Research and Analysis on the Recycling of Old Clothes

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Abstract. This article focuses on some opportunities and challenges that the global used clothing recycling sector faces against the backdrop of fast fashion. The discussion will mainly focus on policy comparisons among different countries, types of technological processes, consumer behaviors, and business models. In terms of case analysis, the forms of old clothing recycling are compared by comparing the two major cases of the "Worn Wear" project of Reju in Germany and Patagonia. In the discussion and analysis, taking the three major economies of the European Union, China, and California as the main body, the commonalities and differences among different economies and enterprises in aspects such as extended producer responsibility (EPR), fiscal incentives, collection systems, and service orientation are revealed. Finally, point out some challenges and gaps that exist in this field at present. This paper points out some challenges and gaps in this field at present, aiming to inspire further research and practical solutions to promote the healthy development of the global old clothing recycling industry.

Keywords: Recycle, Old Clothes, Extended Producer Responsibility.

1 Introduction

In the present era of fast fashion life, the discarding and waste of old clothes cause increasingly serious pollution to the environment. With the continuous development of the textile industry and the increasing demand for fashionable clothes, about 92 million tons of textile waste are generated worldwide every year. These waste clothes often flow into low-income countries, and these countries often lack the appropriate treatment facilities and management mechanisms for these waste clothes. Eventually, they are dealt with by dumping, burning, and other methods that seriously affect the ecological environment. Every year, 200,000 to 500,000 microplastic fibers are discharged into Marine ecosystems worldwide. This processing method results in less than 15% of the textiles being recycled. The recycling rate of textiles is insufficient, and the recycling capacity is far from meeting the demands of the circular economy. In response to this situation, economies such as the United States, China, and the European Union have all implemented different measures and promulgated different policies. For instance, the EU's Waste Framework Directive requires that a separate collection and recycling system for textiles be implemented starting from 2025. China has introduced Extended Producer Responsibility (EPR) in the revision of its Solid Waste law, pushing producers to bear the costs of recycling and reuse: The U.S. Government Accountability Office

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(OAC) report suggests that the federal government should increase investment in textile sorting and recycling technologies to enhance recycling efficiency and reduce costs. Although various countries have introduced a series of policies to address the issue of insufficient textile recycling rates, they still face challenges in terms of technical processes and consumer awareness. This article will adopt methods such as literature review and case analysis to explore several aspects including policy comparison, recycling channel efficiency, consumer perception, and technological development among different national economies, and compare the economic cost structure and benefits behind them.

2 Literature Review

2.1 Circular Economy and Technological Pathways

The existing ways of recycling old clothes at present include mechanical technology and chemical technology. However, both of these methods have their limitations. Although mechanical sorting has a lower cost, its recycling efficiency for blended fabrics is insufficient. Chemical depolymerization can recover high-purity monomers, but its large-scale application is restricted by high energy consumption and equipment costs. Some scholars compared the environmental and economic benefits of two recycling paths through the Life Cycle Assessment (LCA) model and proposed a collaborative optimization strategy of "mechanical pre-sorting + chemical recycling" [1].

2.2 Policy Incentives and Institutional Designs

Some scholars proposed the concept of Extended Producer Responsibility (EPR), laying a theoretical foundation for subsequent textile recycling legislation [2]. The EU's Waste Framework Directive and its derived textile strategy will encourage member states to establish separate collection and recycling systems for textiles between 2021 and 2024 and set recycling rate targets for producers. China's new Solid Waste Law and California's SB 707 respectively encourage domestic brands to establish recycling networks and share processing costs through Statutory Recycling Responsibility organizations (PRO) and financial subsidies [3].

2.3 Consumer Behavior and Digital Incentives

An empirical study in Spain has found that incentives based on points and ranking lists in mobile apps can increase user recycling by more than 25%. The improvement of traceability technology, along with QR code traceability and carbon footprint labels, has significantly enhanced consumers' trust in recycled clothing, increasing their purchase intention by 15-20% [4]. In addition, virtual clothing exchange platforms can reduce the frequency of purchasing new clothes by 30%, but their adoption rate highly depends on the trust mechanism and operational convenience of the platform.

2.4 Business Model Innovation

The "closed-loop leasing + subscription + remanufacturing" composite business model is predicted by the model to increase the average gross profit of the brand by 18% and extend the service life of the products. For instance, a design called Upcycling, through the creative redesign of scraps and old clothes, not only reduces fabric waste by approximately 15% but also brings a premium space of 10-20% to the products, achieving the effect of enhancing market competitiveness and brand value [5]. However, in light of the current situation, this design still has some problems in the research. For example, the comparison between cross-border policies and technological paths is insufficient. Most of the existing studies focus on a single country or a single technical path, lacking a systematic analysis comparing the recycling efficiency and economic costs under different institutional environments such as the European Union, China, and the United States within a unified framework [6]. Secondly, the quantification of multi-channel cost-benefit and environmental impact is insufficient. Although there have been explorations of new channels such as digitalization, the sharing economy, and social enterprises, a systematic quantitative assessment of channels like brand recycling bins, second-hand e-commerce, and community donations in terms of collection volume, sorting costs, and carbon reduction benefits has yet to be established. Finally, the long-term effects of cutting-edge technologies still lack empirical support. For instance, there is not much research evidence to prove technologies such as blockchain traceability and digital points incentives in terms of the long-term changes in consumer behavior and the long-term empirical research on the sustainability of recycling networks [7].

3 Case Analysis and Comparison

3.1 Polyester Chemical Recycling Innovation of Reju in Germany

The German company Reju has invented a polyester recycling technology, which is regarded as the most capital-valuable innovation in this new field. Plastics are formed by linking individual chemical substances called monomers into chains to form polymers. The essence of the Reju process is to break down polyester into monomers through "depolymerization" and then recombine them into polymer chains through "polymerization". Only 0.3% of the materials currently used in the fashion industry meet recyclable standards. Therefore, polyester recycling technology cannot meet the demand of the fashion industry for sustainable materials. Polyester and PET plastic used for water bottles are the same. Mechanical recycling of PET-melting it and re-extruding it - is not ideal because this process reduces the quality of the plastic [8]. The most common material combination found in old clothes is 70% polyester and 30% cotton. In-depth investigation and analysis show that it is actually 60% PET, 5% dye, 2% elastic rubber, and possibly contains a little bit of nylon. Therefore, researchers and enterprises are seeking a technology that can recycle dirty polyester fabrics into clean ones. Jeju's technology meets people's demands. Waste polyester fibers are first crushed into colored fibers. Immediately after, people purified the white powder-like monomer BHET by using the extraction process to remove cotton and impurities. Then these white powder-like monomers BHET will be sent to specialized facilities for re-polymerization to generate high-purity recycled PET particles, which will eventually be used for melt extrusion to produce polyester filaments [9]. Reju's polyester chemical recycling technology has demonstrated remarkable economic benefits. Firstly, this technology uses waste PET as raw material, effectively replacing traditional plastic production's reliance on fossil resources such as petroleum, thereby significantly reducing raw material costs. Especially in the context of fluctuations in international energy prices, it has a more significant cost advantage. Secondly, Reju can handle types of waste such as dyeing and blending that are difficult to deal with by traditional mechanical recycling, broadening the sources of raw materials, and enhancing the recovery rate and the stability of the supply chain. Its recycled products, as recycled materials, comply with ESG and sustainable development market standards and are widely used in packaging, textiles, consumer goods, and other fields. Due to its green attributes, it has gained a certain market premium. In addition, Reju also benefits from the policy support of the state and the European Union for the circular economy and green technology, including measures such as research and development funding, tax breaks, and green loans [10]. Finally, Reju products have a lower carbon footprint and can generate additional revenue through carbon credit and carbon trading mechanisms, further enhancing their comprehensive competitiveness between environmental protection and business.

3.2 Patagonia "Worn Wear"

The outdoor clothing brand Patagonia (Patagonia was founded in 1973 by mountaineer Yvon Chouinard. It initially started with hand-forged rock-climbing equipment and gradually expanded into the field of outdoor clothing and accessories.) In 2013, Worn Wear was launched to counter the common "take-make-scrap" model in the outdoor clothing industry and encourage consumers to buy less, repair more, and extend the service life of products. Traditional (non-organic) cotton production consumes a large amount of water and pesticides. Polyester and nylon are artificial materials that consume energy and resources. The clothing industry is also one of the important sources of rapid fashion changes and serious waste. Patagonia is expanding the value of its product range to extend the product life cycle, using the trade-in resale model to resell second-hand products on its online platform. Customers of the traded products will receive the fees for the traded products, and Patagonia, after conducting quality management on its platform, sells them and makes profits .

Patagonia promises to "build useful things that are durable, repair damaged things, and recycle things that have reached the end of their service life", and customers are required to purchase only what they need and will continue to use, repair, reuse, and recycle, and consider second-hand products. This not only opens up new revenue channels but also effectively maximizes inventory and waste resources, reducing product waste. Converting idle inventory and recycled products into commodities, not only reduces inventory overstock but also directly brings considerable profits to Patagonia. In addition, Patagonia, with the mission of being "born for the Earth", has strengthened its eco-friendly image of "restoring the old to its original state" through Worn Wear, effectively attracting consumer groups that focus on sustainable development. Research shows that brands participating in social responsibility projects can significantly enhance the brand value perceived by the public and strengthen emotional connections. Patagonia has enhanced brand transparency and won the favor of highly environmentally sensitive market segments by publicly reporting maintenance and recycling data.

4 Analysis and Discussion

Overall, there are similarities in the measures taken by various economies in the field of textile recycling, but there are also many differences.

4.1 Commonalities

This article mainly compares the commonalities among the three major economies of China, the European Union, and California in three aspects: the introduction and extension of the EPR mechanism, fiscal incentives, and green financial support, and the improvement of the collection system. The EU's Waste Framework Directive requires the separate collection of textiles to be implemented starting from 2025, stipulating that its member states must participate and set recycling rate targets for producers. At the same time, the revised directive requires each member state to establish its own applicable textile EPR program within 30 months from the effective date of the directive (i.e., by 2028). The Solid Waste Pollution Environment Prevention and Control Law of the People's Republic of China was revised in 2020, strengthening the concept of ERR, requiring producers to establish recycling networks and bear recycling costs, and demanding a 50% category recycling rate by 2025.California SB 707 (2024) marks the first textile EPR act in the United States, requiring clothing producers to form and join government-approved producer responsibility organizations (PRO) by 2026 and officially implement financial incentives and green financial support from 2028. The European Union guides funds to the field of resource recycling and utilization through its "European Green Deal" and "Circular Economy Action Plan". Take the SCIRT project as an example. The government has provided over 5 million euros in funding, with a focus on the separation of blended fibers, digital traceability, full life cycle analysis, etc. The CIMPA project aims to enhance the recycling technology of hybrid polyester, and the EU Horizon 2020 has allocated approximately 9.8 million euros to support the research and development. Representing member state France, we offer a 20%-30% reduction in income tax for manufacturers using recycled fibers. The Netherlands, through the "Green Investment Scheme" with interest rates as low as 0.5%-1.2%, supports equipment procurement, sorting automation, and the construction of recycling distribution networks. China has vigorously issued green bonds, and the funds obtained can be used to purchase environmental protection equipment, resource recycling, etc. In 2022, a textile enterprise in Shaoxing, Zhejiang Province successfully issued 150-million-yuan worth of green bonds, which were specifically used to establish a recycling and processing plant capable of handling 20,000 tons of used clothing annually. In the 2023 green bond project of Changzhou, Jiangsu Province, approximately 20% of the funds were invested in the recycling treatment equipment for fiber regeneration and dyeing and finishing wastewater. In addition, local governments also actively provide subsidies and cooperate with banks for financing. Cities such as Hangzhou and Shanghai offer up to 20% of equipment purchase subsidies and up to 5 million yuan in R&D matching funds to registered EPR-compliant brand enterprises. CalRecycle's RMDZ Program is a green credit platform led by the state government. In California, the United States, low-interest loans for the recycling industry chain are provided through CalRecycle's RMDZ Program. A single project can obtain a low-interest loan of up to 2 million US dollars with a repayment period of up to 10 years. Cal Recycle also funded a "Textile Closed-loop Recycling Program" led by an NGO in the San Francisco Bay Area, with a funding amount of 3 million US dollars, to support the establishment of community collection points and garment recycling workshops.

The European Environment Agency's report indicates that by the end of 2024, over 50% of EU countries have deployed dedicated textile recycling bins, with an average of approximately 120 community collection points per 100,000 people. China's circular economy plan for the 14th Five-Year Plan proposes that by 2025, a three-level recycling network will be established in over 60 cities across the country to cover both urban and rural areas. In addition, Producer Responsibility organizations (PRO) are entrusted to coordinate the placement, transportation, and sorting of brand recycling bins. Some brands (such as Anta and Li-Ning) have built their own "brand recycling cabinets" and cooperate with community volunteers to provide regular door-to-door collection services. The government provides compliant enterprises with a maximum 20% equipment subsidy matching research and development funds. The California SB 707 Textile Responsibility Recycling Act passed by California, the United States in 2024, mentions that PRO will provide retail point recycling bins for consumers - free drop-off bins will be set up in over 10,000 clothing retail stores, and equipped with intelligent sensing technology to monitor overflow status. Mailing and recycling service-Free mailing package labels are provided. Consumers only need to scan the QR code to apply for door-to-door pickup or mailing. Community flash collection activities-Collaborate with local non-profit organizations to hold regular "Textile Flash Recycling Days" in the community or on campus.

4.2 Differences

First, the implementation time is different. The EU will uniformly implement separate collections by 2025 and promote full coverage of EPR by 2027-28. The EPR pilot program in China was launched in 2020, but the progress varies among different provinces and cities. The full implementation goal is expected to be achieved by 2025. California's bill will require the establishment of PRO starting from 2026 and will be fully implemented from 2028. The pace is lagging behind that of the European Union and China. Second, the supervisory subjects are different. On the part of the European Union, it is jointly regulated by the European Commission and member states. China is jointly regulated by the central and local governments. The macro policies are jointly formulated by the Ministry of Ecology and Environment and the National Development and Reform Commission. Local ecological environment bureaus, urban management bureaus, etc. are responsible for the actual implementation and the construction of the recycling system. In California, USA, the operation of the state's textile recycling system is uniformly approved, managed, and supervised by the California Department of Resources Recycling and Reuse (Cal Recycle), which is the only regulatory body. The main difference in the recycling model lies in whether it leans towards technology orientation or service orientation. The European Union and China are more technology-oriented and support high-tech demonstration projects such as chemical depolymerization and biological enzymatic hydrolysis. California SB 707 emphasizes service orientation and encourages brands to carry out services such as free repair, second-hand transactions, and "trade-in" to extend the service life.

4.3 Current Challenges and Gaps

The current challenges are mainly reflected in three aspects， including technical bottlenecks, regulatory blind spots, and public perception. The technical bottleneck still cannot be broken through. In the field of technology, the current technologies are mainly divided into mechanical means and chemical means. The main problem of mechanical sorting is that the efficiency is only about 50% when dealing with cotton-polyester composite fabrics, and the purity and strength of the fibers drop significantly. Although chemical depolymerization can achieve high-purity recovery, the conventional solvent system has high energy consumption and difficult catalyst recovery, making it hard to support industrial scale-up. With the development of AI technology, intelligent sorting is also constantly evolving. However, there are still some problems-although near-infrared spectroscopy and AI vision perform well in the laboratory, due to insufficient labeled sample sets, high equipment costs, and the absence of sample libraries for different fiber mixtures, the sorting accuracy rate fluctuates between 70% and 85%, making it difficult to reach the above 95% level required for commercial operation. There is a regulatory gap between "developed and developing countries". Textile waste exported from the European Union and North America accounts for one-third of the global total. However, the destinations are mostly low-income developing countries and regions with weak recycling facilities. These wastes are often disposed of by dumping and incineration, seriously affecting the local environment and public health. Meanwhile, an international accountability mechanism has not yet been established. 3. Low public participation. The global average textile recycling rate is only about 21%. Due to consumers' insufficient awareness of brand and community recycling programs, over 65% of old clothes are still mixed with other household waste.

In addition, there are also some gaps in academia and policy. First of all, the development of financial derivatives is not sufficient. Although green bonds and carbon credits have mature practices in other industries, there is no specific financial instrument framework for the textile circular economy yet - such as futures contracts for recycled materials, "recycled bonds" or "convertible bonds" designed based on EPR recycling volume - and there is also a lack of model-based research on their risk-return characteristics. Meanwhile, in terms of macroeconomic impact, an economic assessment model for the influence of the textile circular economy on macro-level aspects such as employment structure, trade balance, and regional GDP has not yet been established. In particular, there is a lack of empirical studies comparing the differences in macroeconomic indicators before and after the implementation of circular textile policies in different countries/regions.

5 Conclusion

This article aims to explore the measures taken by major economies and enterprises in the field of used clothing recycling to recycle used clothing more effectively in the current situation where the waste of used clothing is so serious. By studying the measures taken by enterprises, it can be found that many new technology companies and clothing brand companies are now committed to making old clothes into new materials for reuse or directly recycling old clothes and selling them a second time on second-hand platforms. No matter which forms it takes, it greatly improves the utilization rate of old clothes and reduces pollution to the environment. From a more macro perspective, by comparing the three major economies of the European Union, China, and California, some commonalities and differences in their measures for the recycling of used clothes have been discovered. In terms of common points, they have both formulated relevant bills to deepen the extension of the EPR concept. Issue green loan programs such as green bonds at the government level; The recycling system is also constantly being deepened and improved. The differences among various economies are mainly reflected in the different times of policy implementation, the different regulatory subjects, and the different orientations of recycling models. Of course, in this field, there are still some challenges and gaps. In terms of challenges, for instance, the improper handling of used clothes in developing countries and the low public participation rate, etc. Research gaps include insufficient development of financial derivatives and the lack of models for estimating risks, etc.

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