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ENSURING ENVIRONMENTAL SUSTAINABILITY IN TEXTILE ENTERPRISES: THE USE OF RECYCLED FIBRES AND ZERO-WASTE PRODUCTION TECHNOLOGIES

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Abstract
The paper analyses ways to ensure the environmental sustainability of textile enterprises through recycled fibres and zero-waste technologies and proposes a closed-loop production model.

Keywords: textile industry, environmental sustainability, recycled fibre, zero-waste production, circular economy, closed loop, mechanical recycling, chemical recycling, green economy, cotton-textile cluster.

Annotatsiya
Tezisda to‘qimachilik korxonalarida qayta ishlangan tola va chiqindisiz texnologiyalar asosida ekologik barqarorlikni ta’minlash yo‘llari tahlil qilinib, yopiq tsiklli ishlab chiqarish modeli taklif etilgan.

Аннотация
В тезисе проанализированы пути обеспечения экологической устойчивости текстильных предприятий на основе переработанных волокон и безотходных технологий, предложена модель замкнутого цикла.



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Kalit so‘zlar: to‘qimachilik sanoati, ekologik barqarorlik, qayta ishlangan tola, chiqindisiz ishlab chiqarish, aylanma iqtisodiyot, yopiq tsikl, mexanik qayta ishlash, kimyoviy qayta ishlash, yashil iqtisodiyot, paxta-to‘qimachilik klasteri.

Ключевые слова: текстильная промышленность, экологическая устойчивость, переработанное волокно, безотходное производство, циркулярная экономика, замкнутый цикл, механическая переработка, химическая переработка, зелёная экономика, хлопково-текстильный кластер.

INTRODUCTION

The textile and apparel industry is one of the most resource-intensive sectors of the global economy. According to Niinimäki et al., the industry consumes about 79 trillion litres of water per year, accounts for an estimated 8–10% of global CO_2 emissions and generates more than 92 million tonnes of textile waste annually, while the dominant linear model “take–make–dispose” continues to accelerate material throughput [1]. Under these conditions, the transition from linear to circular production has become not only an environmental requirement but also a factor of export competitiveness, since international buyers increasingly demand traceability, recycled content and verified environmental performance.

For Uzbekistan, the issue has particular strategic importance. The national textile industry has been restructured around vertically integrated cotton-textile clusters that cover the full chain from raw cotton to finished garments, which creates favourable preconditions for closing material loops within one organisational system. At the same time, empirical evidence shows that the post-consumer segment remains almost entirely linear: in Tashkent, 55% of households dispose of textile waste directly into municipal bins, although 74% declare readiness to

participate in separate collection if infrastructure is provided [3]. The **aim of this study** is to substantiate the directions for ensuring environmental sustainability of textile enterprises through the use of recycled fibres and zero-waste technologies and to propose a closed-loop production model adapted to Uzbek conditions.

MAIN PART

Methodology. The study is based on a systematic review of international life-cycle assessment (LCA) literature, comparative analysis of recycling and waste-minimisation technologies, and an analysis of recent empirical research on Uzbek textile enterprises. Methods of structural-logical analysis, comparison and modelling were applied.

Environmental rationale for recycled fibres. A comprehensive review of 41 LCA studies by Sandin and Peters demonstrates that textile reuse and recycling, in general, reduce environmental impact compared with incineration and landfilling, and that reuse is more beneficial than recycling [2]. However, the authors emphasise that the size of the benefit depends critically on the replacement rate, i.e., on the extent to which recycled material actually displaces the production of virgin fibre, and on the energy intensity of the recycling process itself [2]. This conclusion is methodologically important: the use of recycled fibres yields a real ecological effect only when it is embedded in a managed production system rather than applied as an isolated marketing measure.

Classification of zero-waste technologies. In the textile chain, waste arises at every stage: yarn ends and fly in spinning, selvedges in weaving, wastewater and chemical residues in dyeing and finishing, cutting scraps in garment production,

and discarded products after use. Accordingly, zero-waste production should be understood not as the absence of waste in a literal sense, but as a system in which each waste stream is either prevented or returned to production as a secondary resource. The main technological groups and their applicability are summarised in Table 1.

Table 1 Comparative characteristics of recycling and zero-waste technologies in the textile chain

Technology	Principle	Main environmental effect	Applicability in Uzbek enterprises
Mechanical recycling of cotton waste	Shredding and opening of cuttings and yarn waste into fibre for blended yarns	Reduced demand for virgin cotton, water and land	High: cotton dominates waste streams; existing spinning capacity
Chemical recycling (polyester, cellulose)	Depolymerisation or dissolution of fibres to regenerate raw material	Fibre-to-fibre loop for synthetics and blends	Medium-term: requires investment and partnerships
Zero-waste pattern cutting and CAD nesting	Digital optimisation of marker layout and design for minimal scraps	Prevention of pre-consumer cutting waste	High: low-cost, fast payback in garment units
Low-water dyeing and wastewater reuse	Reduced liquor ratio, membrane filtration, heat recovery	Lower water and energy intensity, less effluent	High priority under water-scarcity conditions
Collection, sorting and reuse systems	Separate collection and fibre-based sorting of post-consumer textiles	Extends product life; supplies recycling feedstock	Low at present; needs infrastructure and policy support

Source: compiled by the author based on [1], [2], [3].

As Table 1 shows, the technologies differ substantially in investment requirements and readiness. For Uzbek enterprises, the most realistic short-term priorities are mechanical recycling of cotton waste, digital cutting optimisation

and water-saving dyeing. This is consistent with the finding that about 60% of the textile waste stream in Tashkent consists of cotton, which makes it a suitable feedstock for mechanical recycling [3].

Closed-loop production model. Based on the analysis, a closed-loop (zero-waste) production model for a vertically integrated textile enterprise or cluster is proposed (Figure 1). Its distinctive feature is the presence of two internal loops in addition to the main product loop: a pre-consumer loop, which returns cutting scraps and yarn waste directly to the recycling stage, and a resource loop, which recovers water and heat from dyeing and finishing.

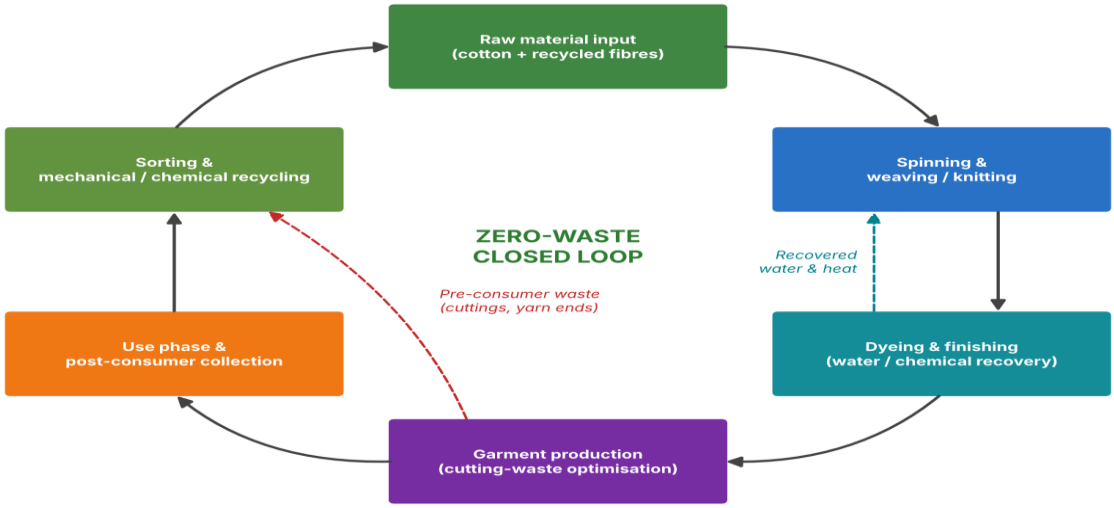


Figure 1. Closed-loop zero-waste production model for a textile enterprise (developed by the author)

The effectiveness of the model must be measured, not assumed. For this purpose, the composite Green Adaptability Index proposed by Olimova is appropriate: it integrates energy efficiency, water efficiency, waste circularity and green-

technology readiness through a geometric mean, so that high performance in one dimension cannot fully compensate for weakness in another [4]. Applying such an index allows management to identify bottlenecks, for example high water intensity in finishing or a low share of recycled input, and to link each bottleneck to a specific instrument such as an energy audit, water reuse or cutting-waste optimisation [4].

Barriers. The analysis identifies three groups of barriers to implementation in Uzbekistan: (1) infrastructural – the absence of separate collection and sorting of post-consumer textiles; (2) market – a weak and unstable market for recycled materials and the price advantage of virgin cotton; (3) institutional – insufficient economic incentives and the absence of extended producer responsibility for textiles [3]. Overcoming them requires coordinated action by enterprises, clusters and the state.

CONCLUSION AND RECOMMENDATIONS.

The study leads to the following conclusions. First, environmental sustainability of textile enterprises is achievable only through a systemic transition from the linear to the circular model, in which recycled fibres and zero-waste technologies are integrated into one managed production cycle. Second, the ecological benefit of recycled fibres depends on the degree to which they actually replace virgin raw materials and on the efficiency of the recycling process [2]. Third, the vertically integrated cluster structure of the Uzbek textile industry is a significant competitive advantage for closing material loops.

On this basis, the following recommendations are proposed:

1) to introduce mechanical recycling lines for cotton cutting and spinning waste at cluster level and to use the regenerated fibre in blended yarns;

2) to make CAD-based nesting and zero-waste pattern design mandatory elements of garment production planning;
3) to prioritise low-water dyeing, membrane filtration and heat recovery as the main investment direction in finishing;
4) to develop pilot projects for separate collection and sorting of post-consumer textiles in large cities in partnership with municipalities and the informal sector;
5) to apply a composite green-adaptability index for annual monitoring of enterprises and to link state incentives to its dynamics;
6) to introduce recycled-content certification and digital material traceability to strengthen access to export markets.
The implementation of these measures will reduce resource intensity and waste generation, improve the export competitiveness of Uzbek textile products and contribute to the national green-economy objectives.

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