cell, which employs a novel technique to transform old viscose, cotton, and other cellulosic fibers into a long-lasting dissolving pulp (H&M Foundation, 2021). This has led to the invention of a new material called Circulose, which has been patented. Loop is a good way to see that and a great place to learn about the other recycling and repair projects that H&M Group is working on. Loop is not the only way for H&M to become a circular business, but it is a big step in the right direction. Last but not least, there is the Green Machine, which seems to be the most promising of the H&M Group's circularity attempts. It was created as a result of an educational collaboration between the H&M Foundation, the Hong Kong Study Institute of Textiles and Apparel, and one of Monki's primary suppliers. The recycling machine uses a hydrothermal method to separate cotton and polyester blends from each other. This is done in a closed loop, without any loss of quality, and on a large scale. It uses heat, water, and chemicals that are less than 5% biodegradable to recycle a lot of clothes. The recycling process and models as well as the increasing number of collected apparel indicate the impact of how H&M is moving forward to sustainability and CE model-based business.

Business model like Sakupe significantly affects the environment. The business model follows a closed-loop supply chain system (Muthu, 2014b). As textile material has a tremendous effect on the environment from Sakupe's business model it has been seen that a digital technological-based system helps their whole operation. Using a textile in a repetitive process helps to determine the life cycle of that textile (Choudhury, 2014b). From the life cycle assessment, the carbon footprint can be determined for the textile. Database which is generated by RFID helps them to determine all the factors and helps to make the assessments.

Sakupe collaborated with OpenCO2net Oy to find out the life cycle of the carbon footprint of workwear (OpenCO2net, 2022). OpenCO2net helped Sakupe find the sources of emissions, choose the right emission factors (Zille & Raoux, 2021), and figure out the carbon footprint of the workwear's care, transportation, and removal according to ISO 14067 (Muthu, 2016). The greenhouse gas emissions were estimated based on data from Sakupe from the year 2021 for one load of laundry. The estimate took into account the whole process of taking care of textiles, including the chemicals used and the amount of water used. For transportation, a sensitivity study was done to compare the effect on emissions of sending workwear to two different customers in different places. The high quality of the garment and Sakupe's textile care practices both have an impact on the product's carbon footprint over its lifetime. As the product lasts longer, emissions from use go up, but emissions from production go down as a percentage of total emissions. Since the product lasts longer in the cycle, there is less need to use resources to make new clothes.

The carbon footprint is an important part of environmental impact assessments because it gives a full picture of how human actions affect the world as a whole. It shows how much energy is used, gives information about the effects of climate change, and sets a standard for sustainability. The lifecycle view shows emissions throughout the whole process, which helps people make decisions and plan for the future. The carbon footprint helps people make better decisions and adopt more sustainable practices by measuring pollution and showing how it affects the world as a whole.

On the other hand, a company like Spinnova is focusing on the raw material and how it can be made more sustainably so that the textiles that use that raw material are taken into account as sustainable textiles. The fiber they are using also demands significantly less water and other resources. On top of that, it is 100% zero waste/ side streams. The company has also dedicated itself to using only sustainable (FSC-certified) raw materials (Lehtonen et al., 2021b). From the case studies it came to know that the technology they are using right now is fully mechanical. The production process just started recently. As their wood pulp which

is considered as raw material, those are coming from outside of the EU they need a proper digital solution for the supply chain that can calculate traceability, emission, and other parameters that can be sustainable and circular. This demand was highlighted during the interview process with the personnel from the company.

As Spinnova is still investigating to use of other materials as raw materials they are arranging pilot programs for that. The garments that will made from Spinnova can be fully repaired via their technology. The main purpose for that is their fiber stays in circulation and does not end up in nature and water. Below TABLE 1 shows the waste generation and TABLE 2 shows the recovery, and disposal of Spinnova in the year 2021.

TABLE 2. Waste generation in 2021(Spinnova, 2022)

Waste Composition	**Tonnes**
Energy waste	1,51
Mixed waste	1,29
Compost	0,7
Cardboard	0,54
Paper	0,58
Recyclable plastic	0,09
Hazardous waste	0,25
Other	0,04
Total	5

TABLE 3. Waste Recovery, and disposal in 2021(Spinnova, 2022)

		Recovery Method		Disposal Method		
		Recycling	Other recovery method	Incineration (with energy recovery)	To Landfills	Other Disposal method
Diverted from disposal (tonnes)	2,56	2,54 100% non-hazardous waste	0,02 100% hazardous waste			
Directed to disposal (tonnes)	2,44			2,12 100% non-hazardous	0,1 100% non-hazardous	0,22 100% hazardous

As Spinnova is working with a collaboration of so many textile manufacturer brands, measurement of the circularity of the material is important in this kind of collaboration. From raw material to the end product calculation of waste composition which is shown in the above tables are really important factors. As the company stated its recent commercial production recently those things are still under development and finding a proper digital solution will be a milestone for the company to develop the circular economy more precisely.

Textile sorting organizations like TEXAID took textile recycling and reuse to another level. The case study has shown how the TEXAID sorting process is working on various operations like collection, sorting, and recycling. According to the sustainability report of 2021 (TEXAID, 2021) TEXAID is always improving its ways of working based on economic, social, and environmental factors. But if it wants to reach its goal of a closed textile loop, players must also work together. Circularity in the textile industry depends on companies like TEXAID. This is because textiles can only be reused efficiently and resources saved if they are collected, sorted, and prepared for use again in an efficient and high-quality way. On the other hand, the market needs to make it easier for people to buy used clothes and make recycled fibers more popular. Also, the below TABLE 3 shows how TEXAID plays a role in the EU textile strategies.

TABLE 4. Role of TEXAID in EU textile strategies (TEXAID, 2021)

EU TEXTILES STRATEGY	THE ROLE OF TEXAID
Circular rather than throw-away cloths have become the norm, with sufficient capacities for recycling and minimal incineration and landfilling	Sorting and preperation of textiles for high value recycling and for extending their life cycle through Re-use
Set design requirements for textiles to make them last longer, easier to repair and recycle,as well as requirements on minimum recycled content	Consulting services for product designers on the use of materials to encourage the durability and recycling capability of textiles.
Introduce clearer information and a Digital product Pasport	Use and develeopment of technologies for being able to identify garments with Digital Product Passports and use the information stored in the passports for the efficient sorting and recycling

From the above case study, it has been found that every year, more linens are thrown away, and this trend is expected to keep going. Even though some can still be used, a lot of textiles that have already been used are sent to recycling instead. To build the infrastructure needed to recycle these textiles properly, there need to know what materials they are made of. The current method for sorting textiles, which relies heavily on human input, can't give accurate information because clothing labels are often wrong or missing, which makes it hard to achieve true circularity. Labels and tags are often missing or, if they are still there, can't be read or have wrong information on them (Fashion for good, 2021). This makes it hard to sort items for recycling.

Considering this manual process TEXAID unveils innovation collaboration with Avery Dennison (2023). This collaboration aims to look into how technology can make it possible to track clothes as they are sorted and recycled. Digital identifiers that can be watched through Avery Dennison's atma.io connected product cloud platform and contain important information about the fibers will help TEXAID sort clothing into the right streams for reselling or recycling. Also, TEXAID wants to improve its textile sorting process by testing digital identification technologies. If this works, garments could be instantly sent to the right resale or recycling

streams. The lack of data in sorting used clothes will be fixed by unique digital identities.

4 DISCUSSION AND RESULTS

4.1 Digital Solutions for Apparel (RFID, IoT, AI, etc.)

Based on the case studies and data covered in the last chapter, it has been found that the apparel industry is going through a major change, which is being driven by the use of digital solutions like RFID, AI, and IoT. These technologies are proving to be crucial to the industry's efforts to deal with environmental issues, the loss of resources, and the need to move toward a circular economy. RFID technology is changing the way inventory management has been done in the past, as Zara has shown. Also, it lets you keep track of each thing in real-time, which helps you see your inventory better and get the most out of it. RFID helps Zara cut down on overstocking and stockouts. This makes it easier to predict demand, which is a key part of CE.

Companies like H&M can set and reach environmental goals, like using only recycled materials, with the help of AI-driven data analytics. AI can be used to analyze data and make predictions, which makes it easier for recycling systems to work (Yuan et al., 2022). Also, machine learning algorithms help find things that can be recycled and match them with the right way to recycle them (Dhulekar et al., 2018). In Sakupe's case, RFID and Internet of Things (IoT) devices and sensors are very important for keeping track of textiles over their entire lifetime. Closed-loop supply lines made possible by the Internet of Things (IoT) and RFID also help with sustainable textile management and circularity. On the other hand, AI and IoT are used in Spinnova to track and improve the mechanical process of turning cellulose fibers into other materials. AI-driven data analysis and IoT tracking also make it possible to find and make materials sustainably (Petrillo et al., 2022). Digital solutions like RFID and digital markers make sorting more efficient and accurate in TEXAID. IoT devices can then give real-time information about the materials and quality of textiles, making it easier to recycle them. In the above results, it was seen that digital solutions like RFID, AI, and IoT are changing the apparel industry by improving inventory management, making sustainable practices better, allowing closed-loop supply chains, and making sorting and recycling better. Using these technologies, businesses can reach their goals for the circular

economy, reduce waste, have less of an effect on the environment, and make more sustainable choices throughout the lifecycle of a product.

4.2 Role of Digital Tools in Supply Chain Accountability

Accountability in the supply line has become very important these days. Companies are using digital tools more and more to make their supply lines more open, easy to track, and environmentally friendly (Calvão & Archer, 2021). RFID technology gives Zara real-time visibility into how goods move through the supply chain. It also makes accurate tracking and tracing possible, which makes it easier to figure out where a product came from. On the other hand, companies like H&M can keep track of their recycling and green efforts with the help of data-driven insights. In Sakupe, IoT devices and sensors help watch textiles in real-time, making sure they meet care and quality standards. AI and IoT technologies are used to track and improve how Spinnova finds and makes renewable materials. Also, AI-driven data analysis makes sure that raw materials are sourced in a way that is sustainable and fair. Digital identifiers, such as RFID and digital labels, make it easier to sort and recycle textiles at TEXAID. IoT sensors provide information about the composition and quality of textiles, which makes sure that materials are sorted properly. In the cases above, digital tools help make the supply chain more accountable by making it easier to see, track, watch, and make sure everyone is following the rules. By using digital solutions like RFID, AI, and IoT, organizations can make sure that their supply chains meet ethical, environmental, and quality standards, which eventually increases transparency and accountability (Shrivastav & Bag, 2023).

4.3 Digital Product Passport (DPP)

The Digital Product Passport (DPP) is a new idea that could change how we connect with products, especially in the textile business, where it could have a big impact (Adisorn et al., 2021). At its core, the DPP is a digital dossier that has all the important information about an object over its entire lifecycle. The main goal of the DPP is to give customers more knowledge, make recycling and reusing more efficient, and cut waste in the manufacturing sector as a whole (Jensen

et al., 2023). Integration of cutting-edge digital solutions like blockchain technology and IoT devices is key to making the DPP work (Circularise, 2023) (Sigma Technologies, 2023) Together, these technologies make it possible to keep track of things from the time they are made until they are thrown away.

CIRPASS, which is funded by the European Commission as part of the Digital Europe program and is a group effort to get ready for the gradual piloting and rollout of a Digital Product Passport based on standards, has set five goals for DPP (CIRPASS, 2023).

1) Making business more sustainable.
2) Using circular value retention and extraction to extend the life of products, make the best use of them, and give economic actors new business possibilities.
3) Giving people information so they can make choices that are good for the environment.
4) Helping the move toward a circular economy by making better use of materials and energy.
5) Making sure people follow the rules by helping the officials keep an eye on them.

The DPP is a very important part of CE, especially in the textile industry (Niinimäki et al., 2023). It makes sure that important information, like what materials were used to make the product, how it was made, and how it could be recycled, is easy to find and understand. This makes it easier for people to trust companies, and manufacturers can use the DPP's useful knowledge to make their products better. Also, recyclers stand to gain a lot from this technology because it gives them access to a lot of data that helps them improve their operations and make recycling and reusing things easy. For customers, the perks are just as important. By looking at a product's DPP, both the manufacturer and the buyer can make better decisions about what to buy and how to do it in an environmentally friendly way. Overall, the Digital Product Passport could be the start of a big change toward circular and environmentally friendly product life management. This would be a step toward a more sustainable and responsible future.

4.4 Assessing Environmental and Social Effects

By looking at the above case studies and statistics, we can also measure some of the environmental and social effects. Better inventory management at Zara means that less material is used and that less carbon is released during production and shipping. RFID technology makes inventory management more efficient by cutting down on overstocking and stockouts. It also helps cut down on resource waste and overproduction. IoT helps Sakupe by keeping track of usage and care. IoT devices also help lower the amount of water and energy used in textile care, which is good for the environment (Alves et al., 2021). Also, the mechanical method that Spinnova uses to make cotton reduces the amount of water used by more than 99% compared to traditional cotton production. This is also good for the environment. Recycling programs like H&M cut down on textile trash and the damage to the environment that comes with putting things in landfills. Digital technologies also make sorting more accurate, making sure that more materials are recycled and reused in the right way.

People can also measure some of the social benefits from the above case studies. RFID technology helps store workers at Zara do their jobs better and faster. It also makes their jobs easier by cutting down on time-consuming manual inventory checks. Also, real-time inventory data makes sure that customers can get the goods they want quickly, which makes customers happier. Sakupe has high quality and safety standards, and it takes care of its patients' happiness and health. Spinnova's AI-driven production of sustainable textiles is in line with customer demands for products that are good for the environment. This meets societal expectations. It helps create jobs and spurs innovation in green technology, which is good for local businesses. Through their programs and projects, organizations like H&M and TEXAID bring attention to textile waste problems and encourage recycling and proper disposal. Digital technologies like RFID, IoT, and AI are used in the clothing business to make customers happier and meet the growing demand for eco-friendly and socially responsible fashion practices

4.5 Risks and challenges in privacy, security, and ethical concerns

The use of digital technology in business has a lot of benefits, but it also comes with some risks and difficulties. RFID, IoT, and AI may pose some risks and problems in the above businesses and how they work. In terms of privacy and security, using RFID technology means keeping track of each piece of clothing. Even though this is mostly for managing goods, there may be privacy concerns if this data is mishandled or used wrong (Kamal, 2021). Also, RFID tags and data may be easy to hack or get into without permission. To stop data breaches, it's important to make sure RFID technologies are secure. IoT devices gather information about how textiles are used and how to take care of them. There could be problems with privacy if this information is not kept safe or if it is used without permission (Vojković et al., 2020). IoT gadgets in clothing may be able to collect private information. There could be data leaks or cyberattacks if these gadgets are not properly protected.

Spinnova's efforts to make textiles in a way that is good for the environment are admirable, but there may be ethical issues about where they get their wood pulp or agricultural waste (Nagendran, 2011). It is very important to make sure that sourcing methods are sustainable and fair. Also, there were worries about how clear its supply chain was and whether or not it used eco-friendly methods. It is important to make sure that the sourcing and production method is open and accountable. To deal with these kinds of risks and problems, need to be proactive and put data privacy, security measures, and ethical sourcing and production methods at the top of your list. To build trust with customers and stakeholders, businesses need to have data security policies, keep their digital systems safe, and keep things open. Also, letting customers know about these practices can help ease their worries and encourage the clothing industry to use digital technology responsibly and ethically.

4.6 Findings and Contributions

In this thesis, a wide-ranging study of how digital solutions affect the Circular Economy of the apparel business has led to several important findings and contributions. First of all, the merging of technologies like RFID, AI, and IoT is causing

a big change in the clothing industry. These digital solutions are tackling important problems like preserving the environment, making the best use of resources, and moving toward a circular economy. RFID has changed the way inventory is managed, as shown by Zara's success in cutting down on overstocking and stockouts. AI has helped companies like H&M set and reach environmental goals by recycling and using data analytics. At Sakupe, IoT and RFID play important roles in making sure that textiles are managed sustainably and that supply lines are circular. Spinnova uses AI and IoT to track and improve the way that renewable materials are made mechanically. TEXAID also uses digital solutions that make sorting textiles faster and more accurate. In short, these technologies are changing the way the clothing industry works by making inventory management, sustainability practices, supply chain transparency, and recycling more efficient. This helps businesses meet their circular economy goals and make more environmentally friendly decisions throughout the lifecycle of a product.

Secondly, this thesis shows how important digital tools are for making the supply system more accountable. Companies are increasingly using digital solutions like RFID more and more to get real-time insight into their supply chains and ensure that products can be accurately tracked and traced. H&M uses data-driven insights to track and improve their efforts to be more sustainable, while Sakupe uses IoT devices and sensors to control and track the quality of textiles in real-time. Spinnova uses AI and IoT technologies to improve the production of green materials. Also, their operation needs to control by a closed loop supply chain system. RFID might be a good solution for operating a closed loop supply chain. and TEXAID are trying to use digital identifiers to sort and recycle textiles more efficiently. These digital tools make supply lines more open and accountable, making sure that ethical, environmental, and quality standards are met. Collaboration with Avery Dennison will open a path to test the RFID system in the sorting process. TEXAID is piloting a digital solution which is scheduled for the beginning of 2024.

Thirdly, the study shows how the Digital Product Passport has become a big deal in the EU. This is a revolutionary idea with a lot of potential, especially in the apparel business. The DPP, which is a digital dossier with detailed information about a product's entire lifecycle, promises to give customers more information,

make recycling and reusing easier, and cut down on manufacturing waste. The DPP is using cutting-edge technologies like blockchain and IoT, wants to make businesses more sustainable, extend the lifecycles of products, help people make decisions that are good for the environment, and promote circular economic practices.

Lastly, the thesis focuses on figuring out how the use of digital technologies in the apparel business will affect the environment and society. Better inventory management at Zara cuts down on material use and carbon emissions, while Internet of Things (IoT) technologies in Sakupe cut down on the amount of water and energy needed to care for textiles. The efficient way Spinnova makes clothes saves water. Trash programs like the one H&M has helped cut down on textile waste, and digital tools make it easier to sort trash in Texas (Lohmar, 2023). Also, these technologies make workers more productive, customers happier, and societal standards higher in terms of product durability and care for the environment.

But it's important to be aware of the risks and problems that come with using digital technology, such as privacy, security, and social issues. RFID and the Internet of Things (IoT) raise privacy concerns, and data security is the most important thing to do to stop unauthorized access or data leaks. Ethics also come into play, especially when deciding where to get supplies. To deal with these problems and build trust among partners, it's important to be open and use ethical production methods. Overall, this thesis gives useful information about how digital solutions are scaling the CE in apparel industries, from making clothes more sustainable to making the supply chain more accountable.

5 CONCLUSION AND FUTURE DIRECTION

Based on what was found in this thesis, there are big measurements for the clothing business in CE and sustainability. When digital technologies like RFID, AI, and IoT were added to the apparel industry, a new era of change began. The above discussion shows EU is always fascinated by reducing waste and environmental problems such as climate change & material shortage. These technologies have become important tools for tackling important environmental problems, saving resources, and making the change to a circular economy in the whole world as well as in EU apparel industries. Companies are now emphases to set and reach environmental goals with the help of digital technology, such as using recycled materials. Machine learning algorithms help recycling methods work even better. Overall, in businesses that use digital technologies like RFID, AI, and IoT are better able to follow the principles of the circular economy, reduce their effect on the environment, and make choices that are good for the environment throughout the lifecycles of their products. Integrating digital solutions makes the supply chain more open and accountable, bringing activities in line with standards for ethics, environment, and quality. This greater accountability leads to more specific and makes it easier to stick to sustainability goals.

Also, the introduction of the Digital Product Passport (DPP) in the EU will have a big impact on the future of the clothing business. The DPP, a digital tool or database that covers an object's entire lifecycle, will give customers access to important information, make recycling and reusing easier, and cut down on waste from manufacturing. The success of the DPP depends on how well it uses cutting-edge technologies like blockchain and IoT devices. Initiatives like CIRPASS, which are funded by the European Commission, aim to reach some goals through the DPP, such as sustainability, circular value retention, educated consumer choices, resource optimization, and regulatory compliance. The DPP makes sure that important product information is easy to find, especially in the textile industry. This lets consumers make choices that are both smart and good for the environment. Also, the use of digital technologies in the clothing business has real benefits for the environment and society. Better inventory management cuts down on the number of materials used and the amount of carbon emission during production and shipping. It also cuts down on resource waste and overproduction.

The study results and ideas for the future open up a lot of new ways to look into and learn more about the growth of digital solutions in the apparel industry for CE and sustainability. In the future, researchers could look more closely at how digital technologies like RFID, AI, and IoT affect different parts of the supply chain, such as how they affect resource efficiency, waste reduction, and the environment. Exploring how these technologies can be scaled up and adapted to different parts of the clothing industry, from fast fashion to sustainable fashion brands, would give us useful information about how they can be used in a wider variety of situations. Also, the Digital Product Passport (DPP), which is a project that is still going on, will make it easier to do more study in many ways. The DPP could be used to see how it affects buying choices and actions that are good for the environment. Standardized protocols could be made, and consumer views and adoption rates could be studied. Also, how the textile sorting industry can develop & make their sorting process accurate with digital tools like RFID. More studies could also look at how the rules and policies for using digital tools and managing data in the textile and fashion industries are changing and what that means for policy. In the end, these chances to do more study will help us learn more about how digital solutions can change things and help promote sustainable practices in the apparel business and beyond.

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