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EVIDENCE-BASED CIRCULAR TRANSFORMATION: A CASE STUDY OF THE MOLDOVAN TEXTILE SECTOR

Purpose. *This study develops an evidence-based transition model for the circular transformation of the textile and clothing sector of the Republic of Moldova. It focuses on pre-consumer textile waste, resource-efficiency barriers and technically appropriate routes for retaining material value. Particular attention is paid to Moldova's alignment with the evolving European Union policy framework and to the transition from a predominantly linear Cut-Make-Trim (CMT) production model towards traceable circular value chains.*

Keywords: *circular economy, textile waste, pre-consumer waste, material flow analysis, CMT, resource efficiency, recycling, extended producer responsibility.*

Objectives. The objectives are: (1) to characterise the principal categories of pre-consumer textile waste generated by Moldovan garment manufacturers; (2) to map the main material-flow nodes and identify points of linear leakage within the CMT model; (3) to examine the economic, technological and regulatory constraints affecting resource efficiency; and (4) to propose a hierarchy-based architecture combining prevention, reuse and redistribution, mechanical recycling and, only for non-recyclable residual fractions, controlled energy recovery.

Methodology. The research applies a qualitative analytical design combined with a screening-level Material Flow Analysis (MFA) based on secondary sectoral evidence. Data from the Employers' Association of the Light Industry of Moldova (APIUS), national indicators, peer-reviewed studies and official European Union and Moldovan policy documents were triangulated to construct a sector-level material-flow model [1–6, 8, 9, 12]. The approach follows the MFA principles described by Brunner and Rechberger [4]. Because nationally harmonised mass-balance data on textile inputs, stocks and treatment destinations are not yet available, the MFA is used to identify nodes, approximate magnitudes and leakage points rather than to claim a closed national material balance. The reported estimate of 8–10 thousand tonnes of pre-consumer fabric waste per year is therefore treated as a sectoral screening estimate, not as a directly measured national inventory [1, 5].

Research results. Global environmental and policy context. The most recent European Environment Agency assessment shows that EU consumption of clothing, footwear and household textiles reached approximately 19 kg per person in 2022, while textile waste amounted to about 16 kg per person; textiles remain among the household consumption categories with the highest aggregate pressures on raw materials, climate, water and land [3]. The 2022 EU Strategy for Sustainable and Circular Textiles set the policy direction towards durable, repairable and recyclable products [2]. This framework has since been strengthened by the Ecodesign for Sustainable Products Regulation (ESPR), which provides the legal basis for product-specific ecodesign requirements and digital product passports and, from 19 July 2026, prohibits large companies from destroying unsold apparel, clothing accessories and footwear [10]. Directive (EU) 2025/1892 further requires Member States to establish harmonised extended producer responsibility (EPR) schemes for textiles by April 2028 [11]. For Moldova, these developments are directly relevant because the sector is closely integrated into EU value chains.

The APIUS sustainability roadmap, based primarily on 2022 sectoral data, records 714 light-industry enterprises and approximately 22,770 employees, with micro and small enterprises accounting for more than 88% of firms. The European Union remains the sector's principal commercial partner, while medium-sized and large manufacturers commonly operate through C&M, CMT or FOB export-service models [1]. This structure supports employment and export integration, but the prevalence of contract manufacturing limits domestic control over product development, materials and end-of-life decisions.

The CMT configuration also creates a specific circularity challenge. Fabrics and accessories are largely imported, and the client may retain ownership or control over materials, whereas cutting waste is physically generated in Moldova. Sectoral assessments estimate approximately 8-10 thousand tonnes of fabric waste per year [1, 5]. More than 90% of surveyed companies separately collect conventional packaging streams such as plastic and cardboard, but textile cutting waste is generally not sorted by fibre composition; most is removed through municipal sanitation services and sent to landfill. Only a small minority of export-service companies return textile waste to clients on request, and local reuse remains limited [1, 5].

The regulatory environment is now changing rapidly. In July 2026, the Ministry of Environment of the Republic of Moldova conducted a repeated public consultation on the draft Regulation on the management of textile products and textile waste. The draft is intended to establish an EPR-based framework for

collection, sorting, reuse, recycling and other treatment routes in accordance with the national Waste Law and EU-alignment objectives [12]. This development increases the importance of auditable waste accounting, fibre-composition information, traceability and documented treatment pathways. Circularity is therefore becoming both an environmental requirement and a condition for continued integration into European supply chains.

1. Waste characterisation

The pre-consumer textile-waste stream is heterogeneous because Moldova imports effectivelly all textile substrates used by the garment sector [1]. Relevant fractions include cotton and other cellulosic materials, polyester and other synthetics, cotton/polyester blends, elastane-containing fabrics, denim, knitted fabrics, wool, non-conforming cut parts and usable end-of-roll materials [1]. Their circular potential depends not only on fibre type but also on colour, contamination, finishes, trims, elastane content and the size of offcuts. Clean mono-material or near-mono-material pre-consumer streams offer the most immediate potential for mechanical recycling, whereas complex fibre blends require more advanced sorting and separation technologies and may be unsuitable for high-quality fibre-to-fibre recycling without additional processing.

2. Material Flow Analysis

To visualise material movement and locate losses within the CMT system, the sectoral flow is represented through four linked nodes: textile input (M_in), manufacturing and cutting, useful product output (M_product), and pre-consumer waste (M_waste) distributed among return, reuse, recycling, energy recovery or disposal. Conceptually, the system follows the mass-balance relation *M_in = M_product + M_waste + change in stock* [4]. In CMT operations, however, legal and contractual ownership of surplus materials can restrict a Moldovan factory's ability to redirect them to secondary markets or recyclers until the material is formally released by the client or classified as waste. This contractual dimension must therefore be treated as part of the material-flow system rather than as an external administrative issue.

Available evidence does not support a closed national mass balance for textile inputs and outputs; therefore, precise sector-wide fabric-utilisation percentages should be interpreted cautiously. The most defensible quantitative anchor is the estimated 8-10 thousand tonnes of annual pre-consumer fabric waste [1]. The principal leakage point is the downstream destination of this material: sectoral interviews consistently indicate that most cutting waste leaves the productive system unsorted and is sent to landfill, while only limited quantities are returned to clients or reused in low-value applications [1]. The immediate

analytical priority is consequently not to refine unsupported efficiency percentages, but to establish standardised measurement, fibre-based textile sorting and traceable destination data at factory level.

3. Resource efficiency and the CMT profitability constraint

The circular transformation of Moldovan light industry cannot be separated from its economic structure. The APIUS roadmap identifies low profitability and chronic underinvestment as persistent constraints; apparel companies invested approximately 3.6% of turnover in 2022 [1]. Under these conditions, capital-intensive sorting, recycling and digital traceability systems are difficult to finance exclusively from internal resources. The transition therefore requires a combination of enterprise investment, producer-responsibility mechanisms, public policy and targeted donor or development-finance support.

The sector comprises two broad groups with different circularity opportunities. Micro and small enterprises and local brands are flexible and can use deadstock, short production runs and direct-to-consumer models, but they have limited capital and weak bargaining power. Medium-sized and large export-oriented factories generally possess more advanced equipment and quality-management systems, but many remain dependent on CMT or FOB contracts. For these firms, circular upgrading depends not only on technology but also on contractual arrangements that define ownership of surplus materials, data-sharing obligations and responsibility for waste treatment.

Technological efficiency: automation and material productivity. Grant-supported programmes such as SMART Factory demonstrate that automation, Lean methods and modern equipment can generate factory-level productivity gains of approximately 20-25% [1]. CAD, digital marker planning and automated cutting can also improve material utilisation by reducing avoidable cutting losses, although productivity gains should not be interpreted as equivalent waste-reduction rates. For circularity, the key requirement is to connect digital production planning with measured material-loss indicators, fibre-composition records and traceable waste destinations.

Energy efficiency and decarbonisation complement, but do not replace, material circularity. The sectoral roadmap documents investments in renewable electricity, energy-efficient equipment and factory modernisation [1]. Their environmental performance should be evaluated through plant-specific energy and emissions data rather than generalised sector-wide assumptions. From a circular-economy perspective, priority should remain on preventing material losses and retaining products and fibres at their highest feasible value, while energy efficiency reduces the footprint of the processes that remain.

4. Hierarchy-based valorisation architecture

The evidence indicates that process efficiency alone cannot eliminate technological textile waste. A national transition model therefore requires organised collection, sorting, aggregation and valorisation infrastructure. A useful European reference is the Croatian Regeneracija model, which demonstrates how separately collected textile waste can be processed into regenerated fibres and non-woven products for construction, furniture and automotive applications [13]. For Moldova, the estimated scale of pre-consumer fabric waste suggests that coordinated aggregation could help create volumes sufficient for economically viable sorting and recycling, but this proposition requires a dedicated techno-economic feasibility assessment.

A hierarchy-based architecture can distinguish three immediate pathways. The first is mechanical fibre recovery for clean and compositionally documented mono-material or near-mono-material streams, especially cotton, selected denim and wool. Cutting and shredding are followed by fibre opening and classification. Where fibre length and quality permit, recovered fibres may be blended with virgin fibres for new yarns; shorter fibres can be directed to non-woven insulation, fillings or geotextile applications. Because pre-consumer waste is comparatively clean and its composition can be documented at source, it is generally more suitable for this route than heterogeneous post-consumer waste [5, 8, 13].

The second pathway is reuse and redistribution of usable surplus fabrics, roll ends and deadstock through a digital B2B platform. These materials should not be treated as waste where direct reuse is legally and technically feasible. A transparent marketplace could connect large export-oriented factories with local brands, micro-enterprises, designers and educational institutions, reducing storage and disposal costs while extending the useful life of materials. This approach is consistent with the wider role of digital redistribution and resale platforms in circular fashion systems [7, 9]. Its implementation would require clear rules on ownership transfer, quality information and traceability.

The third pathway concerns residual fractions for which reuse or material recycling is not technically or economically feasible in the short term. Controlled energy recovery may be considered only as a lower-priority transitional option in authorised installations with appropriate emissions control; it is not recycling and should remain subordinate to prevention, reuse and material recovery. For difficult blends such as cotton/polyester, emerging fibre-separation and chemical-recycling technologies may offer higher-value future routes, but their economic and infrastructural feasibility in Moldova has not yet been demonstrated and should be assessed through regional partnerships rather than assumed.

Taken together, the screening-level MFA shows that Moldova's main constraint is not the absence of potentially recoverable material but the lack of a coordinated system linking measurement, legal traceability, fibre-based sorting, aggregation and appropriate treatment. The proposed transition model therefore combines enterprise-level prevention and digital production control with sector-level collection and recycling infrastructure. Its practical implementation should begin with harmonised waste categories, standardised factory reporting and pilot aggregation schemes, followed by investment decisions based on verified volumes and composition. This sequence would reduce uncertainty, support EPR implementation and increase the probability that pre-consumer textile waste becomes a secondary-resource stream rather than a disposal liability.

Conclusion. The study identifies three principal findings. First, available sectoral evidence consistently indicates a substantial pre-consumer textile-waste stream of approximately 8-10 thousand tonnes per year, but current data are insufficient for a closed national mass balance; improved measurement and traceability are therefore a research and policy priority [1, 5, 8]. Second, low margins and limited reinvestment capacity constrain independent circular modernisation, making coordinated financing and producer-responsibility mechanisms important. Third, the policy context has changed materially: the EU framework now combines the 2022 Textiles Strategy with the ESPR and the revised Waste Framework Directive, while Moldova is developing an EPR-based regulation for textile products and waste [2, 10-12]. Mechanical recycling should be prioritised for clean, compositionally controlled streams; direct redistribution is preferable for usable surplus materials; and energy recovery should be restricted to residual fractions for which higher-value routes are unavailable. The resulting model provides a more realistic basis for moving the Moldovan garment sector from linear CMT production towards measurable and traceable circular value chains.

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