Circular supply chain configuration: A multiple case study in the fashion and textile industry

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Abstract

The F&T industry, a major global polluter, seeks a CE transition to mitigate environmental impact. Supply chain restructuring is vital, particularly in the RSC, necessitating strategic localization and centralization decisions in the face of evolving regulatory and technological landscapes. This study explores RSC configurations and their influencing factors, through multiple case studies. Semi-structured interviews were conducted to 6 RSC actors, covering all steps of the RSC. Findings suggest the need for more local and hybrid RSCs, focusing on collection and sorting in proximity to waste generation. The study aims to guide practitioners and policymakers toward more sustainable practices.

Keywords: Circular economy, Supply chain configuration, Fashion and textile

Introduction

Fashion and textile (F&T) industry is recognized as one of the most polluting industries in the world, generating excessive disposal of pre- and post-consumption waste (Charnley et al., 2024; Sandvik & Stubbs, 2019). The transition towards Circular Economy (CE) is under the urge as a potential solution towards a less environmental intensive future for the sector (Saccani et al., 2023) by restoring and regenerating value from waste (Ellen MacArthur Foundation, 2015).

To this aim, the traditional make-use-dispose linear model in the industry should be replaced by circular strategies. In the F&T industry, this is often interpreted as developing and promoting strategies for reduce, reuse and recycle waste of garment and textile (Rotimi et al., 2021). In light of CE transition, supply chains – being the fundamental and complex construct that sustain the flow of material and associated exchange of information and finances (Ellram & Cooper, 2014), requires holistic rethinking and repurposing (Lewandowski, 2016). This is coined in literature as Circular Supply Chains (CSCs) aiming at "integrating circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems" (Farooque et al., 2019).

The strategic shift towards CE calls for necessary transformation in the structure and the configuration of supply chains spanning across product design, production,

consumption, waste management, reuse and recycling (Farooque et al., 2019; Lewandowski, 2016). A pivotal role in the CE transition is played by the reverse supply chain (RSC), encompassing all the operations needed to close the loop. In particular, companies face the need of setting up, and often create new RSCs to be integrated with the forward supply chains (FSCs) (Miemczyk et al., 2016). As companies navigate this landscape, the strategic decisions regarding the localization of RSCs become increasingly crucial (De Angelis et al., 2018). These decisions are not only influenced by evolving recycling technologies and global supply chain dynamics but are also shaped by legislation. Particularly, impending regulatory changes, notably in the EU, underscore the need for thoughtful localization strategies that balance existing setups with new evolving dynamics, for a just transition of the F&T (Charnley et al., 2024). Besides, centralizing or decentralizing RSC operations is another key strategic decision impacting the overall economic, environmental and other SC performance (Riese et al., 2024).

Previous literature on F&T RSC has focused mainly in the reuse strategy (second-hand), while RSCs for recycling are seeking contributions (Sandvik & Stubbs, 2019). Challenges and opportunities in sorting, value creation and collaboration have been explored (O'Reilly & Kumar, 2016; Paras, Curteza, et al., 2019; Paras, Ekwall, et al., 2019; Sandberg et al., 2018; Zanjirani Farahani et al., 2022; Zhuravleva, 2024; Zhuravleva & Aminoff, 2021). Notably, only (Charnley et al., 2024) has primarily addressed the debate over the localization of CSC operations. However, their focus was limited to post-consumption (PC) waste and textile-to-textile (T2T) recycling. For this reason we decided to focus on studying the RSC configuration including post-industrial (PI), pre-consumption (PreC) and PC waste, including non-textile materials such as fishing nets that can be recycled into textiles (nylon 6). To this aim we formulated these research questions:

RQ1. What are the RSC configurations in the F&T industry?

RQ2. What are the factors shaping RSC configurations in the F&T industry?

Taking a contingency approach, it is evident that there is no one-size-fits-all RSC configuration. Therefore, this study aims to inform practitioners and policymakers about the main forces driving localization and centralization decisions, hence influencing the F&T RSC configurations.

Research Background

The F&T RSC is constituted by three main steps: collection, sorting and recycling. It begins with collection through various channels, generally managed by charities and municipalities (O'Reilly & Kumar, 2016; Sandberg et al., 2018; Zhuravleva & Aminoff, 2021). Municipalities and charity organizations are large collectors of textiles waste through direct donation, bank collection, and they are expanding their channels collaborating with fashion retailers through instore collection activities (Zanjirani Farahani et al., 2022). This enables them to collect not only PC waste, but also PI and PreC. PI and PreC waste include waste generated during production activities in the FSC or unsold and returned finished products before consumer use. After collection, the waste is sorted and classified into different categories, based on factors like damages, color, material, and product type (Paras, Ekwall, et al., 2019), through a series of processes undertaken by charities, municipalities and specialized sorting firms. Depending on the product's state, it might be repaired, cleaned, or sent for further processing. Once the collected product has passed through collection and sorting, the waste flow is divided between the reuse and recycle waste flow. The reuse flow is resold or donated, extending the product life of used garments, while the recycling flow aims at extending the materials life within the waste collected. Therefore recycling requires additional operations

depending on the material to recycle and the technologies adopted. Moreover, closed-loop recycling systems which recycle textile waste to produce textile products are called T2T (Farooque et al., 2019; Sandvik & Stubbs, 2019), differentiating from open-loop system recycling plastic bottles to make polyester fiber or recycling textile waste to make low-value products as insulation panels (downcycling). In the context of T2T recycling technology, two primary approaches stand out: mechanical and chemical recycling. Mechanical recycling involves cutting and shredding fabrics to create new yarn, offering a sustainable alternative with lower energy usage compared to virgin fiber production (Charnley et al., 2024). An emerging innovation, "soft" mechanical recycling, enhances fiber quality and quantity by minimizing length reduction (McKinsey, 2022). Chemical recycling breaks down fibers into molecular components, such as depolymerization or dissolution, yielding high-quality fibers suitable for various applications. This technology targets a wide range of fibers, including cotton and synthetic fibers like polyester, but are still in development stages (Sandvik & Stubbs, 2019).

RSC Configurations

From literature, three main F&T RSC configurations emerge based on their localization: fully local, fully global and hybrids configurations (Figure 1).

Fully local RSCs are constituted performing collection, sorting and recycling operations locally, within a national level. In literature, several fully local configurations were analysed until sorting, focusing on the reuse CE strategy. In particular, (Zhuravleva & Aminoff, 2021) studied the partnerships between charities and waste management companies or private companies for domestic textile waste valorization. Their findings suggest that RSC actors collaborate to maintain all the operations locally for enhancing their environmental footprint. Indeed, local configurations are struggling to emerge for economic reasons, given that exporting textile waste is economically better for charities, but more carbon intensive. The primary role of charities in fully local textile RSCs emerges also from (Zanjirani Farahani et al., 2022). The main driver is their local infrastructures for collection, sorting and resale. Indeed, charities collect textile waste through donations, banks collection or partnerships with other actors, sort it and resell the reusable fraction in their second-hand stores. Fully local configurations including also recycling represent the case of the Prato district, well known for its historic circularity. There, PI waste is generally collected by specialized companies from hundreds of local manufacturers, while PC waste requires further involvement of other actors such as brands and charities (Bressanelli et al., 2022; Ciccullo et al., 2023; Saccani et al., 2023). According to these contributions, sorting and recycling have been integrated into multiple fiber manufacturers, showing an increased correlation between RSC and FSC. According to (Charnley et al., 2024), fully local configurations would lead to a “collapse of collection businesses”, suggesting fully global or hybrid configurations.

Fully global RSCs are constituted performing collection, sorting and recycling operations globally, sometimes across three different continents, and always involving low-cost labour countries. For example, typical is to perform the sorting of post-consumer waste in the importing countries such as Romania and India (O’Reilly & Kumar, 2016; Paras, Curteza, et al., 2019; Paras, Ekwall, et al., 2019). In particular, sorters in India are receiving post-consumer waste from USA, Canada, Europe, Korea and Australia, from charities and traders. Sorted clothes are then, once again, exported globally, and African countries are considered major markets. However, often the sorted waste comes back to the continent of collection to be recycled. Although fully global configurations are mainly driven by labor costs, other factors were identified. Sorting, nowadays, is a manual operation that requires expertise and skills for maximizing value creation from textile

waste (Paras, Ekwall, et al., 2019; Sandberg et al., 2018). Furthermore, legislation also affects localization decisions in fully global configurations. An example is the case of India, which has set up free-trade zones, promoting the import and export of used clothes, thus favoring fully global configurations (Paras, Ekwall, et al., 2019). According to (Charnley et al., 2024), RSC configurations should "align with the current material flows and international trade networks for raw materials, textiles, and new and used apparel".

Hybrid RSCs are constituted performing either the sorting in proximity to the location of collection, or to recycling. Literature has provided few contributions on the localization decisions of sorting and recycling operations. For example, (Miemczyk et al., 2016) analyzed a case of RSC in which recycling was located in proximity to production. This was driven by the technical expertise of the manufacturing company, as well as its infrastructures. Thus, recycling operations were integrated with the forward production operations in the same plant. From (Charnley et al., 2024) the hybrid configuration named "mass regeneration zones" emerges. This would locate sorting and recycling operations in proximity to production activities, necessitating global flows of waste and new products, but reducing them with respect to fully global configurations.

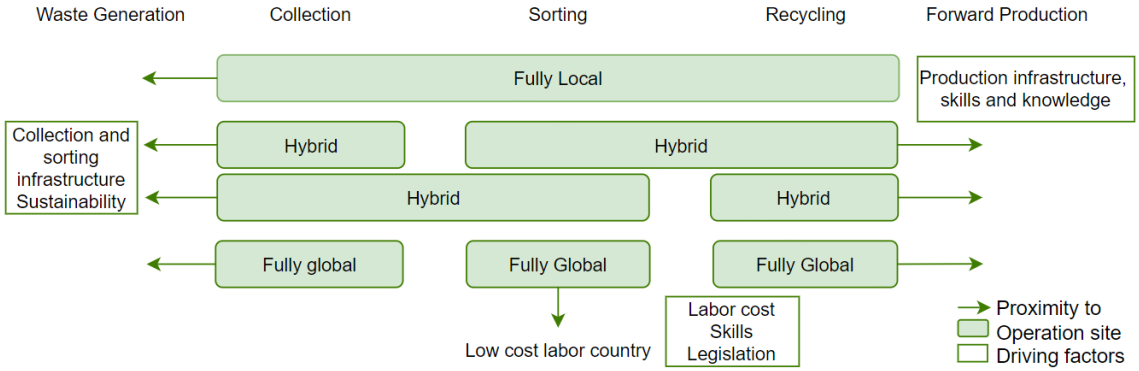

Figure 1 - RSC configurations based on localization

Literature shows different centralization decisions implemented by charities in sorting for reuse. Sorting is performed in a decentralized approach when direct donations are the predominant collection inputs and speed is prioritized. In this way used clothes are collected and immediately sorted in second-hand shops. Instead, when dealing with very high volumes coming for banks or home collection, centralized hubs are preferred (Zanjirani Farahani et al., 2022; Zhuravleva, 2024). However, centralization decisions on sorting for recycle and recycling were not emerging.

Methodology

This research uses multiple case studies to gain a deeper understanding of complex supply chain issues. Case studies are well-suited for this because they allow us to explore situations involving multiple companies and gather information from various sources (Yin, 2009). Our research examines 6 cases within the F&T RSC. The unit of analysis of our study is the RSC configuration of the different case analysed. The selection criteria were predicated on ensuring representation from each step of the RSC. In our research, we specifically aimed to interview a diverse range of companies, both in terms of their technological capabilities, such as those specializing in chemical and mechanical recycling or possessing automated sorting systems, and their position within the RSC. This included companies that play a significant downstream role in the RSC as recyclers, upstream role as collectors and sorters, as well as those that integrate all three fundamental steps (collection, sorting and recycling). Companies interviewed varied in size, ranging

from small and medium enterprises, to larger corporations highly vertical integrated. The list of companies that participated in the study are presented in Table 1. Data collection was conducted through semi-structured interviews, each lasting between 50 minutes to an hour. These interviews were meticulously designed to align with a standardize format, ensuring uniformity and comparability across all data points. The interviews were complemented and triangulated with other data sources, such as company webpages, press releases and reports. These different secondary data sources were complementary in building a rich picture of the organizations. The interviews were recorded and transcribed via Teams. For data analysis, transcriptions were coded using MaxQDA, enabling an effective cross-case analysis.

Table 1 - Interviews and Interviewees specifics

Company	**CSC step**	**Technology**	**Role of informant**	**Duration**
C1	Recycling, Spinning	Soft mechanical recycling	Global Sourcing & SC Manager	1 x 50 minutes
C2	Collection, Sorting, Recycling, Spinning, Weaving	Mechanical recycling	Innovation Manager	1 x 50 minutes
C3	Collection, Sorting		Managing Director	1 x 60 minutes
C4	Sorting, Recycling, Spinning	Chemical recycling, NIR handheld spectrometer (limited)	Head of CE & Sustainability	1 x 60 minutes
C5	Collection, Sorting	NIR automated sorting system	CEO	1 x 60 minutes
C6	Collection, Sorting	NIR handheld spectrometer (limited)	Post-consumer Textiles Expert	1 x 60 minutes

Findings and Discussions

C1 is a Belgian company specializing in textile waste transformation into high-quality fibers, with operational capacity of 3000 tons annually. It covers recycling and spinning operations for both PI and post-consumer waste. Their strategic localization in Belgium, near its textile manufacturer partner, facilitates technology refinement and partnership.

C2 is a European leader in textile recycling, managing RSC from collection to recycling, and parts of FSC like spinning. They expand their European network for increased waste volume. At their Netherlands base, they sort for reuse, sending non-reusable items to Morocco for sorting for recycle, mechanical recycling and spinning/weaving.

C3 is a UK-based leader in textile waste collection and sorting, mainly through collaborations with charities, municipalities and brands. Their manual sorting process, conducted in the UK, targets reuse and recycle through partnerships with T2T recyclers.

C4 is an Italian company specializing in nylon 6 production from PI and post-consumer waste, sourced globally and processed in Slovenia. They also control waste collection and sorting after having acquired strategic suppliers.

C5 is a German collector and sorter sourcing waste from central Europe. It operates sorting facilities in the UAE and Germany, utilizing manual labour (sorting for reuse), and AI and NIRS technology (sorting for recycle). They collaborate with partners to develop recycling solutions.

C6 is a Finnish municipal waste management company focused on post-consumer textile waste collection and sorting, covering 95% of the Finnish population. The collected textile

waste undergoes an initial decentralized sorting process, followed by a centralized sorting for recycling.

Table 2 - Overview of the localization and centralization decisions made by the sample

Case	Collection	Sorting	Recycling	Production
C1 – Hybrid			Centralized in Europe, in process of decentralization with new plant in India	Spinning integrated with recycling
C2 – Hybrid	Decentralized in different channels and European countries	Centralized. Sorting for reuse in proximity of collection, sorting for recycle of recycling	Centralized in Morocco	Spinning integrated with recycling
C3 – Fully local	Decentralized in different channels in UK	Centralized in proximity of collection		
C4 – Hybrid	Decentralized in different channels and countries	Centralized in proximity of collection	Centralized in Europe	Spinning integrated with recycling
C5 – Fully global	Decentralized in different channels and European countries	Centralized. Sorting for reuse in UAE, sorting for recycle in Europe		
C6 – Fully local	Decentralized in Finland	Decentralized sorting for reuse, centralized sorting for recycle		

Cross-case Analysis

The cases cover all stages in the RSC of T&A, namely collection, sorting and recycling. Our analysis shows that all these RSC stages could be arranged in diverse configurations, in terms of localization and centralization (Table 2), depending on several factors.

Collection. The RSC begins with the collection of textile waste, which is performed in the same place of the waste generation. However, depending on the waste flow's type, the waste generation point can be decentralized as in the case of PC waste, or centralized in a FSC's node as in the case of PI or PreC waste.

Local legislation plays a pivotal role in this RSC step, defining what is waste, and authorizing specific supply chain actors for collection and treatment. In the case of C6, legislation mandates decentralized waste collection by local municipalities. In general, PC waste collection involves multiple actors for consolidating at further stages waste flows and achieve greater volumes. This was the case of C3, C5, C2 and C6, namely all the collectors and sorters interviewed. Legislation can influence and enhance this collection stage through EPR schemes. Recyclers (C4) adapt their sourcing strategies based on the implementation of EPR schemes in various regions, leveraging the increased waste collection rates facilitated by such schemes. Overall, PC textile waste is collected by multiple authorized actors in proximity to waste generation.

Collection of PI and PreC waste often requires collaboration between FSC and RSC actors. Collaborations for PreC waste involve brands and collectors/sorters (C3, C5), while collaborations for PI waste involve fiber/fabric suppliers, manufacturers, and recyclers, since this waste flow does not require further sorting operations (C1, C4). Waste generated in a node of the FSC, such as a manufacturing facility or retail warehouse, requires a link between the FSC and RSC for reuse or recycle. Thus,

proximity to waste generation points is crucial also for PI and PreC waste, with companies establishing consolidation hubs near waste generation points (C4, C1). Moreover, the collection tends to be performed in a decentralized approach, independently by the type of waste flow. In particular, while PC waste flows collection is decentralized and performed through bank, door-to-door and in-store collection from multiple waste generation points, PI and PreC waste collection is also decentralized since collectors have collaborations with multiple actors to increase volumes.

Sorting. The localization problem of sorting activities is particularly relevant since there is a mismatch between the points of waste generation and production infrastructure, so the RSC cannot be in proximity of both extremes. "The feedstock of post-consumer waste is in Europe, North America. All the textile manufacturing is in China, Bangladesh, India, so you've got this movement and offset" (C3). While collection is performed in proximity to waste generation points, the localization of sorting activities can be either driven towards the precedent collection or the consequent recycling activities depending on different factors (Figure 1). In some cases, the seek of low labour cost could even drive the sorting activities far from both collection and recycling activities. Textile waste is a low value product to deal with, in which the high incidence of transportation costs emphasizes the need for local configurations (C3, C6). Additionally, companies are driven also by ethical forces to operate at a local level since "we need local solutions for local problems" (C6). Lastly, local legislation also influence the localization decisions of sorting facilities through EPR schemes, or imposing public waste management companies to collect and sort waste flows locally (C6). These factors pull sorting activities to be performed in proximity to waste generation and collection, reducing the movement of waste across regions and countries. However, RSC actors are affected also by other forces which drive the localization decision towards recycling and production activities. Indeed, given the concentration of textile production infrastructure and skills in few locations around the globe, RSC actors may choose to locate sorting facilities close to recycling and production plants (C2). In this way, the movement of sorted waste can be minimized, achieving cost optimization.

Sorting activities are nowadays performed manually. Especially in the sorting for reuse, humans can quickly grab the cloth, twist it, scan it and make a value decision (reuse, recycle, recover). This can hardly be performed in an automated way, but some interviewees think AI might be able to do it in the future (C3). Instead, in sorting for recycle, the level of automation is higher, and companies are investing in automated solutions for sorting in different colour and material categories (C5, C6). This explains why labour cost has been so determinant in the localization of sorting facilities, and still represents one of the biggest economic barriers to move sorting activities in developed countries, where most of the waste is generated. Labor cost not only impacts the localization decision of sorting activities, but also the centralization or decentralization decision. Indeed, while collection has to be performed in a decentralized approach, the decision of centralizing the sorting activities is a strategic decision driven by multiple factors. Based on the empirical data, we have observed that companies may choose to decentralize sorting for reuse for minimizing the movement of the waste, since the sorting would be carried out in the collection location, again for minimizing transportation costs (C6). Other cases instead, opted for centralizing sorting for reuse in order to consolidate higher volumes, achieve economies of scales, and exploit lower labour costs if performed in a low labour cost country (C5, C2, C3, C4). On top of these reasons, sorting for recycling tends to be centralized to fully exploit the investments for automated sorting lines (C5, C6).

Overall, how and where to perform sorting activities resulted to be strategic for the whole RSC, being sorting the connection between collection and recycling. We cannot say

there is a predominant configuration, since different and opposite forces drive these strategic decisions. Therefore, we can have sorting activities performed in proximity to collection and waste generation, in proximity to recycling or in a low cost labour country. Moreover, sorting can be also split, locating sorting for reuse in proximity to collection and sorting for recycle in proximity to recycling (C2). Lastly, sorting activities tend to be centralized, especially sorting for recycle, while we found one case decentralizing the sorting for reuse.

Recycling. It is the last step of the RSC, and represents a link with the FSC. According to (C5) recycling plants and related investments are concentrated mainly in Europe, counting around 70 hubs. Apart from the link between recycling and production, we have also investigated the link between sorting and recycling. Based on our empirical data, only one case has put sorting for recycling in proximity to recycling and production activities (C2). On the other hand, C4 sorts out the waste collected in proximity to waste generation and ships it overseas to its recycling plant. These opposite strategic decisions highlight the debate on the RSC operations localization. Both companies are driven by cost optimization goals, but differences in term of waste type and technologies employed play a pivotal role. Indeed C4's interviewee pointed out: "Recycling and production of synthetic fibers have 'level of automation' natural fibers may never reach". Besides these two cases, the other companies interviewed, which do not directly control recycling, have not showed intentions in moving their sorting activities closer to recycling. This is because specialized sorters have to "find the best circular solution for all the different materials" (C6), and "put the right fibres to the right place" (C3). This fiber type driven approach bring them to evaluate every solution such as reuse, repair, upcycling, recycling (mechanical, chemical etc.), downcycling. Thus, being in proximity to recycling for them means focusing in only one circular solution, but "there are lots of opportunities, we are trying to challenge companies also to think of new solutions as well, because it's not just T2T (recycling), we need many, many alternatives" (C6). In conclusion, the findings suggest a stronger interrelationship between recycling and production, having recycling companies locating recycling plants depending on where production infrastructure, skills and knowledge are, rather than where sorting is performed.

Based on our findings, recycling operations tend to be centralized in one location and integrated with spinning to obtain yarn as output (C4, C1, C2). This enable recycled fibers to skip the first step of the FSC (spinning), thus sharing the margin with less supply chain actors. Indeed, this was one of the strongest driver for C2 to vertical integrate up to the weaving process. In this way the company can offer to brands a closed-loop recycling solution cutting out any other intermediary and, as a result, being more price competitive against virgin fibers/fabrics. Moreover, the high investment costs for building advanced recycling plants together with the need of high volumes to reach economies of scale, drive companies to centralize their recycling operations. However, C1 has already set up a joint venture to replicate its European recycling plant in India, in proximity to both waste generation (PI waste) and production infrastructure. Similarly, C4 do not exclude the possibility to decentralize its recycling plant in Europe, if an EPR scheme would come up or to be closer to waste generation. This last finding foresees a possible decentralization of recycling operations.

Although integrating the recycling and spinning in one location is beneficial for reducing costs and increasing responsiveness, achieving a full integration of forward and recycling operations may be too ambitious, given the length and complexity of F&T SCs. Indeed, the subsequent operations of the FSC after spinning have offshored mainly to the Far East (C3, C4). So integrating the recycling and spinning operations would postpone the problem of global flows connecting spinning to the following operations(C3). "In

Europe, only the truly skilled have survived, truly skilled in the sense, those who produce very high-quality fabrics and primarily supply the luxury sector" (C4).

Future configurations

Against (Charnley et al., 2024), our empirical data foresee a RSC configuration fully local or hybrid. In particular, "the supply chains that we've built up through the 80s and 90s are definitely not going to work in the 22nd century. We need more regional and local solutions […] that create less CO2" (C5). Fully local or regional RSCs not only lowers the environmental impacts of worldwide shipping, but also increases its resilience to shocks such as Covid-19 and the war in Ukraine (C5). This is why, building sorting and recycling infrastructure in Europe, transforming the waste locally into fiber or yarn will allow the industry to take a step forward. Even though locating recycling and production in the same site will be ideal, in Europe we don't have the production capacity to satisfy global demand, thus after recycling, shipping the fiber or yarn to production locations will be needed (C5, C1). Nowadays, companies in the textile RSC do not have visibility on where the waste they sell for reuse ends up (C2, C5, C3). This is why fully global configurations cannot work in this moment, companies cannot "send it to the other side of the world, close our eyes and don't know where it ends up" (C6). In the shift to sustainable RSCs, ethics play a pivotal role in guiding operational decisions beyond legislative mandates, urging proactive ethical choices to drive responsible practices.

Besides, hybrid configurations emerge also from our findings. However, while in the case of "mass regeneration zones" in which sorting and recycling are integrated in global production sites, from our data, collection and sorting should be performed at the local level. This will lead to "specialized recycling hubs", focusing on recycling specific materials with specific technology. So, in this hybrid configuration you collect and sort the waste "as close to source as you can", and after sorting, "You might find cotton goes to Turkey, wool, goes to Italy, polyester probably might go out to China or the South East Asia" (C3). This configuration is a good compromise between the need to deal with waste close to waste generation points and the specialization of production and recycling infrastructure around the world. Indeed, (C2) which is implementing more a "mass regeneration zone" configuration, would need to just move the sorting for recycle close to its collection hubs. This is what the company is investing on, but they are still slowed down by the lack of efficient automated sorting technologies.

Conclusion

This study contributes to enriching existing literature on CSCM along the F&T industry by offering insights into RSC configurations. The findings shed light on the factors influencing RSCs towards local, hybrid, or global configurations, as well as centralized or decentralized RSC operations. Notably, empirical data emphasize the importance of prioritizing local and hybrid RSC models, particularly in collection and sorting processes, aiming for improved environmental performance and resilience. However, to effectively implement these strategies, there is a clear need for legislative support. Therefore, this study not only provides valuable insights into strategic RSC decision-making but also highlights the importance for policymakers to actively facilitate and support the transition towards CE practices within the industry.

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