Life cycle perspective in the textile supply chain: Analysis of Improvement PracticesAnalysis of Improvement Practices

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Abstract

Textile manufacturing is characterized by consumption models based on low-cost fast fashion, rather than on a durable good idea. For this reason, it has become one of the sectors with the highest environmental impacts. The aim of this study is to reveal environmental impacts along the textile supply chain, based on a life cycle perspective to improve resources and waste management.

This study presents a systematic literature review, performed through ISI Web of Knowledge database, with the keywords: ("supply chain" OR "supply chains") AND (lca OR "life cycle assessment" OR "carbon footprint" OR “life cycle”) AND (circular* OR clos* OR loop* OR recycle* OR recover*) AND (textile* OR apparel OR cloth* OR garment OR fashion) and leading to 57 articles. The articles were selected to include only those with a circular supply chain vision. At the end of this step, 30 articles were obtained, which were further analyzed.

The research focused on the identification of the phases with a more impact, between production, distribution, use and end of life, and on possible reduction solutions in terms of circularity.

From the results, the diversity and complexities of the entire system emerge and most of the impacts are relative to production and raw materials, followed by transport and final disposal.

Further studies are necessary to improve data collection along the supply chains in order to apply strategies aimed at reducing environmental impacts. Furthermore, a change is necessary, both in consumption habits and in a complete vision of the practices along the supply chain.

Keywords: textile, supply chain, life cycle perspective, circular

Relevant Topic: **“**Sustainable Supply Chain Management, green supply chain and quality”

Introduction

In recent decades, the textile industry has undergone a rapid transformation, particularly in the apparel sector, from quality production that lasts over time, towards large-scale collections, produced with high frequency. This new trend has developed due to the increase in supply and to the diversification of global distribution chains and online sales markets. Nowadays, besides the luxury sector, which is aimed at a specific customer and characterised by the use of sustainable materials and practises, a new approach has arisen based on the rapid turnover of garments and textiles, known as "fast fashion" (Leal Filho et al., 2024). This term includes clothing, footwear and household textiles, and is characterised by a highly industrialised model of mass production and consumption. These items are often imported and made from cheap low-cost fabrics and labour coming from poorly regulated countries (Brydges, 2021).

The textile industry has expanded globally, in search of cheap resources and market opportunities, especially off-shore in the Far East. China, India, and the USA are significant players, China being the largest producer of textile products, and accounting for 36.3% of global textile and apparel exports (Zhang et al., 2022; Sarokin and Bocken, 2024). The growing demand and new applications in clothing have led to a substantial increase in the annual global textile fibre production. Every year the textile industry supplies more than 100 million tons of products to the market and is projected to reach 146 million tons (17.1 kg) per capita by 2030 (Jail et al., 2023; Leal Filho et al., 2024). Projections indicate that by 2030, the global textile market will be worth an estimated 3 trillion US dollars in retail sales, with an expected annual growth rate of 5.8% (Leal Filho et al., 2024).

The fashion industry is emerging as one of the most criticised industries, raising the environmental burden, and the question regarding the longevity of an item of clothing generates one of the major concerns related to sustainability (de Albuquerque Landi et al., 2023). The production chain, in fact, follows a linear model made up of three main operations, namely the collection of raw materials, the production process, and waste management, which, if compared to other supply chains, is still linked to a low circularity. Consequently, this approach causes important impacts related to the excessive production and disposal of tons of textile wastes, which are difficult to recycle due to their composition and the manufacturing process applied during production. For example, a polyester cotton textile product, made with bio-based cotton and fossil fuel-based PET plastic material, due to ill-fated design, results in the creation of a mixed product which cannot be easily recycled (Islam, et al., 2022).

The fibres can be natural, from plant- or animal-based origin, or synthetic. Plant-based natural fibres are generally extracted after a retting or decortication process in order to remove undesired cell components (Li et al., 2021). Cotton represents the most consumed natural fibre in the textile and clothing industry. Regarding animal-based natural fibres, the most popular worldwide are silk and wool. In the field of manmade fibres, it is possible to distinguish between organic and inorganic ones. Organic fabrics are made from natural materials (e.g. wood, regenerated fibres), whereas inorganic ones are made from synthetic polymers (Amicarelli et al., 2022). Each type is responsible for specific environmental impacts, in terms of energy and water consumption, as well as chemicals used during manufacturing, especially during the dyeing process (Ding et al., 2019; Zhang

et al., 2022). On one hand, the plant-based fibres consume natural resources during growth, harvesting and processing of the plant, while on the other, synthetic fibres are a source of concern due to health risks from chemical use, petroleum consumption and waste management (Zhao et al., 2021; Amicarelli et al., 2022).
To counteract these aspects, product and process innovations have emerged to develop more sustainable manufacturing practices, such as eco-design innovation, circularity, cradle-to-cradle design, closed-loop fashion, through regenerative and shared approaches (Islam, et al., 2022).
Implementation of sustainable practices is a means of strategic advantage to gain competitive benefits and address resource scarcity, consequently supporting the sustainable development of the clothing industry. Due to the fact that consumers are highly influenced by new fashion trends, the clothing industry should place a central focus on consumer perception (Islam, et al., 2021).
The purpose of the present research is to investigate the environmental concerns associated with the textile supply chain with a life cycle perspective, revealing the improvement practices over textile products life cycle.

Methods

The intent of this research was to give an answer to the following research questions (RQ):

RQ1: How is the life cycle perspective incorporated in the textile supply chain in case of circular loops?

RQ2: What are the improvement practices associated with the textile supply chain arising from a life cycle perspective from a circularity perspective?

To give an answer to these questions, a systematic literature review was conducted according to Snyder (2019). This research was developed according to the steps proposed by Durach et al. (2017), identifying the required features of primary studies, the baseline sample, the synthesis sample and finally performing the literature synthesis.

Required features of primary studies

This literature review started by analyzing studies where the main life cycle methodologies were applied or discussed, namely the Life Cycle Assessment (LCA) and the Carbon footprint (CF) methodologies (Hellweg and Milà i Canals, 2014; Notarnicola et al., 2012). Thus, in line with our RQs, only studies related to LCA or CF application or discussion for textile products in case of circular loops were included in this research, considering only articles published in journals, written in English and obtained through the selected keywords.

Baseline sample

A research by keywords was performed in ISI Web of Knowledge database in April 2024. The keywords were selected and combined to collect articles dealing with the focus of this study. The final combination of keywords was ("supply chain" OR "supply chains") AND (lca OR "life cycle assessment" OR "carbon

footprint" OR “life cycle”) AND (circular* OR clos* OR loop* OR recycle* OR recover*) AND (textile* OR apparel OR cloth* OR garment OR fashion). At the end of this step, 57 articles were obtained.

Synthesis sample

The articles obtained from the previous step were further selected, focusing on those dealing with textiles and textile products and with a life cycle perspective application or discussion with reference to possible circular loops. At the end of this step, 31 articles were obtained. Then, based on a relevance analysis, 30 articles were finally selected to proceed with the next step.

Literature synthesis

A descriptive analysis of the articles included in the synthesis sample was performed, to underline the main features, such as year of publication, journal, and life cycle perspective applied or discussed. To perform a content analysis, the selected articles were analyzed separately to identify the circular practices associated with the textile supply chain arising from a life cycle perspective and thus giving an answer to RQ1. Successively, they were crossed to identify how the life cycle perspective is applied or discussed in case of circular loops along the supply chain of textiles and textile products, addressing RQ2.

Results and Discussion

In this section, the descriptive analysis of the articles included in this research and the results obtained through the content analysis are presented.

Descriptive analysis

Among the 30 articles included in this research, it was obtained that the first one was published in 2012 and most articles were published more recently, especially from 2020 (Figure 1).

The Journal of Cleaner Production is the journal presenting the greater number of articles, namely 9 out of 30, followed by Sustainable Production and Consumption with 4 articles, and by Environment, Development and Sustainability with 2 articles. Overall, the articles selected are published in 18 different journals, ranging from journals focusing on recycling and waste management to journals specific for the textile sector, as can be seen in Table 1.

Figure 1*. Year of publication of the articles included in this research*

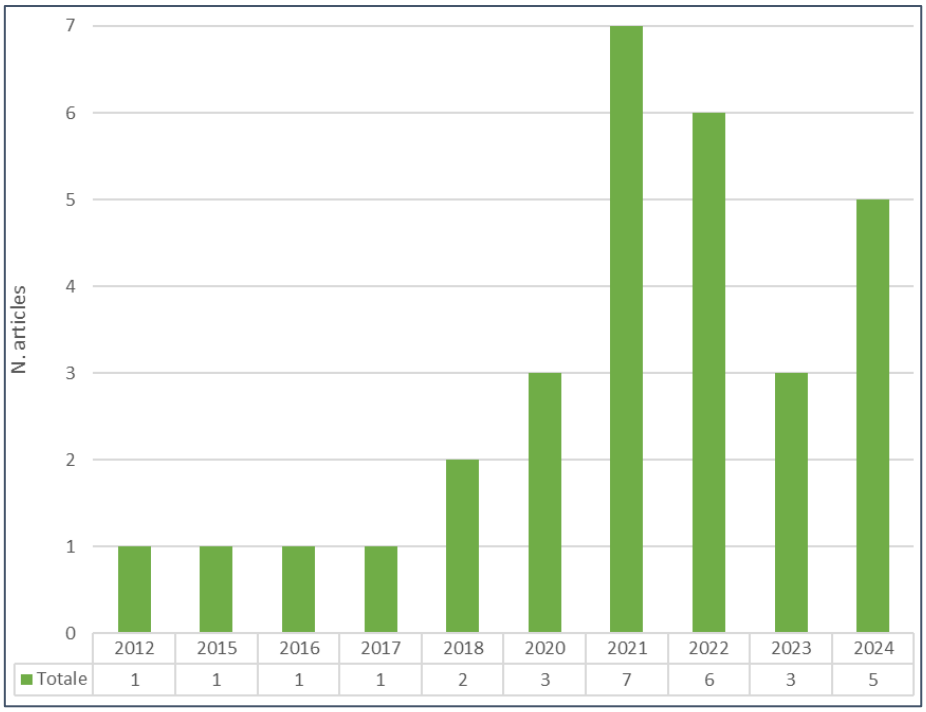


Table 1. *Articles included in this research*

Authors	Year	Journal
Amicarelli et al.	2022	Waste Management
Avadi et al.	2020	Int J Life Cycle Assess
Bonilla et al.	2015	Supply Chain Management: An International Journal
Brydges	2021	Journal of Cleaner Production
Chen et al.	2024	Journal of Cleaner Production
Frota de Albuquerque Land et al.	2023	The International Journal of Life Cycle Assessment
Fung et al.	2020	Production Planning & Control
Giungato et al.	2024	British Food Journal
Glew et al.	2012	Journal of Cleaner Production
Hossain et al.	2024	Environment, Development and Sustainability
Howard et al.	2022	Resources, Conservation & Recycling
Islam et al.	2021	Journal of Fashion Marketing and Management: An International Journal
Islam et al.	2022	Recycling
Jain et al.	2023	Management of Environmental Quality: An International Journal
Jia et al.	2020	Journal of Cleaner Production
Leal Filho et al.	2024	Textile Research Journal
Li and Ma	2018	Sustainable Production and Consumption

Martin and Herlaar	2021	Sustainable Production and Consumption
Moazzem et al.	2021	Sustainable Production and Consumption
Moazzem et al.	2022	Environment, Development and Sustainability
Munasinghe et al.,	2016	Sustainable Production and Consumption
Paras and Pal	2018	Int J Adv Manuf Technol
Patwary et al.	2023	Sustainability
Rehman et al.	2024	Journal of Cleaner Production
Rossi et al.	2021	International Journal of Sustainable Engineering
Sarokin and Bocken	2021	Journal of Cleaner Production
Testa et al.	2017	Journal of Cleaner Production
Vanacker et al.	2022	Journal of Cleaner Production
Zhang et al.	2022	Water Research
Zhao et al.	2021	Journal of Cleaner Production

Content analysis

The content analysis is performed to highlight how the life cycle perspective is incorporated in the textile supply chain in case of circular loops, thus giving an answer to RQ1 (section 3.2.1) and the improvement practices associated with the textile supply chain arising from a life cycle perspective from a circularity perspective, thus giving an answer to RQ2 (section 3.2.2).

The life cycle perspective in the textile supply chain

The life cycle perspective is applied in the textile supply chain in different ways, ranging from the application of LCA methodology to the employment of life cycle thinking as a base to develop qualitative and quantitative analyses (Table 2).

Overall, LCA and CF are the main methodologies applied, in some cases employed in combination with other methodologies, such as energy footprint, water footprint, social life cycle assessment, value mapping and waste flow mapping. Avadì et al. (2020) performed an LCA of organic and conventional cotton products from Mali including the processing of seed cotton in ginning plants to produce cotton fibre bales (cradle to processing plant gate), revealing that the impact is due to the industrial inputs in the agricultural phase. Based on a single score contribution analysis, they obtained that for conventional cotton, pesticide applications are the main cause of impact, followed by mineral fertilisers. For organic cotton, they obtained that the main contributor are pesticides due to the organophosphorus compounds, and organic fertilisation. Moreover, the ginning phase represent less than 3% of the total impacts. In their study, They obtained that considering hectars of cultivation

conventional cotton is more impacting that organic cotton, but opposite results are obtained per ton of seed cotton due to the yield. Glew et al. (2012) which estimated the influence of the end of life scenarios on the environmental impact of product supply chains comparing biomaterial and petrochemical products. They obtained that biomaterial products emit marginally less greenhouse gasses (GHG) than petrochemical products (from cradle to gate). However, when the end of life is included in the estimations, biomaterial products present lower impact that the petrochemical ones, demonstrating that refurbishing, reusing of some components and waste recycling can reduce carbon emissions, compared to landfill disposal. Jain et al. (2023) quantified the impacts of textile and yard industry on the supply chain showing that raw cotton and electricity consumption are two main contributors to the environmental impact. LCA was also applied to calculate the impact of t-shirts and polyester jackets highlighting that for the t-shirts the great contribution is due to consumer usage, mainly due to energy consumption during apparel care, whereas for polyester jackets the greater contributor is the production and revealing the recycled polyester, recycled cotton and organic cotton can reduce the impact of all categories (Moazzem et al., 2021). The life cycle perspective is incorporated applying the LCA methodology also by other scholars, e.g. for leather shoe supply chain showing that the main contributors are the slaughtering and tanning processes (Rossi et al., 2021) and for improving recycled wool through an action research (Testa et al., 2017). Zhang et al. (2022) used LCA to quantify the impacts of nonaqueous solvent dyeing, which helps reducing the water consumption but could affect the water quality due to organic solvents losses.

Multi-methodological approaches, combining LCA with other tools, were used e.g. to explore the adoption of circularity along the supply chain through value mapping and highlighting the importance of the design phase and on the selection of the suppliers (Howard et al., 2022) or to map the waste streams based on life cycle management, showing that the environmental impacts across product life cycles can be reduced if there are improvement in resource efficiency, an increase in product's life extensions, and of materials which can be originated from recycled sources (Rehman et al., 2024). Beyond these, Martin and Herlaar (2021) evaluated the environmental and the social impacts associated with waste wool for sweater production, showing that the largest contributions are due to energy consumption during processing. Zhao et al. (2021) applied LCA and Water Footprint to analyse a denim product, showing that the denim fabric production and cotton fibre production respectively generate significant carbon emissions and water consumption.

An application of the life cycle perspective is also performed through the application of the CF methodology, which was used to estimate the emissions at sectorial level associated with offshoring, showing that the reduction of the emissions is a combination of different factors associated with production processes and transportation (Bonilla et al., 2015); at organizational level for a slow fashion brand showing that the main emissions are due to indirect activities related to raw products and materials, transportation and use phase (Frota de Albuquerque Land et al., 2023). At sectorial level, CF was also employed to give an overview of the impacts and solutions, underlining the complexities related to raw materials, production techniques, and product life cycles and that cultivation, processing, and transportation of the materials generate significant emissions (Leal Filho et al., 2024). Giungato et al. (2024) calculated the CF of protective facial masks against

SARS-CoV-2 used in the food sector, investigating the effect of materials and dry sanitisation. The authors showed that the production of textiles in PP, and their disposal were the main contributor to CF. The CF methodology was also used in combination with the energy footprint calculations to analyse the supply chain of some garments, showing that the highest impact is due to raw materials production, highlighting the importance of procurement policies (Munasinghe et al., 2016).

Beyond these methodologies, qualitative and quantitative research approaches were also applied, along with an article focusing on a descriptive analysis. Fung et al (2020) developed a case study for sustainable planning strategies in supply chain systems and Brydges (2021) based on interviews with the founders, CEOs, and/or brand sustainability managers of 19 Swedish fashion brands, mapped circular economy strategies. The authors proposed examples of circular practices including new design strategies (such as seasonless collections) and the increase of life span. A prospective study from a life cycle thinking point of view was developed by Patawary et al. (2023). Sarokin and Bocken (2021) explored pursuing profitability in slow fashion, highlighting a misapplication of circularity to circularity to drive sales growth and highlighting the need of prioritizing the reduction of consumption and production. Li and Ma (2018) used a descriptive analysis to study the certification standards related to recycled materials involving textiles based on life cycle thinking. Hossain et al. (2024) performed a quantitative analysis through questionnaires to assess the influence of employees' green behaviour and organisational green culture on environmental sustainability practices among textile small and medium enterprises, showing that cultivating green behaviour among employees within an organisation is critical. Paras and Pal (2018) studied the clothes 'reuse' in Nordic countries using the Markov chain for LCA and to develop a model to count the number of cycles or trips that a clothing product could make in a reuse-based closed loop cycle.

Several studies (7 out of 30) present a literature analysis, focusing on different topics or perspectives but revealing insights for our research. Amicarelli et al. (2022) performed a literature review to tackle the take-make-waste approach in the textile production industry through life cycle perspective, revealing that the production and use phases are the main contributors, whereas the end-of-life generally has a minor impact. They showed that distribution and consumption phases are less investigated, and pointed out that new consumption patterns, such as sharing and renting platforms, are less investigated and data are needed. Chen et al. (2024) focussed on the decarbonization practices in the textile supply chain. The life cycle perspective was employed to assign the decarbonization practices to the different stages of the textile supply chain, namely production, distribution, use, and disposal/recycling. With reference to production, the authors revealed product eco-design, supplier selection criteria, clean technology adoption, and waste management strategies; with reference to distribution, they highlighted green logistics implementation and supplier localization initiatives; for the use phase, they identified monitoring and reporting carbon emissions as well as promoting sustainable consumption initiatives. With reference to disposal, they took into account product life extension measures and reverse supply chain processes. Islam et al. (2021) mapped the practices in textiles, apparel and fashion industries considering the life cycle perspective and highlighting that individual functions are more focussed, whereas green process and technologies development with stakeholders, collaborative energy

consumption and resource optimisation, harvesting and reuse of water, bio-diversity, sustainable washing and dyeing techniques, waste reduction in packaging and embroidery are less investigated. Islam et al. (2022) revealed the recycling perspectives of circular business models highlighting the importance of efficient municipal solid waste management, the establishment of a plastic hubs, implementation of extended producer responsibility, strategic partnership, incentives, and product design. Jia et al. (2020) analyzed the circular economy applications in the textile and apparel industry throughout the product life cycle, observing the complexity of basic materials and constituents, product function and aesthetics, which combined together limits the but also determines the extent to which goods could be recycled after use. They showed that design plays a key role in allowing efficient closed loop supply chain practices, e.g., recycling. Other authors highlighted the importance of product durability considering the life cycle perspective in combination to eco-design (Vanacker et al., 2022) and confirming the importance of the production stage and use stage along the supply chain of apparels and textile products (Moazzem et al., 2022)

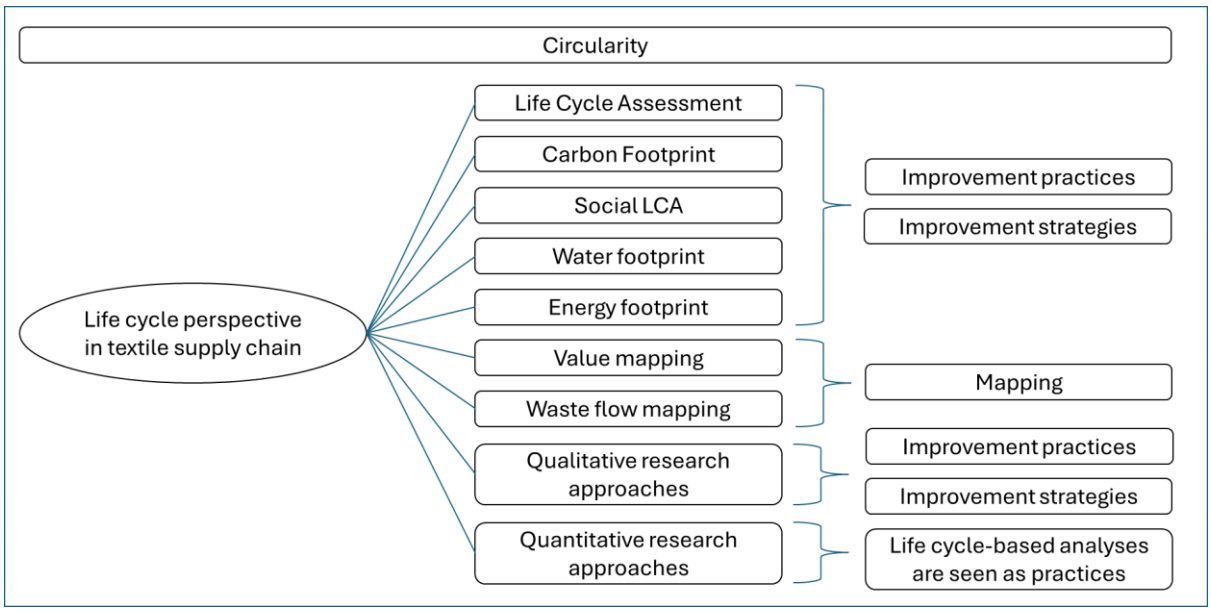
It emerged that in case of circularity loops, the life cycle perspective is incorporated in the textile supply chain through i) the main life cycle-based methodologies to reveal improvement practices and strategies, ii) through mapping approaches to map the supply chain or the waste flows; iii) qualitative research approaches based on life cycle thinking to reveal improvement practices and strategies; iv) quantitative research approaches considering life cycle analyses as an environmental practice.

An overview of how the life cycle perspective is incorporated in the textile supply chain in case of circular loops is reported in Figure 2.

Table 2. *Methodologies applied in the selected articles*

Methodology applied	N. of papers
Case study	4
CF	4
CF and energy footprint	1
Descriptive analysis	1
LCA	7
LCA and SLCA	1
LCA and WF	1
Quantitative study	2
Literature Review	7
Value mapping, LCA	1
Waste Flow Mapping (WFM) assessment and LCA	1

***Figure 2**. Overview of how the life cycle perspective is incorporated in the textile supply chain in case of circular loops*



3.2.2 Improvement practices

The improvement practices suggested in the analyzed articles and associated with the textile supply chain arising from a life cycle perspective from a circularity perspective are reported in Table 3. It emerges that the improvements are incorporated already in the design phase, including criteria regarding the recycled contents of the materials used, the recyclability of the products after use and the reuse (e.g. Sarokin and Bocken, 2021). With reference to the raw materials, it is revealed that the main improvement practices regard the cotton cultivation and in particular the reduction in the use of pesticides and water (e.g. Avadi et al., 2020). Specific changes in the manufacturing process are also proposed, regarding the yarn spinning phase and the deying systems (e.g. Moazzem et al., 2021 and Zhang et al., 2022), along with the improvement of inventory management and the waste flow mapping (Rehman et al., 2024) and waste valorization (e.g. Martin and Herlaar, 2021). Auding and monitoring of suppliers practices are also highlighted (e.g. Islam et al., 2021). With regard to distribution, improvement practices include intermodal transport and packaging improvements (e.g. Bonilla et al., 2015). Product services employment, along with cooperation among different actors along the supply chain are also revealed as improvement practices (e.g. Sarokin and Bocken, 2021).

***Table 3**. Improvement practices along the textile supply chain from a life cycle perspective in case of circularity*

Reference	Improvement practices
Avadi et al. (2020)	Focus future studies on the impacts of pesticides and of the substances end up in the soil with a more detailed modelling and the consumption of rain water
Glew et al. (2012)	Designing for reuse and recycling should be prioritised along with favouring

	biomaterials over petrochemicals
Moazzem et al. (2021)	Reducing resources used in cotton cultivation using use of organic cotton or recycled cotton fiber. Change of fibers Change of yarn spinning systems Increase of apparel lifetime, use of energy-efficient washing machine, use of front-loading washing machines, and avoiding dryer use and reducing consumer washing frequency.
Rossi et al. (2021)	Replacement of lorries by train or ship Substitution of cotton with jute Different procurement mix of leather from suppliers
Testa et al. (2017)	Collaboration among many local actors
Zhang et al. (2022)	Take into consideration nonaqueous dyeing systems but also the related loss of solvents
Rehman et al. (2024)	Improving inventory management Mapping of waste flow
Howard et al. (2022)	Using of recycled materials Aftercare repair service Long-term relationships and auditing with suppliers Behaviour change and knowledge sharing
Martin and Herlaar (2021)	Valorising waste wool Selecting electricity mix for processing and manufacturing
Zhao et al. (2021)	Change the traditional irrigation regime in cotton production Increasing water productivity Sharing successful experiences Change of consumption patterns
Bonilla et al. (2015)	Intermodal transport, transport consolidation and recycling
Frota de Albuquerque Land et al. (2023)	Use of recycled wool Reduction of washing frequency Change of packaging materials
Giungato et al. (2024)	Improve sanitary sterility of the reused products
Leal Filho et al. (2024)	Extending the life cycle of textiles through reuse, recycling Eco-design
Munasinghe et al. (2016)	Consider washing behaviour; types of raw material; recyclability; durability and biodegradability of raw material at the design phase Collaboration and knowledge sharing with raw material suppliers (increasing solar energy supply, optimizing lighting and cooling system during production
Amicarelli et al. (2022)	Improve data collection related to sharing and renting platforms

Islam et al. (2021)	Collaborative approaches Eco-design Auditing and monitoring suppliers
Islam et al. (2022)	Apply technological innovation (e.g. Three-dimensional printing, sensor-based RFID tags, digital twins, additive manufacturing, Industry 4.0, and the Internet of Things)
Jia et al. (2020)	Design for recycling biodegradable clothing Tools for textile traceability
Brydges (2021)	Eco-design (seasonless collections; quality driven) Developing in-house clothing rental, resale programs, Partnerships with second-hand businesses Encouraging consumers to take better care of their clothes (mending, washing) Extending garments life (upcycling)
Sarokin and Bocken (2021)	Collections can be constructed to be operationally slow Product services employment
Lin and Ma (2023)	Propose approaches of future green certifications, strengthen the criteria requirements of the delivery stage and use stage, increasing transportation considerations in the delivery stage, and increase usage scenario consideration in the use stage Reduce packaging materials
Hossain et al. (2014)	Developing environmental conservation policies and processes Enabling workers to develop autonomous motivational states Organising training and seminars

Conclusions

The textile sector represents one of the pillars of the global economy, offering job opportunities and significantly contributing to the economic growth of many countries. It is a rapidly expanding market, thanks to mass consumption models and diversification of sales channels. On the other hand, this sector generates great concerns linked to low circularity, the consumption of natural resources, and waste management.

Through this study it emerges that the production and manufacturing phase of a fabric, such as an item of clothing, can have a greater impact on the environment. Furthermore, composite materials are difficult to manage at the end of their life. It is therefore necessary to adopt a series of measures that allow this supply chain to implement circular economy practices to mitigate these impacts. Furthermore, more detailed studies are needed to implement new processing technologies and diversify the use of raw materials. Finally, from this analysis, it emerges that to achieve sustainability objectives, investments and economic efforts on behalf of companies are necessary. Therefore, only with cooperation between multiple enterprises, it will be possible to address these challenges and at the same time ensure profitability for this industry given its global value, volume and importance.

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