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Sustainability, the Circular Economy and Digitalisation in the German Textile and Clothing Industry

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Abstract: The textile and clothing (T&C) industry is not usually viewed as an exemplar of sustainable development and the circular economy (CE), as the industry has hitherto developed its products in a linear fashion, with relatively little recycling of the finished goods. This article examines the industry's approach to the core sustainability concept and the CE in particular through a review of the available academic literature, evidence from corporate sustainability reports and websites, and feedback from an online survey of industry professionals. More specifically, the article investigates how German T&C companies are addressing sustainability in their corporate strategies and what activities relating to the CE are being pursued in the industry. The role of digital technologies in the transition to sustainability and the CE in the German T&C industry is also explored. The study finds that whilst sustainability is now firmly embedded at the strategic level in the vast majority of the companies studied, attitudes towards the CE are mixed. The use of digital technologies in support of sustainability objectives is also limited at present, but the need to meet compliance requirements and new customer perceptions of sustainability will speed the transition to CE activities, which will be facilitated by the greater exploitation of these technologies. An operational framework for initiating such a transition is developed, and action lists in the key areas of change organization, products, and processes are presented. These may be used as a guideline for practitioners, and the findings also make a small contribution to the scarcity of literature in this field of research.

Keywords: textile industry; clothing industry; sustainable development; circular economy; CE; digital technology; digitalisation; corporate social responsibility; CSR; operational framework

Citation: Wiegand, T.; Wynn, M. Sustainability, the Circular Economy and Digitalisation in the German Textile and Clothing Industry. *Sustainability* **2023**, *15*, 9111. https://doi.org/10.3390/su15119111

Received: 30 April 2023
Revised: 29 May 2023
Accepted: 2 June 2023
Published: 5 June 2023

1. Introduction

The global textile and clothing (T&C) industry is the fourth largest consumer of primary raw materials and water after the food, housing, and transport industries, and the fifth largest producer of greenhouse gas emissions [1]. Less than 1% of all textiles worldwide are recycled into new textiles, and it is thus appropriate that the industry has a pivotal role in the European Commission's Action Plan for the Circular Economy. The Action Plan aims to change the way products are designed, produced, and consumed by focusing on several key sectors such as textiles for the promotion of the circular economy (CE), which has been defined by the European Union [2] as an "economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (p. 2). According to some authors, this contrasts with the traditional linear economy, whose activity leads to the pollution and depletion of natural resources. Alonso-Muñoz et al. [3], for example, concluded that "the circular economy represents a further step forward in the field of sustainability by breaking with the linear production model, with substantial modifications in both operations and relationships" (p. 2).

A number of factors have contributed to the growing focus on the importance of adopting CE practices and business models; the continuing depletion of scarce natural

resources, the unpredictable events associated with climate change, and the increasing introduction of national and international legislation designed to reduce environmental problems are all important drivers of the CE. Indeed, the Action Plan referred to above is one of the key building blocks of the European Green Deal, i.e., the new European agenda for sustainable growth, and as part of this, the EU intends to rely on "innovative models based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by digital technologies, such as the internet of things, big data, blockchain and artificial intelligence" [4] (p. 2). The strategies and measures of the Action Plan will challenge the European T&C industry, which is dominated by small and medium-sized enterprises (SMEs), to adapt processes and products to support a transition to a CE [5].

The overall aim of this article is thus to examine how the industry views sustainability and the measures it is taking to move towards the CE. The links between the CE and the transition to a sustainable future are complex, with several sources suggesting that digital technologies may play a key role in this transition [6,7]. The World Economic Forum [8] (para. 1) claimed "we must accelerate the transformation to a circular economy in order to meet global climate goals by 2050" and that "this can only be achieved through focused and responsible digitalization", while Kottmeyer [9] (p. 17) argued that "digital technologies have the potential to close the realisation gap between theory and practice of the circular economy concept". Ranta et al. [10] (para. 1) point out the limitations of the relevant research to date, claiming it mainly concerns "conceptual and review studies" and that there remains "a lack of understanding of how digital technologies enable individual firms in real-life settings to improve their resource flows and value creation and capture, and thereby enable business model innovation to emerge".

This article has six main sections. Following this introduction, the relevant literature is reviewed, a top line conceptual framework is set out, and three research questions are posed. The research methodology is then discussed. This is followed by the main research results and a discussion of the key emergent themes, in which a simple framework and an illustrative action list for initiating a transition to the CE for SMEs in the T&C industry is presented. The concluding section provides a research summary and offers some thoughts on possible areas for future research in this field.

2. Literature Review

2.1. The European Textile and Clothing Industry

The demand for textiles has grown exponentially over the last few decades, which has led to a globally interconnected and complex T&C industry, in which the EU has taken a central role as an importer and end-user [11]. Rising demand and international competition have accelerated the pace of new fashion collections, and value chains have become more efficient by using low-tech systems and low-cost materials and by outsourcing production processes to low-wage countries. This has made textile products increasingly affordable, further fuelling demand. However, this has only exacerbated the industry's negative impact on the environment. Koszewska [12] (p. 338) notes, for example, that "the direct or indirect sources of most of the ecological concerns that beset the T&C industry are related to surging consumption and fast fashion that comes with it" and lists four main areas of environmental concern: energy consumption (the production of man-made fibres, yarn manufacturing, finishing processes, and the washing and drying of clothes in the use phase); water and chemical consumption (fibre growth, wet pre-treatment, dyeing, and finishing and laundry); solid waste production (mainly the disposal of products at their end-of-life stages and textile/clothing manufacturing); and direct CO_2 emissions (transportation within globally dispersed supply chains).

While value creation within the EU is mainly concentrated in product development, marketing, and supply chain management [13,14], globally interconnected production processes have wider implications for both humans and the environment, including the intensive use of land and water, greenhouse gas emissions, and air, soil, and water pollu-

tion [13]. This has made the T&C industry a key focus of the EU's new Industrial Strategy for Europe and the European Circular Economy Action Plan [4,15].

In its "Strategy for Sustainable and Circular Textiles" [15], launched in March 2022, the European Commission set ambitious targets for the T&C industry. For example, by 2030, all textile products on the European market must be durable and recyclable, consist largely of recycled fibres, and be manufactured in compliance with environmentally and socially sustainable conditions. In addition, the European textile sector should remain economically competitive, resilient, and innovative, while assuming responsibility for its products along the entire value chain, which also includes the use and disposal of these products. Within the textile sector, the fashion industry represents the largest sub-sector, as it is one of the most globalised linear value chains [16]. The EU strategy for sustainable and circular textiles has set out a range of measures for transforming the existing linear model into a circular one. These measures include mandatory eco-design requirements, preventing the destruction of unsold or returned textiles, tackling microplastic pollution, extended producer responsibility for the reuse and recycling of textile waste, and a digital product passport, which is intended to make product and production information transparent. European norms and standards are being developed to contribute to the implementation of the SDGs and the legal requirements of the Green Deal. In particular, the legal requirements for the textile industry to create a digital product passport are being defined in ongoing standardization processes [17].

It is evident that such a transformation requires a fundamental cultural and structural reorientation of the entire linear value chain from product development to manufacturing, use, and disposal through the development of new business models and the use of innovative technologies, involving all relevant internal and external stakeholder groups [18–23]. This will inevitably be a complex process and one that is interweaved with other corporate strategic objectives. The challenge for the industry, which contains many SMEs, is to transition to sustainable and circular business practices whilst remaining profitable in an increasingly competitive sector.

2.2. Sustainability and the Circular Economy

The most widely used definition of "sustainability" is development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" [24] (p. 16), where such development is in harmony with the natural environment. In recent years, the concept has also been steadily gaining importance in the corporate context [25]. Based on the triple bottom line, as put forward by Elkington [26], the view has prevailed that to be fundamentally sustainable in the long term, an organisation must consider all the contexts in which it operates. This includes the three dimensions of sustainability, namely, social, ecological, and economic, which are often also referred to as people, planet, and profit [27]. The economic dimension concerns the efficient use of tangible and intangible resources to ensure the long-term survival and competitiveness of the company and resultant benefits delivery; the ecological dimension focuses on the natural environment and concerns the availability, use, and treatment of natural resources; and the social dimension focuses on human well-being, society, inter-societal relations, and fairness. Sustainability, therefore, is a holistic construct that must be anchored in corporate strategy and a corresponding business model and must be linked to corporate culture, processes, and activities [27–29]. At the same time, sustainability can best be assessed within the value chain in which an organisation operates, thus encompassing the entire supply network and incorporating upstream and downstream supply chain processes [30].

In developing their sustainability strategies and policies, many companies have referred to the United Nations (UN) Sustainable Development Goals (SDGs), which came into effect in January 2016 and have been described by the UN [31] as the "2030 Agenda for Sustainable Development", which is designed to "shift the world on to a sustainable and resilient path" (para. 1). The European Commission [32] argued that "the 2030 Agenda integrates in a balanced manner the three dimensions of sustainable development—economic,

social and environmental" (para. 6), and, in the context of the industrial sector, PriceWaterhouseCoopers [33] commented that with the advent of the SDGs, "sustainability is moving from the corporate side-lines into the mainstream" (p. 6). Recent research [34] found that the three most referenced SDGs in company reports across a range of industry sectors were SDGs 8, 12, and 13 (Table 1). All the SDGs have associated targets, and for every target, there are one or more indicators of which there are 241 in all [35].

Table 1. The Sustainable Development Goals (adapted from [31]).

Number	Sustainable Development Goal
1	End poverty in all its forms everywhere
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Ensure healthy lives and promote well-being for all at all ages
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Achieve gender equality and empower all women and girls
6	Ensure availability and sustainable management of water and sanitation for all
7	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduce inequality within and among countries
11	Make cities and human settlements inclusive, safe, resilient and sustainable
12	Ensure sustainable consumption and production patterns
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Within the wide definition of sustainability, the concept of the CE is increasingly being viewed as a key lever with which to initiate the transition to a more sustainable future. It is of interest and relevance to both academics and practitioners as it offers principles and approaches regarding how companies can implement sustainability [22,36,37]. In its most basic form, "a circular economy can be loosely defined as one which balances economic development with environmental and resource protection" [38] (p. 373), and the Ellen McArthur Foundation [39] suggests that a CE is "restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times" (p. 46). In a similar vein, the CE has been defined by the European Commission [2] as an "economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (p. 2). The CE concept encompasses all stages of a product's life cycle from product design and production through marketing and consumption to waste management, reuse, and recycling. A lasting transition to a CE will require radical changes in product development and manufacturing but also in consumers' buying and consumption practices. The prevention, reuse, and recycling of waste materials means that waste management becomes an opportunity to return as much waste as possible back to productive use.

Consequently, companies need to extend their focus on the use phase and the end-of-life treatment of their products. This requires new and innovative business models, prod-

ucts, and processes that build upon the CE principles often referred to as R-principles [37] (Figure 1) and create sustainable value for a company and all its stakeholders [40]. Geissdoerfer et al. [41,42] refer to business model innovation as a key tool for implementing the CE in organisations.

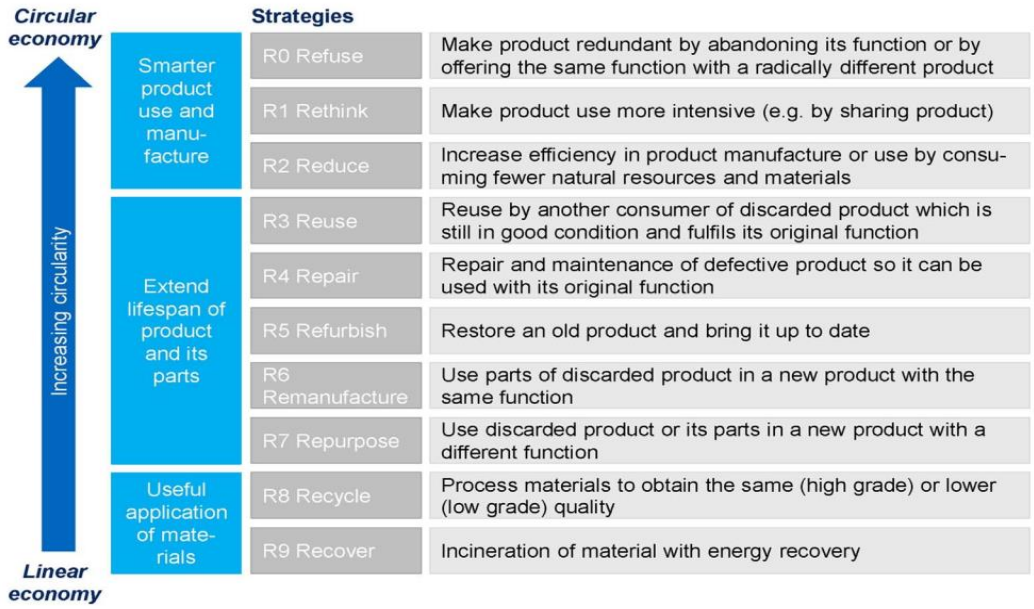

Figure 1. The 9R principles (Source: [37]).

In today's economy, which is characterised by a global division of labour and outsourcing, a sustainable CE can only be implemented through joint, coordinated strategies and practices within supply chain networks [43,44]. As Brown et al. [45] conclude, well-founded partnerships and functioning collaboration are key success factors for circular-oriented innovation. According to Geissdoerfer et al. [41], network infrastructure and the capabilities of the supply chain play a critical role in enabling circular business models, and Montag et al. [46] refer to the holistic integration of circularity into supply chain management as the enabler of circular business models. They present a circular supply chain maturity model, according to which changes are needed at strategic, tactical, and operational levels to move from a linear to a circular supply chain. First, this process requires a paradigm shift within an organisation to ensure that the CE principles are incorporated into the long-term strategy and all the activities necessary to implement it. At the tactical level, the authors focus on the product and its life cycle, arguing that changes are needed at all stages, i.e., from product development to use, disposal, and recycling, to render the linear supply chain more circular. At the process level, the authors refer to the Supply Chain Operations Reference (SCOR) model, which has been adapted for circular supply chains, and illustrate that the majority of the eight SCOR processes need to be completely redesigned with the goal of closing the product and material loops.

It is clear that the first two levels refer to the company and its management. The model suggests that the alignment of an organisation's strategy, business model, and product/service portfolio towards the CE is a prerequisite for implementing CE principles at the operational level. A company's internal strategic and tactical decisions are thus drivers for implementing changes in internal processes and along the supply chain. Therefore, the redesign of supply chain processes is essential for the CE's implementation. As a result, the supply chain is the key to achieving circularity at the corporate level.

In this context, Montag and Pettau [47] provide "a theoretical and conceptual approach for measuring supply chain performance in the circular economy era" (p. 1) based on the SCOR model adapted for circular supply chains (CSC). The authors maintain that the model "provides a comprehensive composition of indicators to holistically measure the supply chain's performance from an economic, environmental, social, and circular

perspective" (p. 1). The framework (Figure 2) not only includes the three traditional dimensions of sustainability economic, environmental, and social – but also the new circular perspective of performance, "thus reconciling the goals of sustainability and circularity" (p. 2). Their research also distinguished between the environmental and circular perspectives, which may have conflicting goals. "While the CE aims for keeping products, components and materials in circulation for as long as possible and with highest value as possible through strategies such as reuse and recycling, environmental sustainability's goal is to reduce the harm on the earth's ecosystem by reducing waste and other negative outputs, such as CO_2 emissions" (p. 5). Based on adapted SCOR processes for circularity, the framework "provides a horizontally integrated composition of performance measures to comprehensively assess the CSC's performance from an economic, environmental, social and circular perspective", thereby "enabling a clarification for the complex relationship between circularity and sustainability" (p. 9).

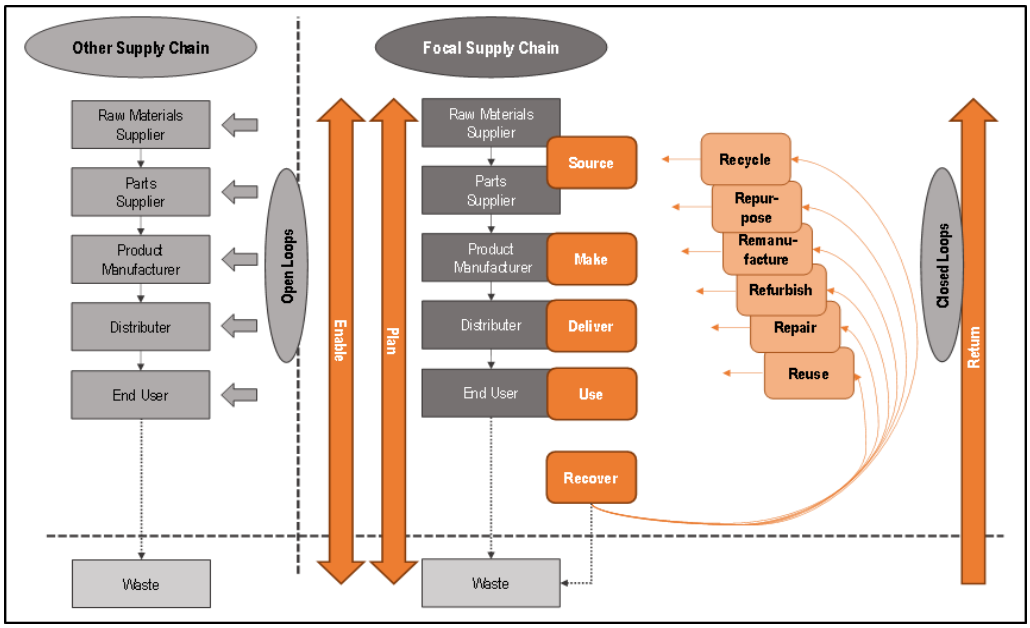

Figure 2. A circular supply chain framework (Source: [46]).

The implementation of the CE in the T&C industry requires a multidimensional approach encompassing various strategies and measures [48,49], and the recent literature discusses a number of concepts, principles, and models of relevance to this study. One of the key approaches for a holistic implementation is to adopt CE principles from the outset, particularly during product design. This may involve measures such as the use of mono-materials, recycled and recyclable materials, designing for disassembly, facilitating ease of repair, optimising material utilisation, and enhancing durability [48,50]. The degree of change may be such that the company transitions to a new business model. Abbate et al. [51], for example, identified both individual and collaborative Product/Service-System (PSS) models, involving leasing or renting (rather than selling) within the Italian apparel industry. As regards the production processes, particular emphasis is placed on approaches aiming to reduce material consumption and minimise the generation of harmful by-products and waste, including wastewater and emissions, and promote employees well-being [51]. Other case studies conducted in Italy have shown that intensive and long-term supplier relationships as well as the vertical integration and digitalisation of production processes are success factors for supply chain orchestration in terms of a circular supply chain [52]. Furthermore, the creation and optimisation of reverse logistics processes are essential prerequisites for maintaining products and materials in the supply chain loop, encompassing measures such as expanding collection and sorting facilities [48],

developing and improving textile-to-textile recycling technologies [53], and investing in the enlightenment and education of individuals, industry stakeholders, and governments [54].

2.3. Digital Technologies and the Circular Economy

In recent years, digital technology and CE concepts have attracted growing interest in both the business and academic communities, and a number of recent papers provide different perspectives on the relationship between the two concepts. Many of the early models and frameworks of digitalisation focused on the emergence of the technologies and their impacts on processes and organisational structures, possibly resulting in new business models [55]. More recently, Lang [56] identified sustainability as a driver of digital transformation, and product transformation as one of four key pillars, illustrating the relationships between sustainability, the CE, and digitalisation.

Digital technologies can be defined as electronic tools, automated systems, and technological devices that allow very large quantities of data to be processed, transmitted, and stored [7]. Two acronyms are often used as generic terms to encapsulate these technologies: SMAC (Social Media, Mobile, Analytics/Big Data, and Cloud) and BRAID (Blockchain, Robotics, Artificial Intelligence/Knowledge Work Automation, the Internet of Things, and Digital Fabrication). Some authors specify that some of these technologies are of particular significance with respect to promoting and supporting the CE. Frost & Sullivan [57], for example, highlight the significance of IoT devices, robotics, and mobile applications, which act in combination with analytical tools and optimisation software. Reuter [58] argued that the IoT can help promote the CE in the metallurgy industry by providing dynamic feedback control loops, whilst Salminen et al. [59] maintain that the IoT enables the improved management and analysis of data coming from various sources "to enhance services provision and the co-evolution of the circular economy" (p. 21). In a similar vein, Bressanelli et al. [60] explored how the IoT, big data, and analytics can support a transition to a CE. They identified eight specific functionalities that were seen to be important in the transition process: improving product design, attracting target customers, monitoring and tracking product activity, providing technical support, providing preventive and predictive maintenance, optimising product usage, upgrading the product, and enhancing renovation and end-of-life activities. Owen-Jackson [61] observed that "Internet-connected sensors can track the location, condition, and availability of assets in a supply chain. Direct exchange of information via secure, decentralised channels like blockchain can keep these communications secure. Together, these innovations can optimise resources, extend lifecycles, and help regenerate natural resources" (para. 10). He also pointed out that digital technology "helps support dematerialization by reducing our reliance on physical resources e.g., retailers selling e-books directly to consumers or digital video and audio being delivered online rather than through physical media" (para 14).

For manufacturing companies, this requires changes in their business models towards a PSS model, as noted by Pagoropoulos et al. [62]. It entails a "shift from selling just products to selling the utility, through a mix of products and services while fulfilling the same client demands with less environmental impact" (p. 19). The authors found that digital technologies have often underpinned the move to a PSS business model with considerable economic, environmental, and societal benefits. Ranta et al. [10] conducted a multiple case study of CE business models enabled by digital technologies using interviews and document data from four innovative Northern-Europe-based companies. The authors identified "four key types of business model innovation for CE that is catalysed by digital technologies and vary in incremental and radical improvement to the resource flows, value creation, and capture" (p. 2). Antikainen et al. [63] also suggest that digitalisation can been seen as one of the enablers of the CE through the incorporation of visibility and intelligence into products, thus indicating the location, condition, and availability of assets.

Some researchers have looked beyond individual company environments to consider these concepts across supply chains. Del Giudice et al. [64], for example, analysed the effect of CE practices on firms' performance for a circular supply chain. Using data collected

through an online survey distributed to managers of 378 Italian companies that had adopted CE principles, the authors found that in designing and promoting CE initiatives, companies must build value-added relationships by exploiting big data, which will stimulate both management and employees to adopt a collaborative approach. Bressanelli et al. [65] take a different approach by proposing a framework (Figure 3) that "shows the linkages between digital technologies, circular strategies and practices, and sustainability performance" (p. 9). The authors conclude that digitalisation "enables a systemic redesign of products, business models, and value chains, impacting all the life-cycle phases of products to reduce material and energy consumption, reuse products, remanufacture components, and recycle materials" and that this promotes "the achievement of enhanced sustainability performance in terms of environmental, economic, and social benefits" (p. 10).

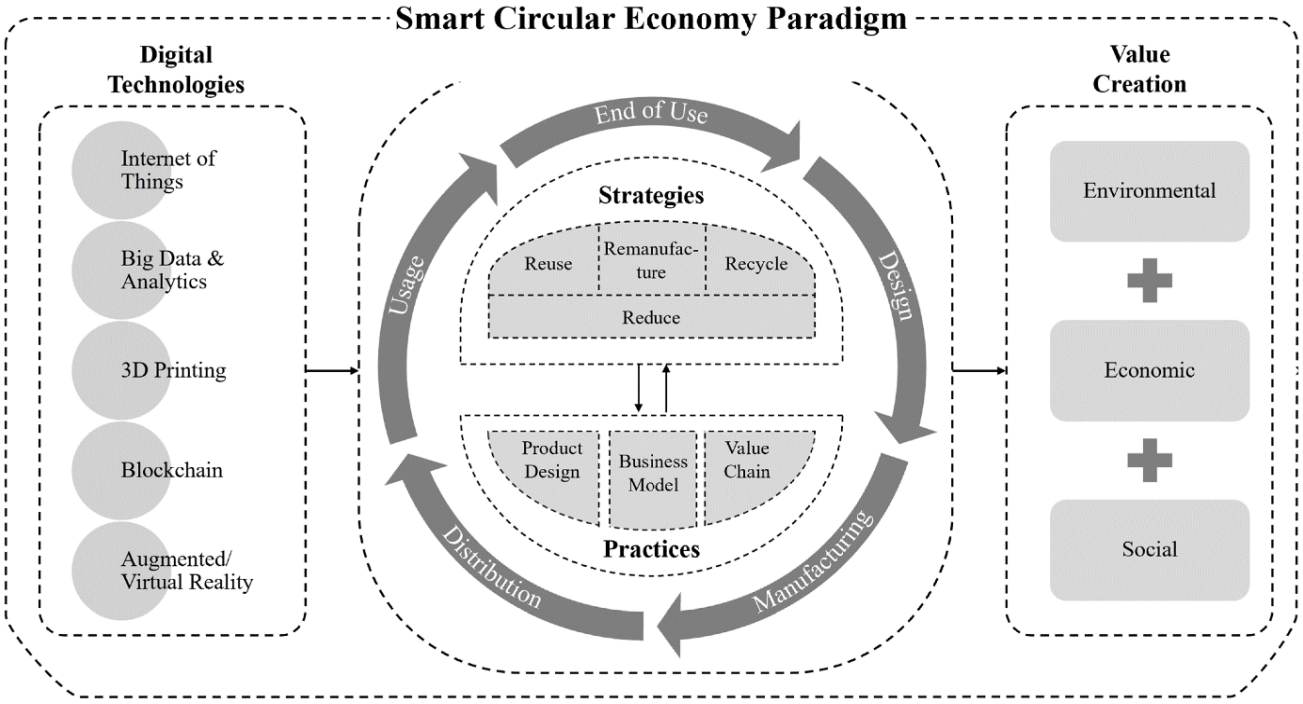

Figure 3. A research framework for the smart circular economy paradigm (Source: [65] (p. 9)).

Other authors have found only a limited degree of exploitation of digital technologies in support of the CE. In exploring digitalisation as an enabler of a sustainable CE in Germany, Neligan [66] analysed data from 600 manufacturing companies and found that traditional efficiency-raising measures that optimise manufacturing processes are still predominant in the manufacturing sector but that "the opportunities offered by digital networking for increasing material efficiency are only used to a limited extent" (p. 106). Wynn and Jones [67] interviewed senior IT executives in eight European organisations and found that although all organisations were pursuing activities to engender the transition to a CE, there was very little direct linkage to digital technology deployment. Nevertheless, digital technologies were used by all these organisations, which saw more general benefits in terms of cost savings and efficiency gains that also supported sustainability objectives but not specifically for this purpose or in support of the CE. Cagno et al. [68] also noted that digitalisation and sustainability have so far been considered separately. They adopted the ReSOLVE framework, developed by McKinsey, to assess the linkage between digital technologies and the CE. They noted the lack of an integrated and holistic analysis of the relationship between the two concepts and highlighted the need to investigate both decision-making processes and specific CE practices from an empirical perspective. Montag and Pettau [47] point out that "future research opportunities lie in the adoption of a digital performance perspective, depicting the impact of digital technology on the CSC performance" (p. 10).

As regards the T&C industry, there are very few studies on the use of digital technologies in the context of the CE. Koszewska [12], in her study of industry examples undertaken to identify and evaluate challenges faced by the industry in adapting to the CE model, concluded that although digitalisation was one of the "new trends (that) are emerging towards the circular economy" (p. 346), "the mainstream recycling technologies and structural solutions that could eliminate barriers to the introduction of a global closed loop in the textiles industry are still few" (p. 344). Centobelli et al. [48] maintain that the digital product passport will significantly contribute to the goals of the EU Strategy for circular textiles. However, this requires transparent traceability throughout the entire chain, from raw materials to recycling, and the sharing of information at every supply chain stage. In a multiple case study, Saccani et al. [52] found that transparency regarding material composition and process traceability is among the key prerequisites for a circular and sustainable textile supply chain. Alves et al. [69] examined various technologies for promoting the CE in the T&C industry and identified the combination of blockchain and Internet of Things (IoT) technologies as ideal for implementing the CE in this sector in order to achieve the necessary transparency along the supply chain. Bürklin and Wynants [70] identified different scenarios for the use of digital technologies in the T&C industry through various case studies, such as intelligent mirrors that help enhance customer satisfaction through improved guidance during the purchasing process or the use of 3D technologies to reduce the number of prototypes (virtual prototyping), improve fit (3D body scanning), or enable demand-driven production (3D printing).

Pal and Jayarathne [71] provide some insights into how different digital technologies can be applied in the T&C industry, including 3D design, artificial intelligence, and Big Data, and the authors discuss "the potential for the adoption of circular economy principles enabled by digitalization, including innovative resale and sharing models" (p. 255). They conclude, however, that there remain "a number of barriers that currently prevent widespread digitalization of the CSCs, which are related to lack of available technology, economic viability, strategic development and digital knowhow" (p. 267). Thus, although there are some recent studies that touch upon digitalisation in the context of the CE, research on how digital technologies support the CE across supply chains, both in the T&C industry and more widely, remains scarce [72].

2.4. Conceptual Framework and Research Questions

A conceptual framework can be seen as a network of interlinked concepts that together represent an overview of the phenomenon being studied [73], which is often in the form of a top-level map of the research area, thus providing the basis for subsequent analysis and model development [74]. Elaboration of the conceptual framework helps researchers focus on the key aspects of the research area in a textual or visual "big picture" [75] (p. 15).

To transition to a sustainable and circular textile industry, the literature suggests there are three main conceptual areas of relevance: first, the adoption of sustainable business strategies through alignment with triple bottom line accounting and the UN SDGs; second, migrating to CE practices via consistently following the R-principles that conserve resources and reduce waste and pollution; and third, the potential of digital technologies to act as a catalyst and driver for transition, which requires a coordinated and integrated approach involving holistic adjustments and changes within an organisation to the business model, products, and internal processes and to cross-company processes along the entire supply chain (Figure 4). This builds upon the maturity model developed by Montag et al. [46], discussed above, which identified the three dimensions of change organisation, product, and process involved in transitioning to a CE.

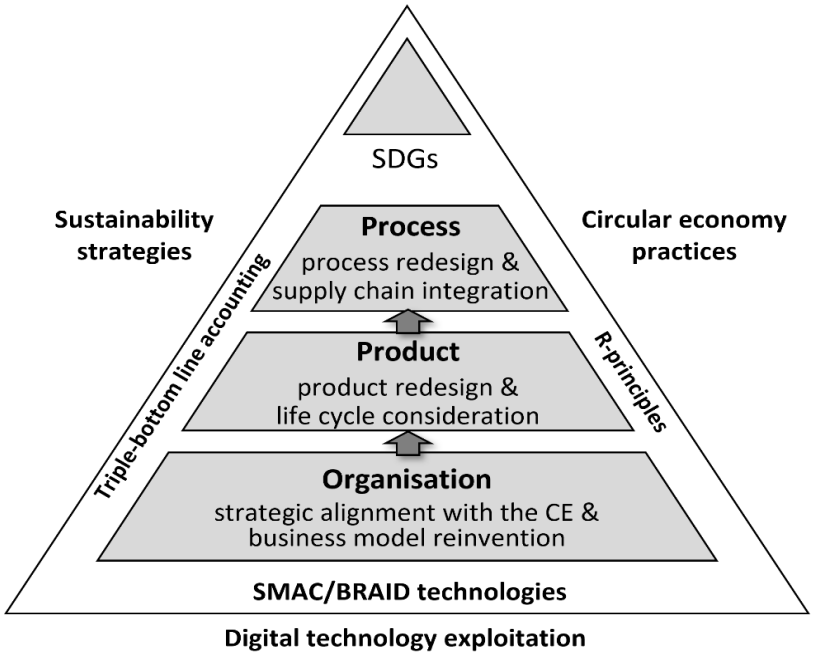

Figure 4. Conceptual framework for the transition to a sustainable and circular T&C industry.

This review of the relevant literature has revealed that the relationship between sustainability, the CE, and digitalisation in the T&C industry is largely unexplored, and to the authors' knowledge, there are currently no holistic models or frameworks for the transition to the CE in the T&C industry. This exploratory paper attempts to address this gap in the literature by building upon the conceptual framework outlined above. The available literature regarding the transformation towards a sustainable and circular T&C industry is very scarce, and guidance for initiating such a transition is more or less non-existent. In this context, this paper examines how SMEs in the T&C industry have approached sustainability and the CE to date and, more specifically, answers the following research questions (RQs):

RQ1. How are German textile and clothing companies addressing sustainability in their corporate strategies and activities?
RQ2. What strategies and activities relating to the CE are being pursued in the German textile and clothing industry?
RQ3. What role are digital technologies playing in the transition to sustainability and the CE in the German textile and clothing industry?

3. Research Method

The research methodology described herein adopts a pragmatic approach, which emphasizes the importance of practical implications and real-world applications and acknowledges the complex nature of the T&C industry. The study aims to generate a comprehensive understanding of the status of the transition towards sustainability and circularity in the T&C industry and the role digital technologies are playing in this transition. The paper draws its empirical material from relevant academic papers and corporate sustainability reports published by German T&C companies. Saidani et al. [76] note that while corporate and industry body reports can be seen to "reflect current industrial reality and needs, and therefore bring meaningful insights", the inclusion of peer-reviewed academic papers "ensures scientific soundness" (p. 2). Literature search and analysis of located reports were carried out iteratively. Following an initial exploratory search, further sources and studies were identified based on the results from industry reports and relevant keywords. Other papers of relevance were identified by searching various academic databases and scholarly sources to ensure a broad and representative coverage of relevant studies.

The decision to rely on publicly accessible corporate sustainability reports for this research was made based on the availability and relevance of the information contained within them. The authors believed that these reports provided valuable insights and data that contribute to addressing the research objectives and answering the research questions. The inclusion of information drawn from publicly available reports does not infringe upon any ethical or legal requirements regarding the use of copyrighted material. The authors ensured proper citation and acknowledgment of the original sources of the reports in accordance with academic conventions and intellectual property regulations.

3.1. Sample Definition

The companies included in this research were systematically selected from the members of the German Partnership for Sustainable Textiles, a multi-stakeholder initiative consisting of companies and associations, non-governmental organisations (NGOs), trade unions, standard organisations, and the German government. This partnership aims to enhance the state of global textile production with respect to processes ranging from raw material extraction to disposal. Of the 75 member companies (as of May 2022), 29 were classified as SMEs as they had fewer than 250 staff and/or a turnover of less than 50 m euros [77] (Table 2). Of these 29 companies, 26 were headquartered in Germany, two were in the Netherlands, and one was in the UK. It is these companies that constitute the basic population for the study. The most recent corporate social responsibility (CSR) reports and sustainability-related information for these companies were then searched for on their websites. CSR reports were available from 18 of these companies; for the remaining 11, some relevant information was found on their corporate websites.

Table 2. Companies featured in the research (basic population).

Company Name	Code	Country	Product Category
ATAIR GmbH	AT	Germany	Clothing production and wholesale
Bierbaum-Proenen GmbH & Co., KG	BI	Germany	Workwear and professional clothing
Blutsgeschwister GmbH	BL	Germany	Fashion brand
Brands Fashion GmbH	BR	Germany	Workwear, sportswear, and other clothes
CHAPS Merchandising GmbH	CH	Germany	Merchandise textiles
DELTEX Handelsgesellschaft GmbH	DE	Germany	Clothing wholesale
Deuter Sport GmbH	DS	Germany	Sports, functional and leisure products
Dibella GmbH	DI	Netherlands	Home, bed and table linen
Elkline GmbH	EL	Germany	Sports, functional and leisure products
Vorfreude GmbH (Brand: Erlich textil)	VO	Germany	Lingerie
ESSENZA HOME GmbH & Co., KG	ES	Netherlands	Home, bed and table linen
GREIFF Mode GmbH & Co., KG	GR	Germany	Workwear and professional clothing
Grenz/gang Organic Fashion	GG	Germany/Italy	Fashion brand
HAKRO GmbH	HA	Germany	Workwear and professional clothing
Hch. Kettelhack GmbH & Co., KG	HK	Germany	Fabric production/processing
IVY & OAK GmbH	IV	Germany	Fashion brand
Jako AG	JA	Germany	Sports, functional and leisure products
Karl Dieckhoff GmbH & Co., KG	KA	Germany	Workwear and professional clothing
Lanius GmbH	LA	Germany	Fashion brand
LODENFREY Menswear GmbH	LO	Germany	Fashion brand
Mantis World Ltd.	MA	UK	Print wear

Table 2. *Cont.*

Company Name	Code	Country	Product Category
ORTOVOX Sportartikel GmbH	OR	Germany	Sports, functional and leisure products
P.A.C. GmbH	PA	Germany	Sports, functional and leisure products
Pervormance international GmbH	PE	Germany	Technical textiles and garments
RETAILPRAXIS GmbH	RE	Germany	Clothing production and wholesale
Schöffel Sportbekleidung GmbH	SC	Germany	Sports, functional and leisure products
Sympatex Technologies GmbH	SY	Germany	Fabric production/processing
Teamdress Stein Deutschland GmbH	TE	Germany	Workwear and professional clothing
Textilhandel-cotton-n-more GmbH	TH	Germany	Workwear and professional clothing

As all the reports identified are in the public domain, the authors adopted the view that they did not need to contact the selected companies or organisations to obtain formal permission prior to conducting their research.

3.2. Analysis Methodology

To answer the RQs noted above in Section 2, the content of the CSR reports and corporate websites was analysed following Mayring's [78] approach for qualitative content analysis by creating themes inductively based on the content. Regarding RQ3, it was observed that the CSR reports and company websites provided limited details about digital technology deployment. Consequently, an online survey consisting of three fundamental questions was circulated to the companies. Respondents were typically CEOs, COOs, sustainability managers, and supply chain managers. The questions concerned the current and future use of digital technologies and their application within the company. This allowed for an assessment of the technologies currently used (or that would be used in the future) and supplemented material available from secondary sources. The online questionnaire responses reflected the view of just one individual in each company; thus, it cannot be seen as a fully comprehensive analysis but rather a subjective snapshot of the status quo and future possibilities of each company.

This research is mainly inductive but combines both qualitative and quantitative approaches. The analysis of CSR reports and websites follows a qualitative approach, whilst in the analysis of the questionnaire responses, a quantitative approach is pursued.

The CSR reports were read and inductively coded in terms of their content related to the research questions (Figure 5). For RQ1, the passages containing information about the organisation's strategy, business model, and specific operational practices and approaches regarding economic, environmental, and social aspects within the organisation, their products, and along the supply chain were identified and coded. For RQ2, passages that provided information relating to the CE about the organisation's strategy, business model, and specific operational practices and approaches were similarly identified and coded. For RQ3, passages containing information about the use and application of digital technologies in relation to sustainability or CE aspects were located and coded. As the information from the analysed CSR reports and websites refers to the past and was found to contain little information about the companies' current or future use of digital technologies, the authors additionally distributed an online questionnaire to the companies from the sample, as noted above. The aim of the online survey was to gain an overview of current and future developments in the companies regarding the use of digital technologies in connection with sustainability and CE aspects.

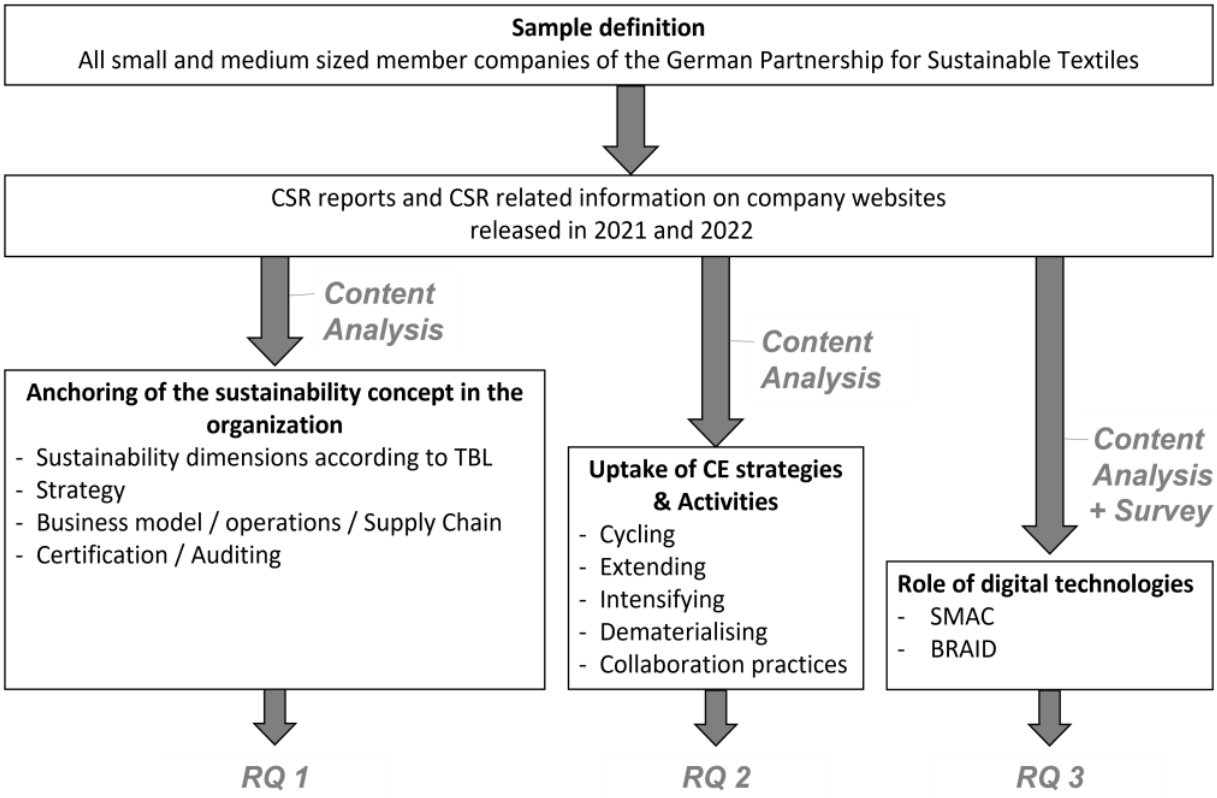

Figure 5. Procedures used to answer the research questions.

4. Results

Of the 29 SMEs studied, 28 companies provide information on sustainability on separate landing pages on their websites. Only one company does not have a dedicated landing page for sustainability but rather provides information regarding sustainability on a more general page on the company website. Of the 18 companies regularly publishing downloadable sustainability reports on their websites, 11 companies had published a sustainability report for 2021 (as of March 2022), 4 companies had published their most recent report in 2020, and 2 companies had published their latest CSR report for the year 2019. The results below use the codes for each company shown in Table 2.

4.1. RQ1. How Are German Textile and Clothing Companies Addressing Sustainability in Their Corporate Strategies and Activities?

From an analysis of the above-noted reports and web sources, eight main themes emerged, providing an overview of how sustainability is addressed and implemented in these companies (Table 3).

4.1.1. Integration of Sustainability into Company Culture and Structure

The vast majority (93%) of the companies studied had departments with associated responsibilities for sustainability issues, which were also reflected in corporate values and culture. OR, for example, sees its culture as being characterised by a respectful community and relationships within the team and with their customers and business partners. In a similar vein, HK [79] notes that "sustainability management is not just about questioning the use of resources, technology, and processes. It is also essential to involve and integrate the staff in the process" (para. 1).

Table 3. Sustainability actions and activities identified in CSR reports and websites.

Activity/Company	AT	BI	BL	BR	CH	DE	DS	DI	EL	VO	ES	GR	GG	HA	HK	IV	JA	KA	LA	LO	MA	OR	PA	PE	RE	SC	SY	TE	TH
Integration of sustainability into corporate culture/structure	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Adoption of UN SDGs				x	x		x	x						x							x	x		x			x		
Cross-supply chain transparency	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x
Sustainability risk management	x	x		x	x	x	x	x	x	x	x	x		x	x	x		x	x	x	x	x			x	x			x
Supplier selection and influence	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emissions and chemicals reduction	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sustainable products and materials	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Adopting sustainable business models				x			x	x		x			x	x				x		x		x	x	x		x			
Other activities	x			x			x	x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x	x		x

4.1.2. Adoption of the UN SDGs

Just under a third (31%) of the companies claimed alignment with the UN SDGs. DS, for example, uses the SDGs as a guideline for structuring its sustainability activities, while HA relates all sustainability goals directly to the SDGs. Across the companies that reference the SDGs, SDGs 8, 12, 13, and 17 are seen as the most relevant and, accordingly, are supported through appropriate measures and policies. SDGs 7 and 16 are the least-noted or overtly supported.

4.1.3. Cross-Supply Chain Transparency

Transparency forms a fundamental prerequisite for sustainable procurement and production, and 93% of the companies studied noted this as a significant policy objective. This is of particular importance in the complex clothing supply chain, in which there is often no direct contractual relationship with the upstream stages of raw material extraction or fibre and fabric production and processing. These are, therefore, not subject to the terms and conditions of the direct contractual partners and in some cases are not even known. However, some companies are already taking measures to render the activities of all actors along the supply chain transparent and thus enable the transition to a sustainable supply chain. SY [80], for example, states that "our direct business partners, particularly the small number of ready-to-wear companies, are amfori BSCI (Business Social Compliance Initiative) verified. Furthermore, we are intensively working on integrating the deeper supply chain (Tiers 2 and 3 [. . .]) into the BSCI Audit process as well" (p. 9). An alternative approach is taken by DI and ES, who prefer to work with vertically producing suppliers who included spinning, weaving, dyeing, and sewing under one roof. In this way, they can influence several supply chain stages and work with a manageable number of suppliers with the aim of long-term, trusting cooperation. Other companies (for example, ES) publish information about direct suppliers and production sites on public databases such as the Open Apparel Registry (OAR) or on the company´s website (for example, VO and SC). Transparency across the supply chain also allows for more effective tracking. BR uses a digital tool to offer complete transparency regarding the origin and manufacturing of products. The tool allows consumers to track a product´s journey by entering a tracking code or scanning a QR code. Certain certificates such as the Green Button and Oeko-Tex Made in Green are intended to ensure compliance with minimum social and ecological standards in the manufacturing and sourcing processes.

4.1.4. Sustainability-Related Risk Management

In total, 76% of the companies claimed to be adopting sustainability-related risk management practices. HK assesses the level of the risk of suppliers and then sets certain requirements for working with them. The risk assessments identify potential negative social and environmental impacts of products relating to the materials used, the various processing steps in the supply chain, and overall complexity. This is in line with the OECD Due Diligence Guidance for Responsible Supply Chains in the Garment and Footwear Sector, which provides a structure for risk analysis. It describes various risks that are particularly relevant and specific to the textile sector, such as human rights violations through child and forced labour, working conditions or low wages, and environmental damage through hazardous chemicals, waste, and emissions.

4.1.5. Supplier Selection and Influence

Clothing manufacturers can influence the social and environmental impacts associated with the production of their products in emerging countries, i.e., where the raw materials are sourced and processed. All companies stated that they base their actions as well as their business relationships on a code of conduct, which is extended to partners in the supply chain and declared to be a prerequisite for business relationships. The code of conduct is normally based on internationally recognised principles and guidelines. For example, BI [81] states that all their supplier relationships are based on the company's code

of conduct, which "precisely defines our due diligence requirements regarding ILO core labour standards, social and environmental standards and general aspects of responsible working relationships, such as the barring of corrupt practices" (p. 20). Subcontracting can undermine these practices, as there is usually no direct supplier relationship with the subcontractors and, therefore, their practices cannot be controlled or influenced. To prevent this, some companies have prohibited subcontracting through their own contracts. To monitor compliance with social and environmental standards at the suppliers, companies either employ their own staff in the production countries or rely on external support through audits and certifications. The companies rely on long-term supplier relationships and support them in implementing social and environmental standards. These standards and measures support the achievement of SDG 8 in the producing countries and are indirectly related to other goals, such as SDGs 1, 2, and 5.

4.1.6. Emissions and Chemical Reduction

Reducing climate-damaging emissions plays a major role in the sustainability reporting of all the analysed companies. Measures to reduce CO_2 footprints are already being implemented, such as at VO and SC, where emissions along the supply chain are monitored and reduction measures have been introduced. At SY and OR, ambitious targets have been set to further reduce emissions and achieve the goal of a climate-neutral supply chain by using innovative production processes and methods, which also help to reduce the use of resources and chemicals. ES [82] was able to "reduce the use of water and chemicals in production [..] by printing more and more digitally rather than conventionally" (p. 30). SY reduced water and chemical consumption in dyeing by using spinneret-dyeing technology instead of conventional dyeing processes. Suppliers are encouraged to implement responsible chemical management and avoid using hazardous chemicals during the production process or in the end products. To minimise the impact of transportation, companies rely on sea and rail transport from the production countries to Europe instead of air freight. Distribution for example, from online shops to consumers is carried out with more sustainable delivery services (e.g., BL, CH, and VO). IV even offers emission-free delivery with cargo bikes or e-cars in many German cities. Other companies use sustainable packaging without plastics (LA) or composed of recycled materials (OR). The measures mentioned here mainly contribute to environment-related SDGs, such as SDGs 13, 14, and 15.

4.1.7. Sustainable Products and Materials

Sustainability guidelines play an important role in minimising negative impacts in product development, notably in engendering the use of more sustainable materials, such as organic cotton, other plant-based fibres, or innovative materials. All companies claimed to be pursuing such measures. For example, VO uses an innovative polyamide made from castor oil to produce fine tights. For synthetic materials, which are mainly used in functional and outdoor clothing, the focus is increasingly on recycled materials. Materials of an animal origin are either completely avoided (BL and DE) or attention is paid to species-appropriate husbandry by using certified materials such as mulesing-free wool (IV, OR, and PA). Companies also focus on high-quality and durable products as well as repairability "because wearing the clothes for longer can effectively reduce the ecological footprint of the products, which are costly to produce" [83] (p. 22). Even companies from the fashion industry, such as BL, GG, and LA, rely on their products being durable and outlasting short-term fashion trends through the use of high-quality materials and timeless design. These measures appear to align with SDG 12 in particular.

4.1.8. Adopting Sustainable Business Models

New or changed business models adopted to achieve sustainability goals are mentioned by 41% of the companies studied. For example, several companies from the workwear, functional clothing, and outdoor clothing sectors now offer repair and spare part

services to extend the lifetime of their products (DS, OR, and SC). Rental or leasing models are also being tested; OR, for example, initiated a pilot project for clothing and backpack rental in 2021 to save resources through the best possible utilisation of products. HA, on the other hand, has adopted a longer-term objective of analysing the options for a new, integrated sustainable business model by 2030.

4.1.9. Other Activities

Philanthropic activities include donations, sponsoring, and "social" projects. For example, LO founded an association to help disadvantaged children in Romania, whilst ES donates 1% of its turnover of a particular collection to social projects. Biodiversity is protected at company sites through flowering meadows (e.g., HA) or insect protection measures (BR). Employees at the head offices are offered job bikes and/or job tickets or healthy food and beverages as well as sports activities.

Overall, the evidence suggests that this industrial sector is highly aware of sustainability issues, which is evidenced in the implemented strategies, policies, actions, and culture. All the companies in the study claimed to account for sustainability principles in their selection of suppliers and in their use of sustainable products and materials in their production processes. Measures to reduce chemical usage and carbon footprints were also pursued by all companies, and the majority were also in the process of adopting sustainability risk management measures and striving to achieve cross-supply chain transparency. Adoption of the UN SDGs and sustainable business models was less prevalent in the evidence, but, overall, nearly all companies had incorporated sustainability-related thinking and actions into their corporate culture and structure. This is further discussed in Section 5 below.

4.2. RQ2. What Strategies and Activities Relating to the CE Are Being Pursued in the German Textile and Clothing Industry?

The CE is explicitly referred to by only 28% of the companies in their sustainability reporting as a core component of their sustainability strategies. Although all companies are adopting some measures associated with the CE, they are presented as being supportive of a general move toward sustainable practices rather than specifically in the context of pursuing a CE based strategy. Seven sets of activities relating to the CE can be identified in the company reports studied (Table 4).

Reducing emissions and waste in the production process was cited as a current activity by 97% of companies. Different approaches to waste prevention were evidenced. Post-production waste is sold to recycling companies (HK) or reused in new collections and products (IV). Pre-consumer waste such as defective or unsold products is offered at reduced prices through alternative channels such as outlet stores (VO) or, in the case of non-saleable products, are fed into downcycling processes as filling material for other industries (BL). OR has introduced various packaging measures, such as new folding techniques, eliminating or digitalising labels, hangtags, and printed invoices and using recycled packaging materials to reduce the use of plastics and other resources.

Table 4. CE activities identified in CSR reports and on websites.

CE Activity/ Company	AT	BI	BL	BR	CH	DE	DS	DI	EL	VO	ES	GR	GG	HA	HK	IV	JA	KA	LA	LO	MA	OR	PA	PE	RE	SC	SY	TE	TH
Reduction in emissions and waste in operations	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Use of recycled materials	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Production of recyclable/biodegradable products				x			x	x						x		x	x	x				x				x	x		
Activities to extend product use phase		x	x				x	x	x	x			x	x	x	x			x	x		x				x	x	x	
Reverse logistics processes/take-back schemes				x			x	x					x					x	x									x	
Reuse or recycling of materials or products		x	x	x				x			x		x		x	x		x				x		x		x	x	x	x
Cooperation/collaboration with partners		x	x	x				x						x		x			x			x	x				x	x	

The use of recycled materials and the recycling of materials in production or packaging were noted by 90% of companies. The use of recycled materials refers primarily to synthetic fibres, which are made from PET bottles or marine waste, for example. True textile-to-textile recycling is evident only at the pilot level. HA is participating in a pilot project in cooperation with a tech start-up, fashion brands, textile collectors, and recycling companies to develop and test holistic processes from product development to recycling to create a "textile CE". SY is pursuing a "zero-waste vision" in which the company intends to implement 100% recyclable products and processes by 2030 and is participating in various collaborations to this end. These include the Accelerating Circularity Project Europe (an NPO that develops and implements processes to achieve circular supply chains in conjunction with actors in the textile supply chain) and Wear2Wear (an association of industrial companies that seek to produce new textiles exclusively from recycled and recyclable unmixed materials and thereby develop processes and technologies for a closed textile cycle).

Just over a third of companies (34%) are involved in the production or sale of easily recyclable or biodegradable products. For example, BR and KA have developed product lines that are certified according to the Cradle2Cradle standard and can thus be (at least partially) returned to technical or biological cycles, whilst SY uses mono materials for certain products, rendering them 100% recyclable. Measures to extend the use phase of products, such as the assurance of durable quality and repairability and the provision of repair services, were evident for 55% of companies.

Very few companies (24%) deal with the life cycle after the sale of the products or packaging, i.e., the part of the supply chain that is essential to "close the loop". There are some examples of reverse logistics processes or take-back schemes either currently in operation or planned involving the return of used products or packaging to the company for reuse or recycling. Over a third of the companies (38%) rely on cooperation and collaboration with other companies, sometimes even with competitors, in the upstream or downstream value chain for processes related to the CE. For example, BI collaborates with a supplier in a pilot project in which waste from production is passed on to a company that uses it to make new yarn. LA cooperates with the reselling platform Buddy&Selly through which worn clothing can be resold, while DI has founded the textile cooperative Cibutex together with partners and competitors to collect and recycle worn-out business textiles.

In summary, the companies studied were less aligned with CE practices when compared with their adoption of more general sustainability activities. Although the vast majority of the companies were pursuing a reduction in waste and emissions in their operations and were intent on the use of recycled materials, other CE activities were undertaken by an average of just 40% of the companies. These findings align with those reported by Arnold et al. [84], further underscoring the limited progress made by German textile companies in transitioning to a CE.

4.3. RQ3. What Role Are Digital Technologies Playing in the Transition to Sustainability and the CE in the German Textile and Clothing Industry?

Just over half of the companies considered (52%) referenced digitalisation or digital technologies in their CSR reports. A number of examples of how digital technologies are supporting sustainability or the CE are referred to in these reports or on the company websites. These are discussed below.

Digitalisation of operational and administrative processes can help reduce resource and material consumption and emissions costs. HA reported on the transition to exclusively digital processes in quality control: "Paperless working has the big advantage of information being available far more quickly and readily, also for communication with colleagues in other teams" [85] (p. 86). In light of the success of this initiative, the entire company plans to switch to paperless processes wherever possible. ES plans to only offer its regularly published book collection digitally in the future in order to save paper. Another example is digital visualisation using 3D software to create prototypes and samples.

BR reported that due to a true-to-the-original representation of the products through 3D visualisation, the company has reduced the costs of misunderstandings on the part of customers and suppliers and faults in production. The use of 3D software thus offers not only economic advantages through the saving of resources but also ecological benefits. BI also reported on the elimination of transportation and resource use to produce samples through 3D visualisation. VO consciously pursued an online-only sales approach to save costs and improve margins, allowing for increased investment in responsible products and production processes. The high level of online meetings necessitated by the COVID-19 pandemic generally provided a positive experience with respect to virtual meetings that will likely reduce face-to-face meetings in the future.

Supply chain and product transparency can be supported through digital product passports and tracing tools. As noted in Section 4.1, digital tracing tools can provide cross-supply chain transparency for consumers. BI plans to introduce a digital product passport by 2025, which is in line with the recommendations of the EU Sustainable and Circular Textiles Strategy [18]. Other companies use product or QR codes and smartphone apps to provide consumers with information about their products, the corresponding supply chain, and their carbon footprint. BR additionally uses a digital tool to track and control chemical management in the supply chain. This allows for the monitoring of chemicals used and the companies' compliance with restricted substances lists.

The use of social media and other digital media technologies can enhance communication with external stakeholders such as suppliers, trade customers, and consumers. At SC, for example, stakeholder communication is supported by digital media and product information. In addition, a supplier portal to connect with suppliers is planned to be implemented. HA is using social media channels such as Facebook, Twitter, and Instagram not only for product communication but also for building awareness in the area of sustainability and insights into the "company world".

Aside from HA, none of the companies cite digital technologies as a key component in the future achievement of sustainability goals. At HA, the digitalisation of business processes is seen as the facilitator of service quality improvement, and digitalisation initiatives are underway in many areas of the company, impacting logistics, traceability in the supply chain, and building technology. The follow-up questionnaire, noted in Section 3 above, was sent to the core population of the 29 companies in the period from February to May 2022, for which 19 responses were received.

The questionnaire respondents indicated that the majority of companies were either currently using, or planned to use, mainstream technologies, i.e., social media, big data and analytics, and digital manufacturing (Figure 6). Social media, as the CSR reports suggested, is mainly used for communication with stakeholders and for advertising purposes. Technologies used for digital product development and manufacturing included 3D design, 3D printing, and Computer-Aided Design (CAD) software, whilst big data and analytics applications provide customer and trend analysis and demand forecasting and planning. It is somewhat surprising that no company is currently using mobile computing and that only two companies are planning to introduce it. In the context of the COVID-19 pandemic and the associated lockdowns and work-from-home activities, it might have been assumed that companies adopted mobile working options, but this seems to be seen as a temporary reaction to pandemic measures rather than as a long-term permanent working option.

When asked if these technologies were used to support sustainability goals, six respondents answered "yes" or "partly", six answered "no", and seven provided "don't know" replies (Figure 7). However, looking to the future, the respondents suggested digital technologies would play a more significant role. When asked if digital technologies will play a key role in the transformation to the CE, seven (37%) responded "yes" and a further nine (47%) attributed at least a partial role to digital technologies in the transition to a sustainable and circular T&C industry. Only 3 (16%) of the 19 respondents answered this question with "no". This is surprising insofar as this assessment has not yet been reflected in the CSR reports.

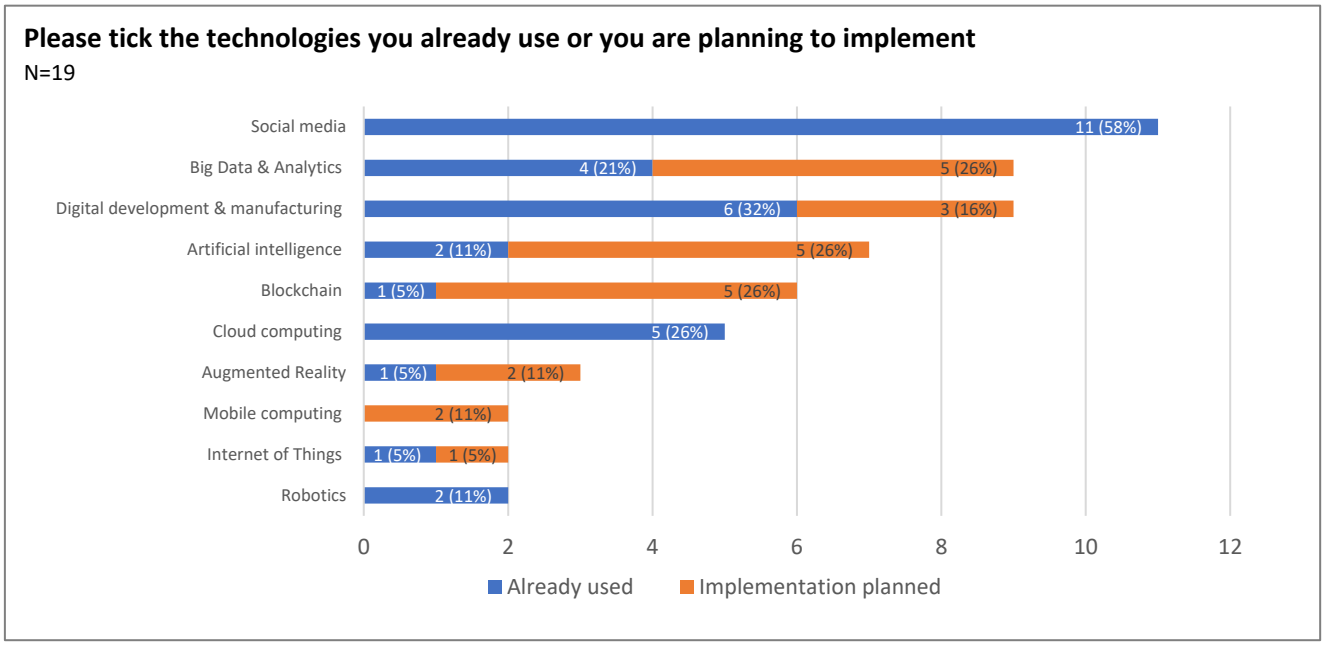

Figure 6. Technologies that are used or planned to be implemented.

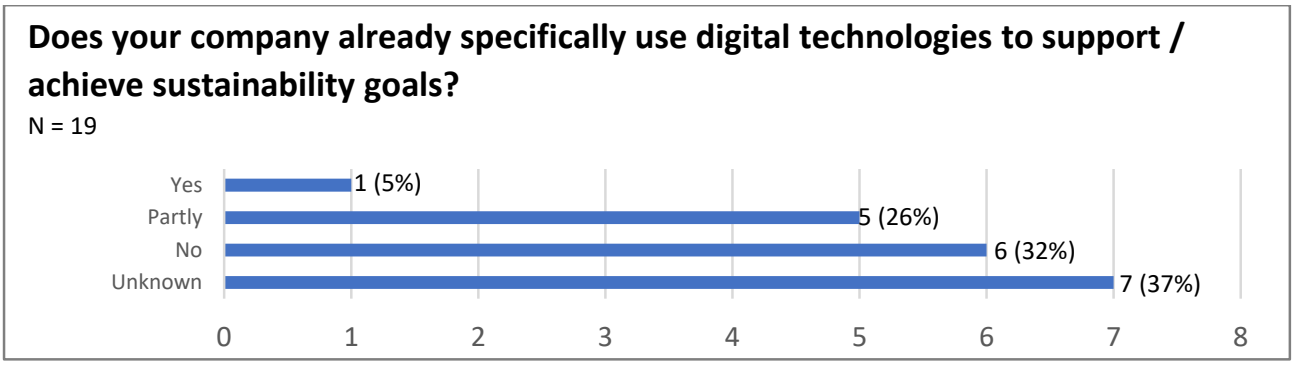

Figure 7. Use of digital technology to support sustainability goals.

In summary, the evidence from the CSR reports and the questionnaires suggests the industry may now be at a turning point in the use of digital technologies for the implementation of sustainability goals and CE-related activities. Although few companies currently report on product or process innovations in connection with digital technologies, the need for increased transparency along the entire supply chain to reduce and avoid negative impacts requires the use of digital technologies for data collection and processing. A few companies are already making product and supply chain information available to consumers quickly and easily using QR codes and Smartphone apps. The comparatively high number of companies planning to implement blockchain and big data applications may indicate that companies are adapting and starting to act in response to these future requirements. It is also clear from individual company statements that it is being increasingly recognised that a lack of digitalisation leads to high administrative costs in achieving sustainability goals. For example, BR reports that the administrative effort is immense in the case of data retrieval and the maintenance of supply chains. Similarly, LO reported that their risk analysis is based first and foremost on the company's data, but due to outdated legacy IT infrastructure, analysing the data is very time consuming, and in-depth analyses of the data are very difficult to carry out. There are thus a number of drivers, including the need to transition to CE practices, that are encouraging companies to proceed with digitalisation.

5. Discussion

The results outlined above raise a number of issues that merit further discussion.

Firstly, the CE is gradually emerging as a key strategic issue for companies in this sector, much like sustainability in general has over the past decade. Sustainability is now firmly anchored in the strategic goals of the majority of the companies that want to be perceived as responsible and sustainable and thereby develop and maintain a competitive advantage. The CE is explicitly included in some companies' sustainability strategies, whilst other companies pursue measures and activities related to individual aspects of the CE in their general sustainability efforts but do not link these directly to strategic objectives. At present, the CE concept is not approached holistically; rather, individual aspects are integrated into the existing linear value creation processes and business models. For example, the reduction in the use of fossil energies and climate-damaging emissions plays a major role in all the analysed companies. However, the focus is on the emissions caused directly by the company, and only five of the twenty-nine companies provide information on emissions that occur in the production processes of the upstream supply chain and measures to reduce them. It is also noteworthy that although the adoption of new digital business models to accommodate sustainable practices is mentioned by 41% of the companies, there is no specific reference to the significance of the CE in such transitioning. This lack of connectivity between the two concepts is evidenced in a recent survey of global CEOs [86] reporting that "84% of companies see digital and sustainability transformation as separate initiatives" (para. 9). More specifically, Arnold et al. [84], in their quantitative study on German textile manufacturers, concluded that "digitalisation opportunities are recognised, but a stringent method of implementation for this is not available yet nationwide" (p. 17). These inconsistencies and contradictions highlight the need for some underpinning theory and modelling linking digitalisation with the CE. As Saccani et al. [52] note, "practices and strategies proposed by the literature are still largely fragmented and not interpreted through an overarching theory, which prevents the understanding of how circular supply chains should be managed and coordinated" (p. 469).

Secondly, there is only a very limited degree of recycling of the companies' end products. The existing concepts for reuse and recycling considered by these companies currently mainly concern packaging materials, and only in individual cases for the textile products themselves. The foundations for the recyclability of a product are already in place in the design phase, in which a material's composition ensures that products can be manufactured without hazardous chemicals, used for as long as possible, repaired if necessary, and recycled at the end of the use phase. This is in line with the eco-design guidelines within the EU strategy for sustainable and circular textiles [18]. So far, however, companies seem to focus primarily on the upstream supply chain. The phases of product use, disposal, and recycling, which are usually downstream processes external to the company, are only considered sporadically and supported by appropriate measures in product development. Products will need to be broken down into their components after reaching their end-of-life stages and fed back into appropriate biological or technical cycles. This will require new processes and procedures for collecting and sorting used textiles from customers and consumers and the technical ability to separate and recycle the individual components.

Thirdly, there are issues regarding the standards and measurement of sustainability. There are no uniform standards for reporting nor any tangible, verifiable indicators, making it very difficult to compare or evaluate the quality and success of sustainability performance. In their analysis of corporate sustainability reports from various global, fast-moving consumer goods companies, Stewart et al. [20] arrived at a similar conclusion, noting the absence of performance indicators or evaluation methods for sustainability in most reports. Surprisingly few companies are actively adopting the UN SDGs in their reporting of sustainability. Companies individually set different priorities, and comparisons are only possible to a limited extent. Similarities in sustainability activities relate primarily to the social and ecological standards employed by suppliers and partners in the Asian production countries,

which the companies assess as part of their inspection operations in line with their codes of conduct. In doing so, they are guided by the OECD's sector risks [87], which are achieved through direct support in the implementation of standards and monitored through regular visits, audits, and certifications. However, cross-supply supply chain transparency and monitoring vary greatly among the companies studied. While some of them trace back all processing steps and ingredients and make them transparent for consumers, others have set this as a goal for the next few years, and others still do not provide any information about their deeper supply chains. Although various labels and certificates are used, there are no standard formats or templates. Most labels focus either on environmental or social factors. Furthermore, they often concern different parts of the textile value chain (raw material production, manufacturing, transport/trade, use phase, and end of life). Only a few labels, such as the Green Button, cover both social and environmental standards along a large part of the supply chain.

Fourthly, the transition to a CE will require appropriate partnerships and collaborative investment. Without knowledge of the entire supply chain, the goals set out in the EU strategy for sustainable and circular textiles [18] cannot be achieved. In particular, the requirement for a digital product passport, which is to be introduced by 2024 according to the EU strategy, will force companies to further address the digital transparency and traceability of their entire supply chains. Size and resource constraints make it difficult for SMEs to develop and implement their own recycling processes. Individual examples such as Cibutex established by DI and other industry actors demonstrate the importance of partnering with other companies to establish recovery and recycling processes. For such companies that operate in the Business-to-Business (B2B) sector, it seems to be easier to develop and implement corresponding collaborative concepts. Companies operating in the Business to Consumer (B2C) sector still lack functioning take-back systems or end-of-life concepts for used products. Arnold et al. [84] (p. 18) also call for "further investigations on new forms of collaboration between manufacturers, retailers, and consumers ensuring materials are kept in use for as long as possible". The expected introduction of producer responsibility in accordance with the EU strategy for sustainable and circular textiles is, therefore, not yet matched by any functioning concepts or capacities on the part of the SMEs considered. Company size is an important factor here, as high investment in technologies, processes, and employee training is often necessary, as examples from the larger companies show [88].

Fifthly, for SMEs operating in the T&C sector, there are no exemplars of best practices in companies of this size, with little guidance available on how to progress the transition to a CE with a more limited resource base. As regards the academic literature, Bressanelli et al. [65] recently observed that "the literature continues to struggle to understand how these technologies might contribute to value creation in the implementation of the circular economy" (p. 2). This research makes a small contribution to addressing this gap in the literature, and a simple operational framework for transitioning to the CE is put forward herein (Figure 8). This builds upon existing models, the initial conceptual framework, and the research findings, and contains a number of possible actions that can be used as a checklist to initiate the transition to a CE. It is not definitive, and not all of these possible initiatives will apply in all company contexts, but it may act as a top-level blueprint with which to kick-start and monitor transition.

The above framework requires that both CE-related and wider sustainability strategies and practices are aligned and encompassed by the company's overall business strategy. Some of the UN SDGs may be useful points of reference with respect to re-orientating corporate strategies. The transition can be initiated via a range of initiatives for changing the overall organisational culture and mode of operation. This may entail cross-company training and awareness programmes, new company structures, the creation of new posts, and the recruitment or redeployment of key personnel to fill them. The core company products may require re-designing to reduce waste and emissions and engender the re-cycling of products and materials. Wider process re-designs will likely be necessary, and

TBL accounting practices, notably as regards environmental impact assessment, can be adopted in financial reporting processes. Cross-supply chain collaboration and action will be required, including new product end-of-life treatment, quality assessment, and data transparency for both upstream and downstream business partners. Appropriate trials of digital technologies to support these initiatives should be undertaken and viewed as use cases that may provide a starting point for wider technology change projects.

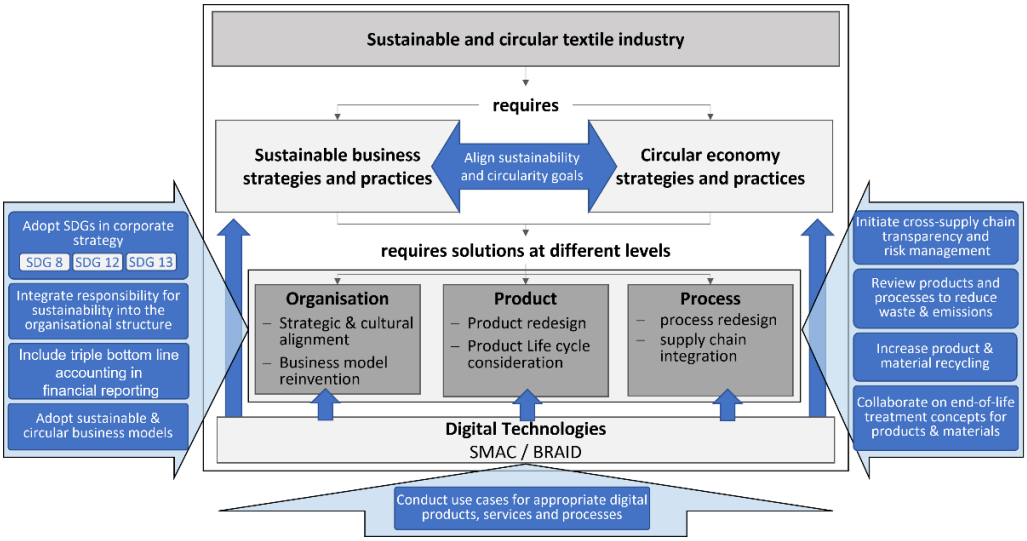

Figure 8. Operational framework for transitioning of T&C SMEs to the CE.

Possible methods of instigating change in an organisation, in a product's development and manufacture, and in associated processes are shown in Table 5. The table matrix has been developed using the change dimensions (organization, product, and process) from the conceptual framework and the action areas (strategy, practice, and technology) defined in Bressanelli et al.'s model (Figure 3). All these change initiatives which are illustrative rather than constituting of a definitive list need to be coordinated, cross-referenced, and well-managed as part of a major corporate change projects led, ideally, by a CEO or other senior manager.

Table 5. Action list matrix for transitioning to the circular economy.

Change Dimension/Action Area	Organisation	Product	Process
Strategy	• Set the CE as a core component of corporate sustainability objectives. • Integrate responsibility for sustainability/CE into organisational structure and culture. • Incorporate SDGs into corporate strategy (business strategy, annual reporting, CSR).	• Develop and implement sustainable product design and development strategies (e.g., design for durability, repairability, recyclability). • Initiate cross-supply chain transparency of product life-cycles. • Set targets for product carbon footprints.	• Establish process owners for sustainability/CE across company. • Review, adapt, and adopt sustainable and circular business models (rental, leasing, and complementary services, e.g., repair). • Introduce auditing and certification procedures within the supply chain. • Implement supply chain risk assessment to identify potential negative social and environmental impacts. • Collaborate with business partners with respect to end-of-life treatment concepts.

Table 5. *Cont.*

Change Dimension/Action Area	Organisation	Product	Process
Practice/ Operations	• Establish sustainability/CE functions and structures within company. • Cascade sustainability and CE objectives throughout the organisation. • Include triple bottom line accounting in financial reporting.	• Implement product development and manufacturing changes to reduce waste (e.g., use recycled and recyclable materials). • Reduce packaging overall and increase use of sustainable packaging materials. • Introduce certification by sustainability labels (whenever appropriate). • Implement product and material traceability and tracking.	• Publish audit-related information about suppliers and production sites. • Consider vertically integrated suppliers (e.g., weaving, dying, printing, etc.). • Implement reduction programmes for emissions, water, and chemicals. • Introduce cross-company waste reduction and recycling objectives and practices. • Establish and implement take-back systems and reverse logistics processes.
Technology	• Develop digitalisation/IT strategy to incorporate sustainability/CE drivers and benefits. • Transition IT function to championing sustainability/CE ("Green IT"). • Use social media and other digital media technologies to support stakeholder communication.	• Use digital technologies to support product development and production efficiencies (e.g., IoT, 3D technologies). • Implement a digital product passport. • Deploy digital technologies to reduce waste and enhance recycling.	• Trial digital technologies in support of sustainability and CE objectives. • Incorporate technology use cases into sustainability/CE processes (e.g., mobile apps, blockchain). • Digitalise administrative processes to reduce the consumption of resources and materials and the corresponding emissions generated. • Implement digital tracing tools to provide cross-supply chain transparency.

6. Conclusions

This exploratory paper has examined how SMEs in the German T&C industry are approaching the issues of sustainability and the CE and assessed the role digital technologies are playing in the transition to a sustainable and circular textile industry. The results suggest these companies view sustainability as a key strategic issue and orient their corporate actions towards the achievement of social and ecological goals to gain competitive advantages by consciously differentiating themselves from the global fast fashion industry. A large proportion of the sustainability reports also refer to specific activities related to the CE, but at present, there is no clear recognition of the concept as a strategic objective, nor is it viewed holistically within these companies or across the extended supply chain. In addition to these insights into the relationship between digitalisation and the CE, another major contribution of the paper is its operational framework and action list matrix (Table 5) derived from the research findings, which can be used as a framework for companies intent on adopting circular economy practices. Thus, the article makes a small contribution to practice and complements the existing literature on digitalisation and the CE in the T&C industry, adding to the perspectives put forward by other authors in different geographical contexts [12,71,89].

Although these businesses currently only make limited use of digital technologies to support their sustainability efforts, the results suggest that digitalisation is increasingly influencing the competitiveness of companies in the T&C sector most notably that of SMEs. At the same time, supply chain transparency is putting more pressure on companies to

make processes and products more sustainable. So far, initiatives to implement more sustainable and circular processes, products, and business models have not been directly driven by digitalisation, which, to date, has seemingly not acted as the catalyst for such a transition. However, indications from the CSR reports and feedback from the online survey suggest the industry may now be at a crossroads, from which many companies will advance with a more positive recognition of the need to transition to CE practices, which will be facilitated by digitalisation to effectively meet compliance requirements and satisfy evolving customer expectations.

This study has limitations in that it is based on publicly available information from 29 SMEs, and the short follow-up survey focused on digital technology deployment. The analysis of company reports provides an incomplete picture and needs to be considered with caution when drawing conclusions at the industry level. The findings are based on the T&C industry in a European context and are not necessarily applicable in other geographical environments or business sectors. Future work based on case studies is needed to investigate best practices and approaches that can facilitate the transformation process for SMEs, including recommendations for action and strategies for their long-term competitiveness in a sustainable and circular textile industry. In this context, the operational framework put forward in this article may act as a starting point for more detailed research, which could apply, develop, and refine the actions required to move towards the circular economy. This framework can act as a reference point for developing sets of actions, such as those indicated in Table 5, for specific companies in the sector, accounting for the varying degrees of digitalisation and differences in company attitudes and approaches to sustainability. Further research could also focus on examining external market influences such as the expected laws and regulations under the EU strategy for sustainable and circular textiles and how SMEs can most effectively align their sustainability strategies and actions. Further studies might also examine how the growing customer awareness of the environmental impact of the clothing industry in different geographical locations is affecting the industry. As Claudio [90] noted fifteen years ago: "the biggest impacts for increasing sustainability in the clothing industry rests with the consumer" and "consumer awareness about the fate of clothing through its life cycle may be the best hope for [future] sustainability" (p. 454). Indeed, this may be the key factor that finally pushes the industry into adopting the CE in its practices and operations.

Author Contributions: Conceptualization, T.W. and M.W.; methodology, T.W. and M.W.; validation, T.W.; formal analysis, T.W. and M.W.; investigation, T.W.; data curation, T.W.; writing—original draft preparation, T.W. and M.W.; writing—review and editing, T.W. and M.W.; visualisation, T.W. and M.W.; supervision, M.W.; project administration, T.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All research data are displayed within the article. The online survey was conducted anonymously.

Conflicts of Interest: The authors declare no conflict of interest.

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