From Linear to Circular: Proposing a Model for Textile Supply Chain Transition

Castellano, D.,* Mercogliano, N.,*, Moroni, F.,, Viola, A.**, Romagnoli, G.****

** Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, V. Vivarelli 10, 41125 Modena (davide.castellano@unimore.it; nicola.mercogliano@unimore.it)*

*** Department of Engineering and Architecture, University of Parma, V.le delle scienze, 181/A, 43124, Parma, (francesco.moroni@unipr.it; alessandro.viola@unipr.it; giovanni.romagnoli@unipr.it)*

Abstract: The textile industry is a large and increasing sector that is commonly recognized as non-environmental-friendly, due to the quantities of pollutants it produces, and to the fact that treating its wastes raises important environmental concerns. A way of reducing its impact can be the development of modern technologies for textile recovery and reuse to meet current and future circular business needs. Effective waste management practices are essential for advancing circularity within the textile supply chain (SC). Specifically, following separate waste collection, a sorting phase should define the portion designated for reuse, while the rest is targeted for recycling. Here, textile wastes might be broken down into fibres through mechanical processes, or through chemical recycling. Although potential applications of recycled materials are manyfold, only a small share of the recycled fibres has been effectively reused for clothing so far. In order to tackle these challenges, the EU Directive 2018/85 requires Member States to introduce a scheme for separate collecting textile waste by Jan. 1, 2025. This regulation forces to speed up the introduction of new collecting, sorting and recycling technologies and facilities that currently do not necessarily exist. In light of these circumstances, the present paper proposes a model for a circular SC of the textile sector, which is the integration of circular thinking into the management of the SC and its surrounding industrial and natural ecosystems. The model will show a high-level abstraction of the Circular Textile Supply Chain (CTSC), outlining and detailing all its features. A graphical representation of this CTSC will be presented too, with the aim to deepen the awareness on textile sustainability and to offer a potential framework as a basis for innovative research studies.

Keywords: Textile waste, Circular Economy, Closed-loop supply chain, Sustainability

1. Introduction

The textile and fashion industries are often criticized for their harmful environmental impact. This is primarily due to the adherence to a linear supply chain model, marked by excessive production of virgin fibres and inefficient waste management practices (McKinsey & Company, 2022) that do not align with the waste hierarchy defined by the EU (Directorate-General for Environment, 2008). Consequently, there is a pressing need to rapidly revolutionize and establish a new circular textile supply chain (**CTSC**) capable of converting waste into value, decoupling economic growth from resource consumption. To foster this transformation towards more sustainable practices among all participants in the textile supply chain, including end-consumers, the establishment and verification of circular models are required. The latter will initially operate at a conceptual level and then delve into incorporating innovative approaches for collecting, sorting, reusing, repairing, and recycling textiles. Based on these foundations, the present paper aims to outline a circular framework to address circularity within the textile value chain, by delineating the physical flows, involved actors, and necessary solutions for implementing the transition. Moreover, the primary outcome will be a graphical representation of a CTSC model, which can serve as a tool for mapping and investigating various aspects crucial for transitioning towards sustainability. Specifically, the existing linear material flow will be depicted, with the addition of all the circular streams designed to efficiently manage pre- and post-consumer textile waste, along with downcycling flows coming from and directed to other supply chains. A circular transition, indeed, endeavours to transform waste into valuable resources via both closed-loop and open-loop return flows.

The remainder of the paper is organised as follow: **Section 2** will outline the challenges encountered within the textile supply chain, together with the strategies proposed by the EU to address them; **Section 3** will delve into the definition of varying SC models and detail our proposed model for a CTSC; lastly, **Section 4** will present the conclusion remarks.

2. The textile supply chain

The textile supply chain has a highly intricate structure, characterised by significant depth and width, in terms of its levels and the multitude of actors involved at each tier. This complexity becomes clear with regards to both forward and backward flows, encompassing physical and informational exchanges. Spanning from the sourcing of raw materials to product design, manufacturing, distribution, retail, and eventual consumption, the textile value chain also includes post-consumer and pre-consumer textile waste management.

The end consumer plays a crucial role in this system by expressing a need that must be fulfilled and by being the trigger for all stages of the supply chain. To meet the ever-expanding and variable consumer demand, historically, the textile industry has favoured linear supply chain models, driven by a relentless emphasis on cost-effectiveness. As a result, this approach caused the tendency of wearing clothing for brief periods before discarding and replacing them, which is a highly unsustainable manifestation of overproduction and overconsumption. This phenomenon, also known as "fast fashion", invites consumers to keep on buying clothes at lower price and of inferior quality, manufactured rapidly to meet the newest style (European Commission and Directorate-General for Environment, 2022a). Moreover, the growing demand for textiles is fuelling the inefficient use of non-renewable raw materials, including the production of synthetic fibres from fossil-fuels (e.g. polyester) (Textile Exchange, 2023). Finally, disposal of textile products through landfill or incineration at the end of their lifecycle, represents another critical issue that need to be addressed in a linear textile supply chain (**LTSC**).

Given these adverse factors, it is evident that there's a pressing need for enhanced resource awareness, the decoupling of growth from resource consumption, and the implementation of a more effective and circular system for managing textile waste. The consideration of cost as the sole determinant in material and method selection is inadequate in today's competitive marketplace, where competition expands beyond individual companies to encompass entire supply networks (Kale, 2016), characterised by interconnected collaborators striving to satisfy, attract, and retain end customers. In this context, sustainability should not merely be viewed as an obligation for environmental protection, but rather as a basis to leverage in the supply chain management and marketing competition, acknowledging its significance across three core pillars: economic viability, environmental conservation, and social equity (Elkington, 2018).

Focusing on **environmental sustainability in the textile supply chain**, two key areas have been addressed in the paper: (i) the initial sourcing and synthesis of raw materials, and (ii) the management of textile waste.

According to the last *Textile Exchange Material Market Report* (Textile Exchange, 2023), from a global standpoint, fibre production has nearly doubled over the past two decades, increasing from 58 million tons in 2000 to a record high of 116 million tons in 2022. Projections suggest this figure could rise to 147 million tons by 2030 if current practices persist. This surge in textile demand is driving the inefficient utilization of non-renewable resources, particularly the production of synthetic fibres derived from fossil fuels, which accounted for 65% of the market in 2022. Despite this growth, recycled fibres comprised only 7.9% of the 2022 market share, with recycled polyester from PET plastic bottles making up 7.3%, and less than 1% originating from pre- and post-consumer recycled textiles. This statistic underscores the inadequacy of the LTSC in establishing efficient circular return flows capable of closing the loop within the textile supply chain.

The reason behind the failure to transform waste into valuable raw materials that can be reintegrated into the supply chain must be investigated into the management of textile products at the end of their lifecycle. Specifically, the lack of separate collection of textile waste may be ascribed as one of the main reasons for failing to recover potentially valuable resources from it. Indeed, the EU generates 12.6 million tons of textile waste annually as of 2019, with 10.9 million tons being post-consumer waste and 1.7 million tons being pre-consumer waste. Currently, approximately 78% (8.5 million tons/year) of post-consumer textile waste, including clothing, footwear, home textiles, and technical textiles, is not separately collected and ends up in mixed household waste destined for incineration or landfill (Huygens *et al.*, 2023). The resulting inefficient waste management system contradicts the waste hierarchy and poses environmental risks both within the EU and in third countries. In response to this issue, however, the EU has implemented mandatory separate collection of textile waste starting from 2025 (European Parliament and Council of the European Union, 2018). Nonetheless, this action alone will result in a significant volume of segregated waste across Europe without the necessary infrastructure and technologies to effectively manage it (European Commission and Directorate-General for Environment, 2023). Consequently, there is a need to concurrently establish a system capable of handling this increased waste volume, by developing and scaling up new sorting and recycling technologies and facilities.

Figure 1: Waste hierarchy as defined in WFD (European Parliament and Council of the European Union, 2018)**.**

2.1 The EU strategy for textiles

On average, within the EU, **textile consumption** ranks fourth in terms of its environmental and climate change impact, following food, housing, and mobility. It also stands as the third largest sector in terms of water and land usage, and the fifth highest in primary raw material consumption and greenhouse gas (GHG) emissions (Directorate-General for Environment, 2022). With the purpose of addressing these criticalities and advancing sustainability in the textile industry, the EU has developed **the Strategy for Sustainable and Circular Textiles** (European Commission and Directorate-General for Environment, 2022a). Two key elements of the strategy are (i) the definition of ecodesign requirements for products and the development of the Digital Product Passport (DPP), and (ii) the implementation of Extended Producer Responsibility (EPR) schemes to strengthen and expand the textile waste management system. Especially:

(i) The **Ecodesign for Sustainable Products Regulation (ESPR)** (European Commission and Directorate-General for Environment, 2022b), on which the EU Council and the EU Parliament have reached a provisional political agreement on the proposal (*Commission welcomes provisional agreement for more sustainable, repairable and circular products*, 2023), will substitute the Ecodesign Directive 2009/125/EC (European Parliament and Council of the European Union, 2009). The regulation will provide performance and information requirements for textile products. Performance requirements for textiles will make them last longer, more suitable for reuse, easier to repair and recycle, and will define a minimum recycled share in products composition. At present, in Europe most of the textile waste targeted for recycling is downcycled for cleaning wipes and non-woven materials, such as insulation for the construction or automotive sectors (Huygens *et al.*, 2023). While sorting and advanced recycling technologies need to be further developed and scaled-up, improving product design remains a key factor to address technical challenges. Indeed, besides improving quality and durability, the main objective of the regulation is the designing of products which will have the best possible features to be effectively managed in their end-of-life phase, especially through recycling. Moreover, information requirements are also needed to improve products environmental sustainability and should be related to product parameters relevant to the product aspect (e.g., product's environmental footprint and durability). The ESPR will require manufacturers to provide information regarding the product's performance concerning specific parameters or relevant data that could impact how the latter is managed throughout the supply chain. Information requirements are essential to drive on the behavioural shifts necessary for ensuring the accomplishment of the environmental sustainability goals outlined in the ESPR. Furthermore, they are expected to drive consumers towards more sustainable choices by providing them, but also public authorities, with a solid basis for comparing products' environmental sustainability. Additionally, in terms of communication, the ESPR will enhance traceability and transparency throughout the supply chain network. This will be achieved notably through the implementation of the DPP, a tool designed to facilitate clearer and more accessible information exchange regarding the product life cycle.

(ii) Mandatory and harmonised **EPR** schemes for textiles, proposed in 2023, by the EU Commission (as part of a targeted amendment of the Waste Framework Directive – WFD 2008/98/EC) (European Commission and Directorate-General for Environment, 2023), will impose accountability on producers for managing the products end-of-life that they introduce to the market in all EU Member States. Producers will cover the management costs of their textile wastes, which will prompt them to reduce waste and to increase the circularity of their products by designing them better. The expenses producers will contribute to the EPR scheme will be modified according to the environmental performance of textiles, following a principle known as "eco-modulation" (Refashion, 2024). These contributions will provide the necessary funding and organisational framework for the textile waste management in all EU Member States. Specifically, the **separate collection of all discarded textile** products, diverting them from mixed municipal waste and thereby meeting the mandatory separate collection rule under the current EU WFD; **the infrastructures** for sorting, preparing for reuse, reuse, and recycling, needed to manage the upcoming increase of textile waste separately collected; the **Investments in R&D to bridge innovation gaps**, such as the scarcity of material detection techniques, automated sorting systems, and solutions for blends and components that are presently non-recyclable. The EPR seeks to guarantee that used textiles are sorted for reuse, prioritizing recycling for those that cannot be reused. Diverting textiles from incineration or landfill, extending the products life cycle, or recycling them when reuse is no longer feasible, represent significant steps to reduce negative environmental impacts linked to pollution and GHG emissions. Moreover, social enterprises engaged in textile collection and treatment will experience increased business prospects and a broader market for second-hand textiles.

In conclusion, ESPR and EPR must be closely interlinked and developed simultaneously. The EU Commission's proposal for a Regulation on Ecodesign for Sustainable Products presents a noteworthy chance to enhance the sustainability performance of products and their informational requirements. Simultaneously, the revision of the Waste Framework Directive, incorporating EPR schemes, addresses the expansion of the textile waste management system for processing these products upon disposal. This approach also includes financial incentives to encourage the design and production of more sustainable products (Ellen MacArthur Foundation and Valérie Boiten, 2022).

3. A model for Circular Textile Supply Chain

Textile waste is generally characterized as any unwanted or discarded fabric or garment that is no longer suitable for its initial use. It can be categorized into three main groups based on their origins: pre-consumer waste, post-consumer waste, and post-industrial waste (Tang, 2023). **Pre-consumer textile waste** is the waste produced during the creation, manufacturing, or treatment of textiles, typically consisting of fabric remnants, yarns, rejected or unsold flawed items. **Post-consumer textile waste** is the waste generated when textile goods have been utilised and are discarded either before or at their lifespan's end. This type of waste includes items like clothing, bedding, or curtains that are disposed of by households or business (Stanescu, 2021). Lastly, **post-industrial textile waste** is the waste produced by other sectors that utilise textiles in their processes or products, such as discarded medical textiles, automotive textiles, or packaging textiles (Tomovska *et al.*, 2017). In this article we will consider only the first two types of waste, since our focus is on textile SC.

Adopting an effective waste management system that aligns with the waste hierarchy depicted in Fig.1, represents a first step towards a circular business model, which embodies the principle of the Circular Economy (CE) of creating value by leveraging the worth retained in used products to generate new offerings. In fact, the focus of circularity is on resources, not outputs. Depending on their physical properties, available technologies, and consumer demand for these transformations, resources can be recovered, recycled or reused. Still, the initial step in any circular model is to reduce resource consumption because its primary objective remains to preserve natural resources and prevent waste generation (Dragomir and Dumitru, 2022).

Consequently, the transition from a LTSC to a supply chain model that integrates the concepts of Circular SC (CSC) represents a way of reducing waste, and/or turning it into valuable materials. In most cases, a linear SC draws resources from the geosphere and biosphere and discards end-of life products, packaging material, and waste from various stages of the SC. A Closed-loop SC (CLSC) instead enhances environmental sustainability by returning goods and packaging materials to the manufacturer for value recovery (Guide and Van Wassenhove, 2006); however, it still produces wastes since it is often not possible to reuse or recycle SC by-products within the same SC that generated them. While a linear SC unavoidably implies waste generation and CLSC represents an excessively restricted model in terms of waste valorisation, a CSC can create higher value through collaboration with other organizations within the same industrial sector (open-loop, same sector) or across different industrial sectors (open-loop, cross sector) (Weetman, 2020). Additionally, as stated by (Farooque *et al.*, 2019), the concept of waste reduction towards a hypothetical "zero-waste" paradigm, is an integral part of their definition of CSC management as *"the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials towards a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users."*

The remaining of the section introduces graphical representations of a LTSC (Fig. 2) and our proposed CTSC model (Appendix A). Moreover, the main processes of the CTSC related with the management of post-consumer textile waste will be described in dedicated subsections.

Considering LTSC in Fig. 2, pre-consumer and post-consumer textile waste reach both the end of the SC to be disposed of primarily in landfill or through incineration to recover energy. We decided to add also the recycling and reusing options (depicted in green), even if the proportion of textile waste subjected to those processes is minimal within the framework of the linear model (Ellen MacArthur Foundation, 2017). On the contrary, in Appendix A is represented our proposed model for a CTSC (colour coded as in Table 1).

Table 1: Colour coding scheme for CTSC model in Appendix A.

Palette	Colour name	Description
	Black	LTSC
	Grey	Waste disposal
	Apple Green	Pre-consumer waste return flows
	Bottle Green	Post-consumer waste return flows
	Teal	Repair performed by the end-consumer
	Blue	Open-loop flows

Black is used to represent the linear textile supply chain that goes from raw materials to end-of life products reaching mixed-collection, but also the waste flows converging towards the disposal into landfills or energy recovery (in grey). The green shades show the material flows of pre-consumer wastes (apple green) and the post-consumer wastes (bottle green), specifically these flows allow to close the SC loop as displayed by the arrows that, through a sequence of processes, re-enter into the original SC. Teal is used to show the repair process performed by the end-consumer. Finally, the blue coloured parts refer to the connection between the original SC and other externals SCs thus opening the loop to enable a full CSC.

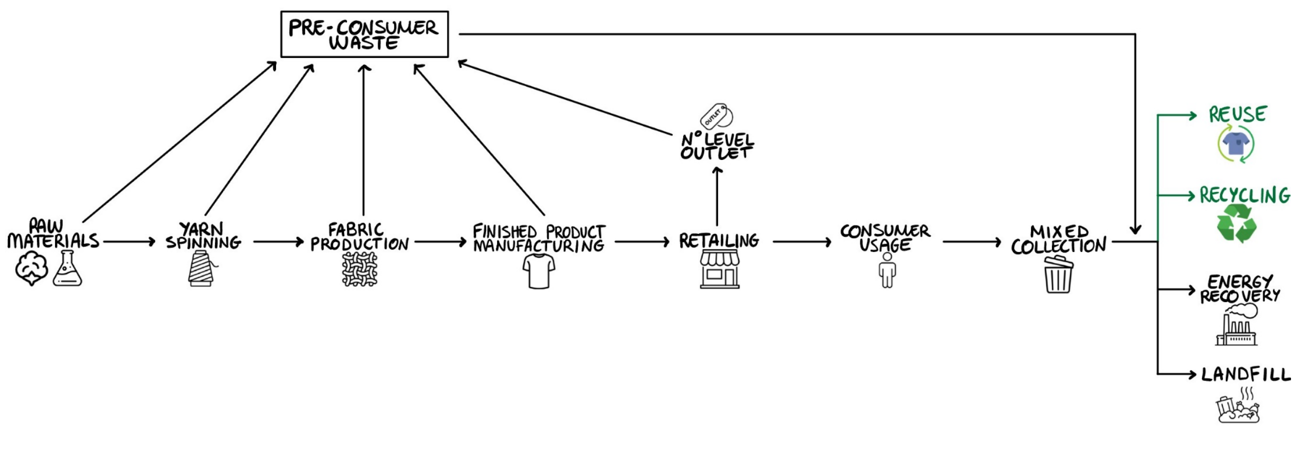

Figure 2: Linear Textile Supply Chain Model.

3.1 Repair

The act of repair, which comprehends the disassembly and parts' substitution, aims to extend the lifespan of products. This extension delays the need for replacement, thereby decreasing waste and resource consumption associated with it. As such, repair is a significant strategy for sustainable consumption and plays a key role within a CE (Svensson-Hoglund, Russell and Richter, 2023). This practice can be carried out by both the end consumers and retailers (as an additional service, e.g. Patagonia "Worn Wear" program (*Trade In Patagonia Clothing & Gear | Worn Wear – Patagonia Worn Wear*, no date)). Still, today a large part of the population is not fully informed about repairing opportunities. As an example, a recent study on the textile industry in the United States found that almost 70% of the consumers surveyed choose to buy a new garment instead of repairing it (Diddi and Yan, 2019). These untapped repair opportunities result in a negative environmental impact.

3.2 Separate Collection

In this stage recyclable and reusable materials are divided from the residual or mixed waste and thus gives opportunities to make more value out of valuable resources that would be otherwise incinerated and landfilled. Typically, the main collection strategies for textiles consist of pick-up and drop-off schemes (Huygens *et al.*, 2023):

(i) Pick-up schemes include door-to-door and kerbside collection;

(ii) Drop-off schemes (or bring banks/points) include underground and road containers placed on public areas, where households or enterprises can bring waste. Collection centres also accept a wider range of waste streams, including bulky waste. Retailers can set up take back formats too, where citizens can dispose their used textiles.

Finally, in the EU different actors play a varying role in the collection of post-consumer textile waste, such as municipalities, charities, social enterprises, second-hand shops and retail companies.

3.3 Sorting

The sorting of post-consumer textile waste is crucial for successful recycling, determining the quality and quantity of recycled fibres and products. Currently, sorting can be done in two ways: manual sorting or automated sorting (Köhler *et al.*, 2021). However, this process is challenging due to the variety of fabrics, colours, patterns, and contaminants in the waste streams (Tang, 2023). After separate collection two sorting phases should take place: (i) the first one is commonly defined as sorting for reuse, where the aim is to distinguish between the fraction with the appropriate quality for reuse, the portion with inadequate quality but suitable for recycling, and the remaining part which will be incinerated or landfilled; (ii) the second one tackles only the textiles share proper for recycling and implies materials identification for addressing the appropriate recycling technique.

3.4 Recycling

There are different ways to recycle textile waste, among them the main are mechanical, chemical and thermal recycling (Duhoux *et al.*, 2021). The process of **mechanical recycling** transforms these wastes into fibres, which can be used for the same or different purposes as the original fabrics. These fibres have found applications in the construction of buildings and materials for slope protection. **Chemical recycling** involves the use of chemicals to break down waste textiles into monomers, which can then be used to create new textiles or other materials. Lastly, **thermal recycling** is a method based on heating with the aim to recover either polymers or low molecular weight building blocks.

4. Conclusion remarks

The imperative transition from a linear to a circular supply chain in the textile industry is underscored by the pressing environmental concerns and the need to comply with upcoming EU regulations. This transition is significantly influenced by the advancements in textile recovery and recycling technologies, which are pivotal for effective waste management and the development of circularity within the textile supply chain. The role of EU directives is strategic in this context, as they accelerate the adoption of new technologies and facilities for textile waste collection, sorting, and recycling.

The proposed CTSC model provides a comprehensive framework for addressing circularity within the textile value chain, by delineating the physical flows, involved actors, and necessary technical solutions. Its graphical representation serves as a useful tool for mapping and investigating the key aspects for transitioning towards environmental sustainability.

However, given that this work mostly adheres to EU guidelines and presents a high-level abstraction of a supply chain model, we believe it is necessary for future developments to prioritize a further examination of scientific literature with the aim of exploring the technological solutions currently available and those in development concerning the aspects illustrated in the model.

Acknowledgements

This research was funded by the European Union and the Italian Ministry of University and Research through the project SusTex: Sustainable Textile, Id 2022X2788M, Grant number D53D23011410006.

Furthermore, the Ph.D. position of one of the authors is funded by the European Union - NextGeneration EU, under the Italian National Recovery and Resilience Plan (NRRP), Mission 4 Component 1, project code D92J23000190006.

References

Commission welcomes provisional agreement for more sustainable, repairable and circular products (2023). Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6257 (Accessed: 19 February 2024).

Diddi, S. and Yan, R.N. (2019) 'Consumer Perceptions Related to Clothing Repair and Community Mending Events: A Circular Economy Perspective', Sustainability 2019, Vol. 11, Page 5306, 11(19), p. 5306. Available at: https://doi.org/10.3390/SU11195306.

Directorate-General for Environment (2022) EU strategy for sustainable and circular textiles. Available at: https://environment.ec.europa.eu/strategy/textiles-strategy_it (Accessed: 20 November 2023).

Directorate-General for Environment (2008) Waste Framework Directive - European Commission. Available at: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en (Accessed: 19 February 2024).

Dragomir, V.D. and Dumitru, M. (2022) 'Practical solutions for circular business models in the fashion industry', Cleaner Logistics and Supply Chain, 4, p. 100040. Available at: https://doi.org/10.1016/J.CLSCN.2022.100040.

Duhoux, T. et al. (2021) 'Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling – Final report'. Available at: https://doi.org/doi/10.2873/828412.

Elkington, J. (2018) 25 Years Ago I Coined the Phrase "Triple Bottom Line." Here's Why It's Time to Rethink It. Available at: https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it (Accessed: 17 April 2024).

Ellen MacArthur Foundation (2017) A New Textiles Economy: Redesigning Fashion's Future. Available at: https://www.ellenmacarthurfoundation.org/a-new-textiles-economy (Accessed: 29 April 2024).

Ellen MacArthur Foundation and Valérie Boiten (2022) Building a circular economy for textiles supported by common rules on Extended Producer Responsibility (EPR) in the EU. Available at: https://www.ellenmacarthurfoundation.org/extended-producer-responsibility-for-textiles (Accessed: 22 November 2023).

European Commission and Directorate-General for Environment (2022a) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EU Strategy for Sustainable and Circular Textiles, EUR-Lex - 52022DC0141 . Brussels. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0141 (Accessed: 20 November 2023).

European Commission and Directorate-General for Environment (2022b) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC, EUR-Lex - 52022PC0142 . Brussels. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:0142:FIN (Accessed: 4 December 2023).

European Commission and Directorate-General for Environment (2023) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2008/98/EC on waste. Brussels. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0420&qid=1707729490112 (Accessed: 28 April 2024).

European Parliament and Council of the European Union (2009) Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. Brussels. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0125 (Accessed: 19 February 2024).

European Parliament and Council of the European Union (2018) Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste. European Parliament, Council of the European Union. Available at: http://data.europa.eu/eli/dir/2018/851/oj (Accessed: 28 April 2024).

Farooque, M. et al. (2019) 'Circular supply chain management: A definition and structured literature review', Journal of Cleaner Production, 228, pp. 882–900. Available at: https://doi.org/10.1016/J.JCLEPRO.2019.04.303.

Guide, V.D.R. and Van Wassenhove, L.N. (2006) 'Closed-Loop Supply Chains: An Introduction to the Feature Issue (Part 1)', https://doi.org/10.1111/j.1937-5956.2006.tb00249.x, 15(3), pp. 345–350. Available at: https://doi.org/10.1111/J.1937-5956.2006.TB00249.X.

Huygens, D. et al. (2023) Techno-scientific assessment of the management options for used and waste textiles in the European Union. Luxembourg: Publications Office of the European Union. Available at: https://doi.org/10.2760/6292.

Kale, V. (2016) Enhancing enterprise intelligence : leveraging ERP, CRM, SCM, PLM, BPM, and BI. CRC Press. Available at: https://www.barnesandnoble.com/w/enhancing-enterprise-intelligence-vivekkale/1128424824?ean=9781498788199 (Accessed: 13 April 2024).

Köhler, A. et al. (2021) 'Circular economy perspectives in the EU textile sector', EUR 30734 EN, Publications Office of the European Union, (June), p. 143. Available at: https://doi.org/10.2760/858144.

McKinsey & Company (2022) Scaling textile recycling in Europe - turning waste into value. Available at: https://www.mckinsey.com/industries/retail/our-insights/scaling-textile-recycling-in-europe-turning-waste-into-value (Accessed: 5 December 2023).

Refashion (2024) What are Eco-modulations? Available at: https://refashion.fr/pro/en/eco-modulations (Accessed: 29 April 2024).

Stanescu, M.D. (2021) 'State of the art of post-consumer textile waste upcycling to reach the zero waste milestone', Environmental Science and Pollution Research 2021 28:12, 28(12), pp. 14253–14270. Available at: https://doi.org/10.1007/S11356-021-12416-9.

Svensson-Hoglund, S., Russell, J.D. and Richter, J.L. (2023) 'A Process Approach to Product Repair from the Perspective of the Individual', Circular Economy and Sustainability, 3(3), pp. 1327–1359. Available at: https://doi.org/10.1007/S43615-022-00226-1/FIGURES/10.

Tang, K.H.D. (2023) 'State of the Art in Textile Waste Management: A Review', Textiles 2023, Vol. 3, Pages 454-467, 3(4), pp. 454–467. Available at: https://doi.org/10.3390/TEXTILES3040027.

Textile Exchange (2023) Materials Market Report 2023. Available at: https://textileexchange.org/knowledge-center/reports/materials-market-report-2023/ (Accessed: 8 February 2024).

Tomovska, E. et al. (2017) 'Attitudes towards managing post-industrial apparel cuttings waste', The Journal of The Textile Institute, 108(2), pp. 172–177. Available at: https://doi.org/10.1080/00405000.2016.1160764.

Trade In Patagonia Clothing & Gear | Worn Wear – Patagonia Worn Wear (no date). Available at: https://wornwear.patagonia.com/pages/trade-it-in?_gl=1%2A13temn5%2A_ga%2AODQwMDU1OTY0LjE3MDgzNTA1NzU.%2A_ga_1SYPSJZYJ5%2AMTcwODM1MDU3NS4xLjEuMTcwODM1MDYyNy4wLjAuMA.. (Accessed: 19 February 2024).

Weetman, C. (2020) A circular economy handbook : how to build a more resilient, competitive and sustainable business. 2nd ed. Kogan Page.

Appendix A. PROPOSED CIRCULAR TEXTILE SUPPLY CHAIN MODEL (CTSC)