Data-Driven Service Innovation in Used Clothing Collection: Integrating User-Centered Drop-off Point Layout with Low-Carbon Inventory Management

Jialin Karen Tang[1], Anne Sophia Koornwinder-gott[2]

[1]Stevenson College, University of California Santa Cruz, 1156 High St, Santa Cruz, CA 95064, USA

[2]Sacred Heart University, 5151 Park Avenue Fairfield, CT 06825, USA

jtang125@ucsc.edu (Corresponding author); anne@koogot.com

Received date: Oct. 23, 2025; revision date: Nov. 3, 2025; Accepted: Nov. 25, 2025

ABSTRACT

Fast fashion and linear consumption models have led to rapid growth in the volume of used clothing globally, presenting severe environmental and social challenges for local governments, charitable organizations, and social enterprises. Although the field of operations research has proposed various complex models for optimizing collection networks and supply chains, these models are rarely truly integrated into user-facing service design and circular business models. This paper constructs a service-oriented used clothing collection framework that combines front-end user-centered collection bin placement and layout with back-end low-carbon inventory management in the resale stage of secondhand clothing. The paper synthesizes core findings from two recent analytical studies: first, an optimal location and recommendation simulation model for used clothing collection bins based on multi-dimensional user preferences and location-based social networks; second, a two-echelon supply chain low-carbon inventory decision optimization model for secondhand clothing resale scenarios under carbon tax and carbon labeling policy constraints. Building on this foundation, the paper proposes an integrated service system architecture that coordinates and unifies user-level service recommendations, environmental impact visualization, and the effects of policy instruments through collaborative design. This framework distills key design principles for service innovation in used clothing collection systems: (1) achieving personalization in collection service access methods by mining user preferences and travel behavior patterns; (2) managing inventory-related carbon emissions in secondhand clothing resale operations through policy-sensitive decision rules; (3) embedding data flows and analytical modules into the service value proposition; (4) achieving synergistic alignment among user experience, operational efficiency, and environmental performance. Finally, the paper discusses the management and policy implications of this framework for local governments, charitable organizations, social enterprises, and platform-based service providers in building data-driven, user-centered, and low-carbon used clothing collection services, and looks ahead to future research directions for service innovation in circular textile systems.

Keywords: used clothing collection; service innovation; user-centered design; low-carbon inventory; carbon tax; carbon labeling; simulation; sustainable development

1. Introduction

The textile and apparel system is positioned at the core of circular economy and sustainable consumption discussions. Over the past two decades, global clothing production has grown rapidly while the actual wearing time of garments has continuously shortened, resulting in large quantities of underutilized clothing and the ongoing accumulation of post-consumer textile waste. Meanwhile, the environmental impacts from fiber production, dyeing and finishing processes, transportation, and waste management remain highly significant, primarily manifested in greenhouse gas emissions, water resource consumption, chemical

pollution, and microplastic emissions. Used clothing collection and resale are widely recognized as important pathways for reducing the environmental footprint of the fashion industry and promoting more circular consumption patterns. However, the actual effectiveness of such initiatives depends largely on how service systems are designed and the level of operational management.

In practice, the flow of used clothing is realized through a service system that connects donors, collection infrastructure, sorting and resale channels, and end beneficiary groups. Such service systems need to be attractive to users, operationally feasible, and capable of generating tangible environmental benefits. However, existing research often treats user-facing service design and operational optimization as separate research domains. Recommendation system and service design research primarily focuses on user behavior and digital interaction interfaces, while operations research emphasizes optimization models for facility location, route planning, and inventory management. The core challenge arising from this is: how to integrate the above research threads into a coherent data-driven service innovation solution that can simultaneously enhance user experience, operational efficiency, and environmental performance.

This paper responds to the above challenge by synthesizing two complementary analytical studies in the used clothing system domain. The first study constructs a simulation-based optimization model for the location and recommendation design of used clothing collection bins, explicitly incorporating factors such as user donation preferences, social activity space locations, and travel costs. This study formalizes the collection bin recommendation problem as a 0-1 integer programming model and proposes a simulation algorithm embedded with location-based social networks; the model is empirically validated using data from over 50,000 used clothing donation records and 1,633 collection bins in Connecticut, United States. The second study focuses on a two-echelon secondhand clothing resale supply chain consisting of suppliers and retailers, systematically analyzing low-carbon inventory decision problems. Under carbon tax and carbon labeling policy constraints, this study derives optimal emission levels, pricing strategies, and contract arrangements, and further compares the impact mechanisms of different policy instruments on carbon emissions, market demand, and overall supply chain profit under decentralized and centralized decision-making frameworks.

By integrating the above two research perspectives, this paper aims to answer the following questions:

1. How can user-centered recommendation mechanisms and collection bin location analysis be embedded into the overall design of used clothing collection services?
2. Under carbon tax and carbon labeling policy constraints, how can low-carbon inventory management mechanisms be incorporated into the back-end operational system of such services?
3. What service design principles and governance mechanisms can achieve synergistic alignment among user satisfaction, operational performance, and environmental performance?

The contributions of this paper are primarily manifested at the conceptual and integrative levels. Based on rigorous analytical models, this paper proposes a service system architecture and corresponding design principles to connect front-end user services with back-end low-carbon operations in used clothing collection systems. For policymakers and practitioners, this framework provides an actionable blueprint for building data-driven circular service systems; for academic researchers, it presents a multi-level research agenda positioned at the intersection of service innovation, operations analysis, and sustainable development.

2. Related Work

2.1 Service Innovation and Circular Textile Systems

The transition from linear textile systems to circular textile systems is not only about the application of new

materials and technologies, but equally a matter of service innovation. Circular business models in the fashion sector—such as resale, rental, repair, remanufacturing, and upcycling—are inherently highly service-intensive in nature: they create value not through continuously selling new products, but by extending the usage lifespan of garments, expanding usage methods, and facilitating the recirculation of clothing. In the landmark report "A New Textiles Economy," the Ellen MacArthur Foundation points out that circular business models are key levers for decoupling economic growth from virgin resource consumption, and estimates that under conditions of reasonable scaled development, resale, rental, repair, and remanufacturing models could account for approximately 23% of the global fashion market by 2030, creating approximately $700 billion in economic value. From a service perspective, such models shift the value creation logic from one-time transactions toward ongoing value co-creation processes among users, brands, platforms, and other ecosystem participants.

In recent years, research on circular fashion business models has further provided more refined analytical frameworks to help understand this transformation process. Coscieme et al. (2022) summarize circular pathways in the fashion and textile sector into four main types: durability-oriented models (extending product lifespan through design), access-oriented models (such as rental, time-sharing, and sharing), clothing collection and resale models, and regenerative circular models centered on material value recovery. These pathways break down the traditional boundaries between products and services; even seemingly "product-centric" strategies, such as durability design, often require the parallel development of service activities around care, repair, and quality assurance. The "Guide to Circular Business Models in Fashion" published by the Waste and Resources Action Programme (WRAP) in the United Kingdom further translates the above framework into a seven-step operational process for enterprises, covering key elements such as value proposition design, operational implementation, customer engagement, and financial viability. It is worth noting that this guide and related research repeatedly emphasize that circular business models only possess substantive environmental value when they genuinely replace linear consumption patterns, rather than simply layering new revenue sources on top of the continued expansion of fast fashion.

Within the above research context, service innovation is often implicitly present but rarely explicitly positioned at the core of analysis. Conceptual research on the circular economy and service-dominant logic points out that circularity should be better understood as a service-based value creation reconstruction process, with its core lying in value co-creation through ongoing processes of use and access, rather than fixing value in physical goods at the point of product sale. Service-dominant logic (SDL) emphasizes that all economic exchanges are essentially service exchanges, and what enterprises provide is not value itself but value propositions. Applying this perspective to the circular textile sector means that clothing rental, repair, and resale should not be viewed as mere additional channels for circulating physical inventory, but should be designed as complete service systems that include clear role divisions, resource allocation, and institutional arrangements. Vargo (2021) and subsequent research on the integration of SDL and the circular economy further point out that without explicitly introducing a service perspective, circular economy narratives tend to remain trapped in "object-centric" logic; conversely, by emphasizing performance-based contractual arrangements, product-as-a-service models, and multi-stakeholder service ecosystems that maintain continuous circulation of garments, the service essence of the circular economy can be truly manifested.

Empirical research in the fashion sector demonstrates how service innovation is used to concretize and implement circular business models. Major brands and platforms are scaling rental and resale services as core components of their business operations, often leveraging digital channels to enhance service convenience and acquire continuous data flows. For example, clothing rental services drive the fashion industry's shift toward a "product-as-a-service" logic, integrating usage rights, cleaning, and maintenance into ongoing service contracts. Resale and consignment platforms extend the lifespan of garments by matching household-end supply with demand from new users, and their operations are highly dependent

on service functions such as curatorial selection, authentication, pricing mechanisms, and logistics coordination. Repair and alteration services—whether provided through storefronts, community workshops, or mail-in service models—not only support durability-oriented circular models but also play an important role in deepening relationships between brands and consumers.

Meanwhile, related research has also begun to focus on the key capabilities that enterprises need to possess in implementing and scaling circular fashion services. Salmi et al. (2022) point out that dynamic capabilities such as experimentation capability, cross-boundary collaboration capability, and digital infrastructure are crucial for apparel brands' transition from linear to circular business models. Henninger et al. (2025) and Barletta et al. (2024) further explore the "true circularity" of these models, noting that without substantial adjustments to production scale and business logic, many current practices remain at the incremental improvement level and struggle to fundamentally reduce material throughput. From the service innovation perspective, this issue raises deeper research questions: how should circular fashion services be designed to genuinely replace linear consumption patterns, and in contexts where services such as rental may stimulate more frequent outfit changes, how can rebound effects be avoided or mitigated?

Despite the above research progress, several gaps remain, which constitute the practical motivations for this paper's focus on used clothing collection services. First, existing research on circular service innovation is mostly concentrated on brand- or platform-led models, such as global resale applications or clothing rental services, while community-level systems (such as municipal collection bins, charity shops, and localized collection mechanisms) are often viewed as infrastructure rather than important carriers of service innovation; however, such systems actually handle considerable volumes of used clothing and are crucial links in continuously providing inventory for circular business models. Second, the integration between front-end user experience (such as donation convenience, subjectively perceived accessibility, and digital interaction interfaces) and back-end low-carbon operations (such as inventory management in the resale process and carbon emissions from warehousing and transportation) remains limited, and analytical methods for facility location and supply chain optimization are rarely explicitly incorporated into service design discussion frameworks. Third, most research on circular fashion services does not incorporate policy instruments such as carbon taxes or carbon labeling into the analytical perspective, even though these policies simultaneously shape enterprise incentive mechanisms and user cognition in reality.

In response, this paper approaches the used clothing collection problem from a service innovation perspective, combining user-centered service access models (such as personalized collection bin recommendations) with low-carbon inventory management and policy-sensitive service design. Rather than proposing a new independent business model classification system, this paper uses service logic as an analytical framework to connect the relationships among user experience, operational analysis, and governance mechanisms in circular textile systems, aiming to provide a more explicit service system perspective as a complement to existing circular fashion research by highlighting data-driven approaches, user-centricity, and environmental policy factors.

2.2 User-Centered Collection Service Design

Digitalization is increasingly recognized as a key enabling factor for driving the circular economy and sustainable transformation. Digital tools are not optional add-ons but constitute core infrastructure that connects materials, products, and diverse stakeholders in service-based value creation processes, taking forms including sensors, QR codes, blockchain, data platforms, and artificial intelligence. In the textile and apparel value chain, this trend is specifically manifested in the rapid emergence of traceability solutions, digital product passports, environmental performance dashboards, and consumer-facing applications, which make previously invisible environmental impacts and logistical flows clearly visible and transform them into perceivable and actionable information.

In the upstream segments of the textile system, digital technologies are enabling unprecedented

transparency and information continuity. Related traceability research indicates that Radio Frequency Identification (RFID), QR codes, barcodes, Internet of Things (IoT) sensors, and blockchain-based platforms are being widely used across multi-tier suppliers, consolidators, and brands to track fibers, fabrics, and finished garments throughout their entire lifecycle. The European Union's Digital Product Passport (DPP) initiative epitomizes this trend: DPP is envisioned as a digital record attached to every garment, encompassing material composition, chemical substance information, production location, care and repair instructions during the use phase, and end-of-life disposal options. For the textile industry, DPP is expected to provide crucial support for circular development by facilitating sorting and recycling, helping consumers verify sustainability claims, and linking regulatory requirements (such as the EU's Ecodesign for Sustainable Products Regulation) with concrete product-level data.

From a service perspective, such traceability solutions and digital product passports can be viewed as information services supporting circular business models, providing foundational conditions for new forms of value co-creation: consumers can obtain sustainability information about products by scanning codes, repair services can identify compatible components accordingly, and recycling enterprises can automatically identify fiber blend structures. Digital platforms such as the Aura Blockchain Consortium in the luxury fashion sector demonstrate that shared data infrastructure can support services including product authentication, provenance tracing, and circular resale across brands. However, this challenge is not merely technical—that is, issues of data collection and storage—but even more organizational and institutional: relevant stakeholders need to reach consensus on standard systems, data sharing rules, and governance mechanisms.

At the downstream and consumer level, digital transformation is giving rise to new modes of participation and behavior change mechanisms. A growing body of research has documented digital strategies and tools for guiding end consumers to participate in circular fashion, including various applications supporting wardrobe management, peer-to-peer resale, rental reservations, repair arrangements, and collection drop-offs. Many tools incorporate gamification mechanisms, reward systems, and social features to encourage sustainable practices such as reuse, repair, and donation. Alves et al. (2023) propose an eco-gamification platform that guides users to record their sustainable behaviors (such as reducing washing, performing repairs, or donating) and reinforces behavior change through point incentives and carbon footprint reduction feedback. Such platforms translate abstract environmental goals into concrete, trackable tasks embedded in daily service interactions, thereby enhancing the perceivability and actionability of sustainable behaviors.

Beyond specific industry solutions, broader research on data-driven sustainable management emphasizes the role of dashboards, analytical tools, and ESG software in environmental performance monitoring and guidance. Organizations are increasingly using sustainability dashboards and ESG analytics platforms to collect data on energy use, emissions, water resources, waste, and social indicators, visualize trends, and support decision-making. These tools not only help improve compliance and regulatory reporting efficiency but can also reveal operational inefficiencies and improvement opportunities. In service contexts, dashboards can be embedded into daily management processes, for example, providing store managers with real-time feedback on waste and energy consumption, or enabling service designers to intuitively understand how adjustments to recycling return programs affect collection volumes and environmental performance.

It is important to emphasize that digital transformation in circular textile systems is not limited to high-tech platforms or enterprise-level systems. As service ecosystem research points out, resource integration occurs within networks composed of diverse stakeholders including small and medium enterprises, local governments, non-governmental organizations, and community projects. For these smaller-scale participants, the digital tools used may be merely spreadsheets, low-code applications, QR codes, or basic geographic information systems, yet they can equally form meaningful data loops to support planning,

communication, and learning. From this perspective, digitalization should be understood from two dimensions: first, the technical sophistication of the tools themselves, and second, the extent to which data is genuinely used to support decision-making and facilitate value co-creation.

Despite the considerable progress made in the above research, several gaps remain when viewing used clothing collection as a complete service system. First, most traceability and Digital Product Passport (DPP)-related initiatives primarily focus on new product stages, that is, tracking garments from production to first use, while community-level and secondhand circulation segments have not been sufficiently incorporated into these data infrastructures. Second, although consumer-facing resale and wardrobe management applications continue to emerge, user-centered design regarding "service access methods" in the collection stage remains underexplored, such as how digital tools can guide users to optimal donation locations or how to intuitively present the environmental impact of their donation behaviors. Third, research related to sustainability dashboards and ESG analytics is mostly concentrated on enterprise-level information disclosure and resource efficiency management, with less exploration of how to translate these analytical results into narrative forms that can effectively engage donors and consumers in circular textile services.

This paper responds to the above gaps by focusing on small-scale, service-oriented digital practices in used clothing systems and combining user-centered analysis (such as donation behavior and location preferences) with low-carbon operational issues (such as inventory-related emissions and policy scenario analysis). By considering even simple websites and spreadsheets as part of digital service infrastructure, this paper echoes the view that circular economy transformation depends not only on large digital platforms but equally on the data practices conducted by diverse stakeholders in their daily operations within service ecosystems.

2.3 Low-Carbon Inventory Management in Secondhand Clothing Supply Chains

In used clothing systems, front-end service innovation primarily focuses on service access methods, user experience, and engagement mechanisms, while back-end operations—including collection, sorting, warehousing, and resale—largely determine the system's environmental performance and economic viability. Among these, inventory management is particularly critical: the duration of clothing storage, storage conditions, and the coordination of logistics flows between different tiers not only directly affect energy consumption and greenhouse gas emission levels but also relate to the freshness and attractiveness of inventory goods.

In the broader field of supply chain research, a fairly rich body of research has formed around low-carbon supply chain management and carbon-constrained inventory models. Such research builds upon classical inventory theory by introducing carbon emission factors from production, warehousing, and transportation stages, typically analyzed in conjunction with regulatory systems such as carbon taxes, carbon trading mechanisms, or carbon emission caps. For example, Benjaafar et al. (2013) incorporate emission constraints into lot-sizing decision models and find that even relatively simple emission reduction constraints can significantly alter optimal order quantities and replenishment frequencies. Hua et al. (2011) introduce a cap-and-trade system within a two-echelon supply chain framework, revealing how emission quotas and trading prices affect firms' ordering and pricing decisions. Building on this foundation, scholars have further extended related models to cover various scenarios including vendor-managed inventory, joint replenishment, and production-inventory coordination decisions under carbon policy constraints.

Parallel to model research centered on carbon policies, closed-loop supply chain and reverse supply chain research focuses on how end-of-life products are collected, remanufactured, recycled, or disposed of. Related research explores optimal collection rates, collection quantities, and remanufacturing decisions under environmental regulatory constraints and consumer preferences for remanufactured or regenerated products. In the textile and apparel sector, closed-loop supply chain research focuses on analyzing how brands and third-party collection entities design collection programs, refurbish clothing, and manage

product quality and inventory entering secondary markets. Pal (2017) and Ülkü and Hsuan (2017) point out that for circular fashion to be practically viable, reverse logistics and reuse/remanufacturing decisions must be tightly coupled with front-end business models and consumer-facing value propositions.

Against the above broader research backdrop, used clothing collection presents a series of unique challenges in inventory management. Unlike new apparel, used clothing entering the system is often highly heterogeneous, with significant variations in condition, style, and size, and collection quantities are typically difficult to predict; its resale value is highly sensitive to temporal factors (such as fashion trends and seasonal changes), quality factors (such as wear level and defect conditions), and consumers' subjective perceptions of cleanliness and sustainability. Meanwhile, the storage and handling processes for used clothing similarly consume energy and generate carbon emissions through heating, cooling, transportation, and loading/unloading activities. Therefore, low-carbon inventory management in this context must achieve trade-offs among the following aspects:

- Maintaining adequate category structure and inventory scale under the premise of supporting resale and charitable distribution;
- Minimizing the storage duration of goods whose value decays over time and reducing the associated carbon emissions;
- Strengthening decision coordination between upstream collection entities and downstream retailers or charitable organizations.

A substantial body of research has explored carbon-emission-aware pricing and coordination issues in two-echelon or multi-echelon supply chains through game-theoretic modeling. Zhang et al. (2014) and Xu et al. (2016) analyze the interaction mechanisms among wholesale prices, retail markups, and emission reduction efforts under carbon tax or cap-and-trade systems, and propose contract schemes to coordinate incentives between manufacturers and retailers. However, such models mostly focus on new products and have not sufficiently considered the demand structure changes triggered by disclosing life-cycle emission information through carbon labeling.

This model studies a two-echelon supply chain consisting of secondhand clothing suppliers (such as sorting centers or collection organizations) and retailers operating resale channels. In the model, suppliers choose inventory carbon emission levels through emission reduction investments (such as improving energy efficiency in warehousing and handling operations), while retailers are responsible for setting sales prices for secondhand clothing. Demand is specified as a function of price and inventory carbon emission levels, thereby characterizing the mechanism by which carbon labeling influences consumer choices: low-emission inventory can be promoted as more environmentally friendly, thus attracting carbon-sensitive consumers. The model systematically analyzes four regulatory scenarios: no regulation, carbon tax, carbon labeling, and parallel implementation of carbon tax and carbon labeling; and further compares operational outcomes under two decision-making frameworks: decentralized decision-making (Stackelberg game with supplier as leader) and centralized decision-making (supply chain integration).

The research conclusions are highly instructive for service innovation in used clothing systems. Gao et al. find that for environmentally friendly suppliers (i.e., those with relatively low emission reduction costs), compared to no-regulation scenarios, carbon tax and carbon labeling policies typically induce lower optimal inventory carbon emission levels, increased market demand, and higher profits; whereas for high-emission suppliers, policy effects depend on key thresholds such as consumer carbon sensitivity and tax rates, and beyond certain levels, increasing tax rates or strengthening labeling requirements do not further reduce emissions but may instead undermine overall profitability. The research also shows that compared to centralized decision-making, decentralized decision-making is more likely to lead to suboptimal environmental and economic performance outcomes, but through Nash bargaining-based wholesale price contracts, supply chain coordination can be achieved and additional gains can be distributed relatively fairly

under centralized scenarios.

From a service perspective, this low-carbon inventory model can be reinterpreted as the "backbone" mechanism supporting environmentally differentiated secondhand clothing services. Inventory carbon emission decisions and carbon labeling are no longer merely technical variables at the operational level but constitute important components of the service value proposition, directly influencing how resale services are designed, pricing strategies, and communication discourse. For example, retailers can segment secondhand clothing product lines into "low-carbon" and "standard" services supported by inventory carbon emission practices and transparent labeling. Wholesale contracts between collection entities and retailers can also be viewed as part of service governance mechanisms, defining who bears responsibility for emission reduction investments and how benefits are distributed. The model also provides important insights for understanding how public policy instruments (such as carbon taxes and carbon labeling) shape the space for viable service innovation.

Despite the important progress made in the above research, low-carbon inventory management literature, including that by Gao et al., typically abstracts user-facing service elements to a high degree, with related models mostly analyzing single products or unit demand, failing to explicitly incorporate how service design factors (such as donation convenience and user perception of carbon labeling information) affect donation scale and market demand. Conversely, much research on circular fashion service innovation often does not incorporate inventory carbon emissions or carbon policy factors into analytical frameworks. The integrated perspective proposed in this paper aims precisely to bridge this gap by connecting user-centered service access and donation behavior analysis with low-carbon inventory management mechanisms as elements of service design, constructing systematic integration between front-end services and back-end operations.

3. Integrated Service System Architecture for Used Clothing Collection

Based on the above two studies, this paper proposes a service system architecture that connects user-centered collection bin services with low-carbon inventory management in secondhand clothing resale. This architecture consists of three tiers: (1) the user-facing service layer; (2) the operational analysis layer; (3) the policy and governance layer.

3.1 User-Facing Service Layer

The user-facing service layer aims to support individual participation in used clothing collection activities with minimal participation barriers and maximum transparency, with its core components including:

- User Segmentation and Preference Mining: Utilizing logistical and behavioral data (such as donation history, geographic location, dwell time, etc.) to cluster users and identify their dominant preferences regarding time, cost, and distance. This approach follows the K-means-based user segmentation thinking from collection bin location research, dividing users into groups such as time-preference-oriented, cost-preference-oriented, and distance-preference-oriented.
- Personalized Collection Bin Recommendations: For each donation decision, the service system recommends one or more collection bins that minimize the user's primary cost (such as travel time) while satisfying secondary cost tolerance thresholds. This recommendation algorithm is implemented in simulation-based integer programming form, selecting collection bins with the lowest primary objective value while satisfying all constraints.
- Digital Channels and Communication Mechanisms: Displaying nearby collection bins, recommended drop-off points, operating hours, and expected travel times through simple websites or applications, which can be integrated with maps and location services. Users can also intuitively understand how their behaviors contribute to collective collection effectiveness and environmental performance (see Section 4).

This layer primarily embodies service innovation centered on service access, convenience, and personalized guidance.

3.2 Operational Analysis Layer

The operational analysis layer processes data from donation and resale operations to optimize the system's environmental and economic performance, with its main components including:

- Inventory Carbon Emission Decision Rules: Based on the low-carbon inventory model, suppliers (such as sorting centers or resale operation entities) weigh emission reduction investment costs, carbon tax levels, and consumer sensitivity to carbon labeling to determine inventory carbon emission levels. Under centralized or coordinated decision-making scenarios, optimal emission levels and pricing strategies are derived by maximizing overall supply chain profit while satisfying regulatory constraints.
- Carbon Emission-Aware Pricing and Labeling Mechanisms: The retail prices and carbon labels conveyed to consumers simultaneously reflect market demand conditions and inventory carbon emission levels. For environmentally friendly suppliers, higher carbon tax levels and stronger consumer environmental awareness typically drive down inventory carbon emissions and may support higher price premiums; for high-emission suppliers, policy effects depend on key thresholds that determine whether regulatory measures can effectively drive emission reductions.
- Coordinated Integration of Donation Flows and Inventory Decisions: Data from the user-facing service layer (such as donation volumes, temporal distribution characteristics, and spatial distribution patterns) is used to support inventory planning decisions (such as batch processing strategies, transfer frequencies, and warehousing capacity allocation); conversely, inventory constraints can also feed back into service design (such as temporarily restricting donations when collection bins are overloaded or guiding users to alternative drop-off points).

This layer embodies analytical models being embedded into the system in the form of "service intelligence" modules, rather than existing in isolation as standalone optimization tools.

3.3 Policy and Governance Layer

The policy and governance layer shapes how this service system interacts with broader sustainability and regulatory frameworks, primarily manifested in:

- Carbon Tax and Carbon Labeling Systems: Carbon tax and carbon labeling mechanisms influence operational entities' motivation for emission reduction investments and service differentiation strategies by altering incentive structures. Low-carbon inventory research indicates that the actual effectiveness of such policy instruments depends on supplier types (environmentally friendly or high-emission) and decision-making modes (decentralized or centralized).
- Municipal and Charitable Governance Mechanisms: Governance arrangements of municipal departments and charitable organizations determine the authority for collection bin location, operating entities, and data sharing methods. User-centered recommendation systems often require collaborative cooperation among local governments, non-profit organizations, and potential private platforms for implementation.
- Data Governance and Privacy Protection: When mining user preferences and location data, data governance and privacy issues must be fully considered. Collection bin location research protects user privacy while enabling simulation analysis through random matching of social activity locations; in real-world services, transparent data usage policies and clear user informed consent mechanisms should be established.

These three tiers together constitute a multi-stakeholder service system in which data and analytical tools organically connect user experience, operational management, and policy instruments.

4. Integrated Application of Analytical Insights in Service Design

In this section, this paper distills and summarizes key principles for service design through juxtaposed comparison of these two analytical studies.

4.1 Personalized Service Access as Service Innovation

The collection bin recommendation model demonstrates that users exhibit significant differences in tolerance regarding time, cost, and distance, and these preferences can be mined through historical donation behaviors. Service designers can not only make collection bin recommendations based on this but also customize differentiated communication strategies (for example, emphasizing environmental impact for users with higher distance tolerance and highlighting convenience for time-sensitive users), and plan corresponding promotional and marketing activities around social activity locations with higher potential.

Principle 1: *Collection services should treat collection bin selection as an individualized service decision rather than merely an infrastructure allocation problem, and achieve personalized recommendations through concise and effective data analysis.*

4.2 Low-Carbon Inventory Management as Service Support

The low-carbon inventory model reveals how inventory carbon emission levels in secondhand clothing resale can be optimally decided under different policy scenarios and consumer carbon sensitivity conditions. For service design, this means environmental performance derives not only from production stages but equally depends on inventory management approaches. Retail services can adopt different inventory strategies (such as shortening storage durations and increasing turnover rates) and communicate their carbon impact to consumers through carbon labeling and narrative expressions.

Principle 2: *Resale services should explicitly incorporate inventory-related carbon emissions into their service support systems and achieve alignment between economic and environmental objectives through corresponding coordination mechanisms.*

4.3 Data as Narrative: Making Impact Visible

Both studies generate rich quantitative analytical results, including user segmentation and collection bin recommendation spatial distribution maps, as well as emission, price, and profit variation surfaces under different carbon tax and carbon labeling policy intensities (see figures on pages 5–9 and 13–16 in the inventory model paper regarding emission, demand, and profit patterns under different policy intensities). From a service innovation perspective, these analytical results can be reframed as "data narratives" for stakeholders, such as showing donors how personalized collection bin layouts reduce travel-related emissions, or explaining to consumers how carbon labels genuinely reflect changes in back-end operational approaches.

Principle 3: *Analytical results should be transformed into concise and intuitive visual narratives that make environmental and social benefits clearly visible to donors, consumers, and partners.*

4.4 Policy-Sensitive Service Strategies

The low-carbon inventory model reveals significant threshold effects: when carbon tax or carbon labeling intensity exceeds a certain level, further tightening of regulation does not continue to incentivize high-emission suppliers to reduce emissions, and decentralized supply chains may respond to policies differently than centralized supply chains. Therefore, service innovators must design service strategies with robustness to policy changes and be able to flexibly adjust service solutions as policy environments evolve, such as adjusting price structures in a timely manner or strengthening (or weakening) emphasis on carbon labeling in promotions.

Principle 4: *Service strategies related to secondhand clothing should incorporate sensitivity analysis to policy parameters into*

design and enhance adaptability to policy changes through governance mechanisms such as contractual arrangements and coalition

5. Managerial Implications and Policy Implications

5.1 Implications for Local Governments and Charitable Organizations

Local government collection coordination departments and charitable organizations can leverage this integrated framework to redesign their service systems. Rather than deploying collection bins based solely on experiential rules, they can pilot donation behavior data collection, conduct brief user clustering analysis, and use simulation methods to test different collection bin configuration schemes before actual deployment. Meanwhile, they can establish partnerships with resale operation entities that adopt low-carbon inventory management practices, thereby organically linking improvements in front-end service accessibility with reductions in back-end carbon emissions.

5.2 Implications for Social Enterprises and Platform-Based Service Providers

Social enterprises and digital platforms operating secondhand resale channels can incorporate inventory carbon emission analysis into their service value propositions. Specifically, they can introduce carbon labeling mechanisms for secondhand goods, adjust pricing strategies and communication approaches based on analytical results, and design wholesale contracts with upstream collection entities that incentivize low-carbon inventory management. Furthermore, such platforms can provide users with personalized drop-off routes and collection bin recommendations through applications, thereby organically bundling user convenience with environmental value to form differentiated service packages.

5.3 Implications for Policymakers

Policymakers considering the introduction of carbon tax and carbon labeling policies in the textile sector can gain important insights from this integrated perspective. The low-carbon inventory model demonstrates that carbon tax levels and carbon labeling intensity need to be calibrated in conjunction with supplier types and supply chain structures to achieve emission reduction goals without undermining economic viability; while the collection bin location model highlights the importance of user-centered infrastructure design for enhancing actual participation rates and collection diversion rates. This suggests that if accompanied by support for digital infrastructure construction, data sharing mechanisms, and analytical capabilities at the community level, the overall effectiveness of related fiscal and regulatory policies will be significantly amplified.

6. Future Research Agenda

This integrated analysis proposes several research directions worthy of further exploration, providing insights for subsequent research on service innovation and sustainable development in used clothing systems:

1. Multi-level Modeling: Constructing integrated models that simultaneously incorporate user-level collection bin recommendations, community-level collection behavior patterns, and supply chain-level inventory carbon emission decisions, rather than treating these issues as isolated research subjects.
2. Behavioral Experimental Research: Conducting field experiments to test whether personalized collection bin recommendations and impact narratives can substantively change donation behaviors, and whether they enhance consumers' willingness to pay premiums for low-carbon secondhand goods.
3. Platform Governance Research: Exploring how data and analytical capabilities can be equitably

shared among local governments, charitable organizations, platform service providers, and logistics partners, and the impacts of different governance arrangements (such as data trusteeship mechanisms) on service innovation.

4. Cross-Context Comparative Research: Comparing differences across regions in policy systems, infrastructure levels, and cultural attitudes toward secondhand clothing to assess the transferability and applicable boundaries of the proposed service design principles.
5. Extension to Other Material Flows: Extending the application of this integrated service framework to other circular flows (such as electronics, books, small appliances, etc.) and comparing similarities and differences in user preferences, inventory dynamics, and policy interaction mechanisms across different domains.

7. Conclusion

Used clothing collection sits at the intersection of environmental protection, social value creation, and service innovation. This paper integrates two analytically rigorous research findings—one focusing on user-centered used clothing collection bin location and recommendation, the other exploring low-carbon inventory management in secondhand clothing supply chains under carbon tax and carbon labeling systems—and proposes a data-driven service system architecture for used clothing collection. This framework emphasizes personalized service access methods, carbon-emission-aware inventory decisions, and the utilization of data simultaneously as a decision support tool and narrative vehicle.

For researchers, this integrated analysis demonstrates how operations research models can be reinterpreted as service design tools and embedded within circular business models; for practitioners and policymakers, this paper provides concrete design principles and action pathways to achieve synergy among user experience, operational efficiency, and environmental performance in used clothing collection services. As digital technologies and environmental policies continue to evolve, integrating user-centered analytical approaches with low-carbon operational mechanisms will become key to building circular textile systems that are technically efficient, socially engaging, and environmentally effective.

References

Alves L, Ferreira EF, Domingues AR (2021) Towards circular economy in the textiles and clothing value chain: A review of traceability approaches. *Waste Management & Research* 39(8): 1030–1045.

Alves L, Cruz EF, Ferreira EF (2023) Towards an eco-gamification platform to engage consumers in the textile & clothing circular economy. *Sustainability* 15(6): 5398.

Barletta M, Daddi T, Iraldo F (2024) Business strategy and innovative models in the fashion industry: A circular economy perspective. *Business Strategy and the Environment* 33(5): 2593–2608.

Benjaafar S, Li Y, Daskin M (2013) Carbon footprint and the management of supply chains: Insights from simple models. *IEEE Transactions on Automation Science and Engineering* 10(1): 99–116.

Circularise (2024) Digital product passports (DPP): What, how, and why? Available at: https://www.circularise.com (accessed 2025-10-01).

Cruz EF, Alves L, et al. (2023) Digital solutions for engaging end-consumers in the textile and clothing circular economy: A systematic review. *Cleaner and Responsible Consumption* 10: 100090.

da Cruz AMR, et al. (2025) Digital product passports in promoting circular economy: A review and research agenda. *IFAC-PapersOnLine* 58(29): 902–909.

Coscieme L, Manshoven S, Gillabel J, Grossi F, Mortensen LF (2022) A framework of circular business models for fashion and textiles: The role of business-model, technical and social innovation. *Sustainability: Science, Practice and Policy* 18(1): 451–462.

Dehghannejad M, et al. (2025) Cascading of circular business models in the textile and apparel value chain. *Circular Economy and Sustainability* (in press).

EPRS (2024) *Digital Product Passport for the Textile Sector*. European Parliamentary Research Service, Scientific Foresight Unit (STOA), Brussels.

Ellen MacArthur Foundation (2017) *A New Textiles Economy: Redesigning Fashion's Future*. Ellen MacArthur Foundation, Cowes.

Ellen MacArthur Foundation (2020) *Circular Business Models: Redefining Growth for a Thriving Fashion Industry*. Ellen MacArthur Foundation, Cowes.

Gao H, Tang JK, Gong D, Zhao X, Yan X (2024) Optimising low carbon inventory decisions and coordination for used clothing under carbon tax and carbon labelling system. *Ecological Chemistry and Engineering S* 31(4): 507–525. https://doi.org/10.2478/eces-2024-0033

Greenside Solutions (2025) Environmental dashboard: Real-time sustainability. Available at: https://www.greensidesolutions.com (accessed 2025-10-01).

Henninger CE, et al. (2025) How circular are circular business models? The case of the fashion industry. *Journal of Cleaner Production* (in press).

Hua G, Cheng TCE, Wang S (2011) Managing carbon footprints in inventory management. *International Journal of Production Economics* 132(2): 178–185.

Interzero (2025) Environmental Sustainability Dashboard. Available at: https://interzero.at (accessed 2025-10-01).

Kirchherr J, Piscicelli L, Bour R, Kostense-Smit E, Muller J, Huibrechtse-Truijens A, Hekkert M (2023) Conceptualizing the circular economy (revisited): An analysis of 314 definitions. *Resources, Conservation and Recycling* 188: 106586.

Key ESG (2025) How to excel at sustainability data analytics. Available at: https://www.keyesg.com (accessed 2025-10-01).

Microsoft (2024) Microsoft Sustainability Manager: Turn environmental data insights into action. Available at: https://www.microsoft.com/sustainability (accessed 2025-10-01).

Pal R (2017) Sustainable design and business models in textile and fashion: A review. In: Muthu SS (ed) *Sustainable Management of Luxury*. Springer, Singapore, 127–157.

Plan A (2024) 7 best sustainability software in 2025. Available at: https://plana.earth (accessed 2025-10-01).

Salmi A, Kuula S, Antikainen R (2022) Implementing circular business models in the textile and clothing industry. *Journal of Cleaner Production* 380: 135004.

Semantive (2025) Data-driven sustainability: How custom ESG dashboards are revolutionizing corporate reporting. Available at: https://www.semantive.com (accessed 2025-10-01).

SimpleKPI (2025) Environmental sustainability KPI dashboard example. Available at: https://www.simplekpi.com (accessed 2025-10-01).

Ülkü MA, Hsuan J (2017) Towards sustainable consumption and production: Competitive pricing of

remanufactured products. *Journal of Cleaner Production* 164: 1358–1370.

Vargo SL (2021) Beyond circularity—A service-dominant (S-D) logic perspective. *Circular Economy and Sustainability* 1(1): 59–74.

Vellesalu A, Fuentes C, Peñaloza L (2023) A service ecosystem perspective in the textile and clothing sector: Resource integration for circular economy. *Journal of Macromarketing* 43(3): 310–326.

WRAP (2021) *Changing Our Clothes: Why the Clothing Sector Should Adopt New Business Models*. Waste and Resources Action Programme (WRAP), Banbury.

WRAP (2023) *Circular Business Models Guide for Fashion*. Waste and Resources Action Programme (WRAP), Banbury.

Position Paper. Munich: acatech – National Academy of Science and Engineering.

Xu L, Wang C, Zhao J (2016) Decisions in a supply chain with a carbon cap-and-trade system. *Journal of Cleaner Production* 112: 4494–4507.

Zhang B, Xu L, He Y (2014) Carbon emission reduction and coordination of supply chain with vendor-managed inventory. *International Journal of Production Economics* 161: 140–151.

ZigZag / various industry sources (2025) Digital enablers of the circular economy. *acatech*