WEP Warwick Evans Publishing

International Journal of Global Economics and Management

ISSN: 3005-9690 (Print), ISSN: 3005-8090 (Online) | Volume 10, Number 6, Year 2026
DOI: https://doi.org/10.62051/ijgem.v10n6.18
Journal homepage: https://ijgem.org

Exploration of the Supply Chain in the Fashion Industry Under the Sustainability Concept

Buhe Jiang

School of Design, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, United Kingdom

ABSTRACT

The carbon emissions of the fashion industry account for 4–10% of the global total, exceeding the total emissions of international aviation and shipping industries. Greening the fashion supply chain has become an urgent priority. The annual greenhouse gas emissions of China's textile and clothing industry are about 220 million tons, accounting for 2.7% of the total industrial emissions in the country, placing significant emission reduction pressure across all supply chain stages. This paper analyzes path selection and implementation outcomes for fashion supply chain restructuring, drawing on sustainability frameworks, EU policy documents, China's 14th Five-Year Plan, and real-world practices from H&M, ANTA, Patagonia, and other enterprises. As of 2024, data shows that China's production of recycled fibers exceeded 10 million tons, accounting for over 20% of the total fiber processing volume; 90% of textile enterprises have set clear climate action targets, with an average reduction of over 14% in carbon emission intensity across the industry in the past two years. The EU's ESPR Regulation, which will come into effect on July 19, 2026, prohibits the destruction of unsold clothing, forcing the restructuring of the global supply chain system. Against persistent industry headwinds—including fragmented regulatory standards and disproportionate cost burdens on small and medium-sized enterprises (SMEs)—cross-stakeholder collaboration will serve as the core driver of the fashion sector's transition to a circular economy.

KEYWORDS

Sustainable fashion; Supply chain restructuring; Circular economy; Carbon reduction; Blockchain traceability

1. INTRODUCTION

The $2.5 trillion global fashion industry is a cornerstone of the world economy, yet it is also defined by extreme resource consumption and pollution intensity. Annual carbon emissions from the global textile supply chain reach 2.1 billion tons of CO_2 equivalent, a single cotton T-shirt requires 2,700 liters of water to produce, and 92 million tons of textiles are discarded to landfills or incinerators each year as the industry's environmental impacts continue to rise unchecked. Covering every stage of the value chain—from raw material production and fiber processing to manufacturing, distribution, consumption, and waste disposal—the supply chain compounds environmental pressures at each step, creating an intertwined network of value generation and environmental cost [1].

China is the world's largest producer and exporter of textiles and clothing. In 2024, the industrial added value of enterprises above designated size increased by 4.4% year-on-year, and it has the most complete industrial supporting system in the world. This creates profound barriers to the sector's green transition. Data from the China National Textile and Apparel Council shows total industry carbon emissions hit roughly 209 million tons in 2020, with brands driving over 90% of emissions across the entire value chain. Most decarbonization challenges stem from supplier networks outside brands' direct oversight. The European Union has built the world's strictest fashion regulatory system: it released the Sustainable and Circular Textile Strategy in 2022, will revise the Waste Framework Directive to expand producer responsibility in 2025, and implement the ESPR Regulation banning unsold apparel destruction in 2026.

Advancing supply chain sustainability delivers dual value: it upholds environmental responsibility, and acts as a core strategy to build long-term competitive advantage. Leading brands have shown that sustainable materials, clean production processes and circular business models reduce long-term costs, boost brand premiums and strengthen consumer loyalty. The industry is in a policy and market-driven transition, but faces constraints: inconsistent standards, weak tech innovation, limited SME capacity and insufficient cross-stakeholder collaboration. This paper explores sustainable development paths for fashion supply chains, providing theoretical and practical reference for the industry's green shift.

2. STRUCTURAL CHARACTERISTICS AND EMISSION REDUCTION PRESSURE OF SUPPLY CHAIN ENVIRONMENTAL FOOTPRINT IN THE FASHION INDUSTRY

The fashion supply chain's environmental impact spans all stages of the product lifecycle, with environmental footprints differing sharply across production steps. Raw material preparation is the phase with the most concentrated environmental load. Production of raw polyester fibers involves high-temperature processes including petroleum refining, polymerization, and spinning, resulting in carbon emissions of approximately 5.5–15 tons of CO_2 equivalent per ton; Cotton cultivation is highly dependent on irrigation, with an average water consumption of about 8920 liters per kilogram of lint globally. Regional groundwater levels have declined in water-scarce cotton regions such as India and Pakistan. The chemical fiber manufacturing industry and textile industry together contribute 92% of the industry's total carbon emissions [2], and the printing and dyeing process accounts for about 10% of the country's total industrial wastewater emissions. Microplastic contamination represents another concern, with 20–35% of primary microplastics in the ocean coming from the shedding of synthetic fibers from household washing machines.

Carbon emissions from China's textile and apparel industry are heavily concentrated in upstream stages, with emissions mainly concentrated in the material manufacturing and processing links. The textile and chemical fiber manufacturing industries together account for more than 85% of the industry's total emissions. In 2020, the total carbon emissions of the whole industry were about 209 million tons and accounted for 2.7 per cent of the country's industrial emissions. Energy consumption per unit of output value has dropped by more than 65% since 2005, but the total emissions are still relatively high. For international brands such as Nike and H&M, more than 90 per cent of the emissions occur outside of their direct operational control, so most of their carbon footprint is from supplier networks that are not supervised by the brand. Cooperation among the links of the supply chain can reduce carbon emissions.

In the past two years, some good results have been achieved in the decarbonisation of this industry. According to data from the China National Textile and Apparel Council, the total reduction in enterprise-level emission intensity has been more than 14%, and brand enterprises have reduced the emissions of their supply chain by 18%. By the end of 2024, 90 per cent of the textile and apparel enterprises will have set specific climate goals; 67 per cent will have established climate risk identification and assessment systems; and 51 per cent will have promoted emission reductions in the value chain voluntarily. The development of this progress is uneven, and there are considerable differences among large enterprises and small- and medium-sized enterprises, brands and factories, and domestic and foreign trade markets. Further decarbonization across supply chains encounters multiple constraints in terms of technology, cost, and capacity.

The tightening of international regulations further amplifies the pressure to reduce emissions, with the EU Carbon Border Adjustment Mechanism, ESPR ecological design requirements, and the construction of digital product passports creating three layers of overlapping regulatory requirements. Global clothing emissions grew 7.5% year-on-year in 2023, the first rebound seen since 2019. This turnaround is mainly driven by higher production and the wide use of low-cost polyester [3]. The industry has not yet decoupled emissions reduction from economic growth, and supply chains' full emission reduction potential remains unfulfilled. Technological innovation must therefore go hand in hand with institutional reform.

3. SUSTAINABLE RAW MATERIAL SUBSTITUTION AND CARBON REDUCTION PATH AT THE SOURCE OF SUPPLY CHAIN

Replacing raw materials is the core way to reduce carbon emissions at the source of the fashion supply chain, and the use of recycled fibers and bio-based materials keeps expanding. In 2024, China's production of recycled fibers exceeded 10 million tons, accounting for over 20% of the total fiber processing volume, and the recycling rate of waste textiles reached over 30% [4]. The penetration rate of sustainable materials for leading international brands has significantly increased, with H&M Group achieving 89% of its use of recycled or sustainable materials and 29.5% of its use of recycled materials by 2024, surpassing its 2025 target ahead of schedule; 99% of the waterproof fabrics used in Patagonia's Fall 2024 collection are free of persistent chemicals including PFAS.

The sustainable transformation of the cotton supply chain is steadily advancing, and the coverage of the certification system for organic cotton, recycled cotton, and Better Cotton is continuously expanding. As of 2024, ANTA Group has achieved 100% LWG Gold certification for its footwear leather suppliers, with over 99% of leather raw materials traceable throughout the entire chain, ensuring material and environmental compliance from the source of procurement. Significant breakthroughs have been made in bio-based fiber technology, with the carbon footprint of polylactic acid fiber (PLA) throughout its entire lifecycle reduced by 40–60% compared to traditional polyester. Solvent-based cellulose fibers such as Lyocell have achieved industrial large-scale production, and cutting-edge innovative materials such as seaweed fiber and mycelium materials have entered the stage of commercial exploration. Material innovation reduces environmental impacts while creating differentiated competitive advantages for products. Li-Ning's environmentally friendly material technology has been fully applied to its core product line.

Chemical substance management has become an important dimension of sustainable control of raw materials. The ZDHC (Zero Discharge of Hazardous Chemicals) Roadmap to Zero involves over 175 participating companies worldwide, covering major brands and core suppliers in the textile and apparel industry [5]. H&M Group has already phased out priority controlled chemicals such as PFAS and DMF ahead of schedule, working toward zero hazardous chemical discharge across the supply chain. Li-Ning will conduct a special environmental audit on its core material suppliers in 2025, and the construction of its chemical management system has achieved significant results. Cost barriers remain a major obstacle to material substitution, with mainstream sustainable material market prices typically 20–50% higher than traditional materials, and a cost sharing mechanism for various links in the supply chain has not yet been formed.

The standard certification system is highly fragmented, with multiple certifications such as GOTS, OCS, RCS, Bluesign running in parallel, resulting in high compliance costs for enterprises. The construction of the carbon footprint accounting standard system for the entire life cycle of Chinese textiles continues to advance, and multiple industry standards have been released and implemented in the cotton and chemical fiber fields. Mutual recognition with international standards remains limited. Establishing a unified sustainability assessment framework would help promote mutual recognition of certification results, reduce supply chain compliance costs, and increase investment in material innovation research and development to expand the scale and application scope of sustainable material supply.

4. APPLICATION OF CLEAN PRODUCTION TECHNOLOGY AND GREEN UPGRADE OF MANUFACTURING LINKS

Textile printing and dyeing is the supply chain stage with the highest energy and water consumption, and the large-scale application of clean production technology has become the core path for emission reduction. Compared to traditional flat-screen printing, digital printing reduces water consumption by over 80% and chemical use by approximately 60%. The continuous improvement of printhead accuracy and the steady decrease in the cost of specialized ink are driving up market penetration. Advanced technologies such as waterless dyeing, low-temperature dyeing, and enzymatic desizing have been industrialized, and the bath ratio of air flow dyeing equipment has been reduced to below 1:4, saving more than 50% of water compared to traditional equipment. The widespread adoption of heat recovery systems and water reclamation facilities in large printing and dyeing enterprises has raised the industry's overall water reuse rate to over 45% [6].

The clean transformation of energy structure is steadily advancing. Over 130 of ANTA Group's core suppliers have adopted renewable energy, and the number of clothing suppliers using coal boilers in H&M Group has decreased to 27, with the goal of completely phasing out coal in the supply chain by 2026. Distributed photovoltaics are being rolled out in textile industrial parks, and textile industry clusters such as Jiangsu, Zhejiang, and Guangdong are advancing the construction of rooftop photovoltaics in their factories. Some leading enterprises have achieved full coverage of rooftop photovoltaics. The Climate Innovation Action led by the China National Textile and Apparel Council has gathered key enterprises to form three major technological routes: renewable energy application, energy efficiency improvement, and production process optimization.

Digital technology empowers fine control of production processes. The Energy Management System (EMS) monitors energy consumption data in real-time, optimizes production scheduling with artificial intelligence algorithms, and promotes a continuous decrease in energy consumption per unit product. The top manufacturing enterprises have applied digital twins to model the production process and have found certain energy-saving opportunities to improve their overall equipment effectiveness (OEE). Most SMEs do not have the funds for large-scale technological upgrades, as the initial investment in new clean-production equipment is high, the return on investment is extended, and financing options are relatively limited [7]. As environmental demands for printing and dyeing have continuously risen, some small and medium-sized enterprises (SMEs) have been unable to meet the new environmental standards so far. Thus, further industrial concentration will occur.

Coal-phase-out has been widely accepted by the industry. Patagonia has introduced a mandatory coal phase-out policy for its suppliers, and many of the major foreign brands have generally focused on exit plans for 2025-2030. The "coal-to-gas" and "coal-to-electricity" projects for China's textile industry are still under construction, and to date, significant results have been achieved in reducing the use of coal-fired boilers. The supply of natural gas is unevenly distributed and costly. Promote the spread of clean production technology through a combination of policy support and market mechanisms. In combination with policies such as green credit and carbon reduction tools, energy-efficiency benchmarks can be employed to promote all-round green upgrading of the entire manufacturing chain.

5. CONSTRUCTION OF CIRCULAR ECONOMY MODEL AND DEVELOPMENT OF REVERSE LOGISTICS IN SUPPLY CHAIN

The circular economy model is changing the structure of the fashion industry's supply chain and moving away from the old linear “produce-consume-dispose” mode to a closed-loop system of 'design-production-use-recycling-regeneration' [8]. Eco-design will serve as the driving force. The EU's ESPR Regulation will require textiles to be more durable, repairable and recyclable, and prevent the destruction of unsold clothing. Starting from July 19, 2026, large enterprises will need to implement the destruction ban, and regulations for medium-sized enterprises will take effect in July 2030. Policies will require brands to consider environmental impact in the design stage and improve the design to extend the life cycle of the product.

The system of recycling and reusing old clothes is gradually developing. Brands such as H&M, ZARA, and Uniqlo have widely introduced bins for used clothing collections in their stores, and Patagonia's "Worn Wear" programme provides professional garment repair services to extend the life of the products through functional repairs. China's amount of textile waste recycling has been increasing steadily, but the all-China recycling rate is still lower than in developed countries. The main reasons are a lack of collection channels, outdated sorting equipment and low-value uses. ANTA and Sailong Technology have developed T2T closed-loop regeneration technology to recycle shoe supply chain cutting waste spinning scraps into regenerated yarn and have achieved internal production circulation.

The two-hand trade and clothing rental models are developing at a high speed. Steady growth has been recorded in transaction volumes on platforms such as ThredUp, Depop, and Xianyu, while H&M leverages its multi-brand second-hand business matrix—including Pre-loved, ARKET Archive, COS Resell, and Sellpy—to promote clothing recycling. Already maturely applied in niche markets spanning high-end dresses, children’s clothing, and sports equipment, the leasing model has been buoyed by a gradually emerging consumer mindset that prioritizes access over ownership [9]. The long-term viability of these circular business models remains unproven at scale. The high cost of reverse logistics, large differences in the quality of recycled products, and bottlenecks in large-scale sorting and regeneration technology remain to be addressed.

Extended Producer Responsibility (EPR) has become an important policy tool for promoting a circular economy. The EU requires member states to establish a unified textile EPR system, with producers paying according to the scale of product deployment and funds used for the construction and operation of the recycling system. France has taken the lead in establishing an EPR system for textiles, while countries such as Germany and the Netherlands have successively initiated legislation. China will put forward a plan for the implementation of extended producer responsibility for textiles to clarify the recycling liabilities of brand enterprises, importers and e-commerce platforms. The construction of reverse logistics network requires industry-wide collaboration, sharing of recycling channels and sorting facilities to reduce operating costs, and strengthening the research and development of closed-loop recycling technology for chemical fibers to improve the quality and application scope of recycled fibers.

6. APPLICATION OF DIGITAL TRACEABILITY TECHNOLOGY AND IMPROVEMENT OF SUPPLY CHAIN TRANSPARENCY

Blockchain technology can be used to achieve full-traceability of the fashion supply chain at all stages, from fibre production to the end consumer; thus, problems of information asymmetry in traditional supply chains have been resolved [10]. The TextileGenesis platform utilizes digital token technology to verify the authenticity of sustainable textile sources at the product batch level, serving international brands such as H&M and Stella McCartney. Toread has collaborated with Best Supply Chain on technology, achieving a 100% application rate of blockchain in transportation business, and real-time on-chain data storage for each link.

The EU is rolling out a Digital Product Passport (DPP) system, with textiles included in the first batch of implementation scope. Under the regulatory timeline, relevant requirements will be phased in between 2026 and 2027. Each garment will have a unique digital identity, which records the full lifecycle information such as material composition, product carbon footprint, maintenance and usage guidelines, recycling and disposal paths, etc. Consumers can obtain product environmental impact data by scanning the code. VeChain and other blockchain technologies have been widely applied in the luxury goods industry. The LVMH Group has launched the Aura Blockchain Consortium, which connects multiple luxury brands and achieves dual goals of product anti-counterfeiting and supply chain transparency.

Standardization of supply chain data is the core prerequisite for building a traceability system, promoting horizontal comparability of supply chain ESG performance. The Higg Index and SLCP (Social & Labor Convergence Program) are mainstream assessment tools in the industry, and over 20,000 factories worldwide have completed the Higg FEM environmental module validation. Key challenges include significant differences in indicator systems, insufficient comparability of cross-platform data, and high costs of repeated audits among different evaluation frameworks. The China National Textile and Apparel Council has taken the lead in promoting the construction of unified ESG data standards for the industry, and the proportion of ESG information disclosure by enterprises above designated size has steadily increased.

The sharing of supply chain data needs to balance the protection of trade secrets and the need for collaborative openness. Most supply chain partners remain reluctant to share data. Zero-knowledge proof, federated learning, and other privacy computing technologies provide feasible solutions that support joint computation and verification without requiring raw data disclosure [11]. The digital foundation of SMEs is relatively weak, and the construction and operation costs of traceability systems are high. Industry-level public service platforms are needed to lower the application threshold. The transparency of the supply chain is gradually transforming from compliance requirements for enterprises to market competitive advantages. Consumers' attention to brand environmental responsibility continues to rise, and a transparent, traceable supply chain has become a core asset for brand differentiation.

7. CONCLUSION

The sustainability-driven transformation of fashion supply chains has moved from theoretical advocacy to real-world implementation. Improved policies, green technology innovation and rising consumer demand are together driving industrial change. As the global textile industry's core hub, China has cut industry-wide carbon emission intensity by an average of over 14% in the past two years. Recycled fiber annual output has topped 10 million tons, and more than 90% of large firms have created climate action plans, with significant transformation progress achieved. Key barriers include fragmented standards, limited transformation resources for SMEs and missing industrial chain collaboration mechanisms. The five implementation paths of material substitution, clean production, mode innovation, digital traceability, and multi-party collaboration are organically connected to support the construction of a sustainable supply chain system.

The EU's ESPR destruction ban, digital product passports, and extended producer responsibility have established the world's strictest regulatory framework for the fashion industry, creating external pressure for transformation. Chinese textile export enterprises need to accelerate their adaptation to international rule changes and systematically enhance their green competitiveness in the supply chain. The first group of leading enterprises has selected a long-term investment strategy for the construction of a stable competitive advantage. H&M, ANTA, and Patagonia are examples of enterprises that have found a replicable transformation path, but most small-scale manufacturers are still hindered by technological deficiencies, lack of funds and scale disadvantages, and require specific policy support and supply chain strengthening provided by large-scale enterprises.

The future development of the fashion supply chain presents a clear direction of evolution: global standards are gradually converging, and carbon footprint accounting, information disclosure, and ecological design will form unified international rules; with deep digital empowerment, blockchain, artificial intelligence, and digital twins are fully integrated into all aspects, and data-driven refined management has become an industry standard; third, industrial ecology will move toward collaborative governance, forming a value co-creation network involving brands, suppliers, consumers, recycling enterprises, and regulatory bodies. The government, enterprises, and consumers are working together to promote the sustainable and systematic transformation of the fashion industry.

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