DATA ANALYSIS FOR THE PREDICTION OF TEXTILE WASTE RECYCLING IN UKRAINE

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ABSTRACT

The textile and sewing industry is known to be the second most environmentally harmful industry for the environment. To maintain a circular economy, textile sources should be recycled, repaired, and used as much as possible while retaining their value. This research provides primary information about the database of post-production textile waste. The data suggests that 30 garment companies produce 778.11 tons of post-production textile waste per year, with cotton accounting for 42.14% and polyester for 32.45%. It is important to consider processing waste using different technologies according to the certification of textile waste to determine its raw material composition and purity. For an effective waste management policy, it is essential to implement it systematically, continually assess outcomes and challenges, and involve all stakeholders and activities that generate and manage waste. This is crucial in formulating an effective waste management policy.

KEYWORDS

Recycling; Textile waste; Cotton waste; Polyester waste; Pre-consumer waste; Post-production waste.

INTRODUCTION

The urgency of climate change, loss of nature, and pollution is worsened by unsustainable production and consumption. The textile industry, a significant contributor to these issues, must step up and implement sustainable practices. The industry's value chain significantly contributes to global greenhouse gas emissions. There is a growing need for the industry to recycle and use sustainable materials, reduce textile waste, and achieve net-zero emissions [1]. By 2030, the sector's CO_2 emissions are projected to increase to nearly 2.7 billion tons annually, equivalent to one year of emissions from almost 230 million average passenger vehicles [2]. Transforming the textile value chain towards sustainability and circularity is not just a necessity but a crucial step toward a circular economy, and the industry's contribution to this transformation is vital.

Zero-waste design is a powerful tool for implementing a circular economy. The Zero Waste International Alliance defines it as an ethical, economical, efficient, and visionary objective that guides people in transforming their lifestyles and practices to mimic sustainable natural cycles [3] [4]. Zero-waste design aims to effectively consume resources throughout the product lifecycle by optimizing material usage, promoting reuse, recycling, and recovery, and designing products that can be easily modified or repurposed [5]. These actions minimize textile waste, which can be categorized as pre-consumer or post-consumer waste streams. Circular fashion approaches mainly concentrate on used garments or post-consumer waste [6-8]. Less attention is paid to textile waste and remnants from garment manufacturing, known as post-production or pre-consumer waste [9-10].

World sustainable trends are increasing the recycling and collection of textile waste, which could lead to an annual reduction of around 18 million tons of CO_2 emissions. This would involve reducing incineration and landfill use and moving the industry towards a closed-loop system [1].

Now, efforts are being made to address global trade dynamics and support countries that cannot process the waste they receive, helping them establish effective recycling and safe waste management solutions. Textile incineration or destruction is not recommended unless the textiles are highly contaminated. Instead, textiles should be reused, recycled, or repurposed [2]. The study results [11] show that reusing textiles has a more significant positive impact than recycling. Both strategies should be integrated, and proper management through separate collection for reuse and recycling can help

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reduce environmental impacts. Recycled fibers generally have lower environmental impacts than virgin fibers, except for some cases like polyester or cotton recycling. At the same time, regenerated textiles can have better properties than primary ones [12].

By 2030, the aim is to source all priority materials that have a low climate impact and do not negatively affect other Sustainable Development Goals. This includes having 25% of key raw materials with lower climate impact by 2025 and having 45% recycled polyester to achieve a 90% recycled volume share by 2030 [13].

Four archetypes of textile recycling (mechanical, thermo-mechanical, chemical, and thermo-chemical) are well-known [14-15]. They are used according to textile waste content [14] and have different parameters, such as open- or closed-loop, energy efficiency, and restoring or maintaining the original quality fibers [16-18]. That's why knowing the raw material content of textile waste is essential in developing a sustainable action roadmap and selecting the most appropriate technology for textile recycling.

There are enough examples of creating sustainable action plans and designing sustainable and circular products. Textiles and clothing are strategic pillars of the European economy, accounting for around 140,000 companies and employing more than 1 million people across the region. As announced by the European Commission, new regulations will be introduced by 1 January 2025, including the obligation to separate textile waste collection [19]. ReHubs was created as a joint initiative by EURATEX to upcycle textile waste and circular materials all over Europe [20]. Its goal is to establish a collective effort based on European recycling hubs to upcycle textile waste and increase the scale of collecting, sorting, processing, and recycling pre-consumer and post-consumer materials. This initiative aims to achieve fiber-to-fiber recycling for 2.5 million tons of textile waste by 2030. Europe faces a textile waste problem of 7-7.5 million tons, of which only 30-35% is collected today. While some countries are designing schemes to address the waste collection challenge, there is currently no large-scale plan to process the waste. Looking ahead, the textile recycling industry in Europe could bring about economic, social, and environmental benefits. Once matured and scaled, it could become a profitable sector with a total market size of 6-8 billion € and around 15,000 direct new jobs by 2030 [20].

The United Kingdom's sustainable initiative plans to transform the textile industry and close the loop on materials by adopting chemical or mechanical recycling of materials back into textile fibers. The UK will reduce the greenhouse gas footprint of new products by 50% to limit global warming to 1.5 °C per the Paris Agreement and achieve Net Zero by 2050. Also, the water footprint of new products will be reduced by 30%, and the use of virgin textile materials will be decreased to meet consumer needs [21].

Waste collection and processing, of course, have a regional aspect. For example, a Canadian pilot research project described key data collection and analysis methods to gain insight into the potential for implementing circular practices to reduce waste for Montréal [22] effectively. The study compared the circular processes in three main good green innovation stages: primary sorting, secondary sorting, and landfill or energy recovery in the Architecture, Engineering, & Construction Industries. Quantitative data from reports was collected and compared, but missing or unclear information was identified. In cases where information was unavailable, estimates were made using direct proportions and simple projections, assuming that the missing information had the same characteristics as the current data. This helped create a schematic diagram of the general function of waste management in the Montréal metropolitan area. It's important to note that much of the available information was related to Quebec as a region, so the authors extrapolated numbers logically to a city [22]. Therefore, gathering sufficient analytical data and applying them to a specific area is crucial in cases without a database.

In the pre-consumption textile waste study was based on five years of comprehensive field research in four Bangladesh, India, and Estonia factories. Upcycling design approaches were developed, and an accompanying business model was developed to integrate and implement them [10]. Authors recommended optimizing textile waste by cutting leftovers and minimizing overconsumption [10]. Therefore, to achieve maximum circularity, it is recommended that cutting leftovers unsuitable for upcycling be sent to mechanical recycling with the rest of the textile waste and that a design be implemented that minimizes cutting leftovers and the production of excess garments.

Based on this research results [10], it can be said that depending on the factory size, the textile waste and fabric leftovers generated in the garment manufacturing process range from 25 to 40% of the total fabric used. Generally, there are three main reasons for fabric leftover generation and fabric loss in garment manufacturing. These are the leftovers due to the technical particularities of production processes, problems with the quality of the fabric, and issues related to manufacturing and resource planning (e.g. order faults or cancellations, overproduction). Testing different upcycling design methods and leftover types shows that 50% of pre-consumption textile waste can be upcycled into new garments [10], and some tannery waste is used effectively in construction [23]. Thus, the sewing industry can significantly improve its overall circularity by redirecting streams of pre-consumer textile waste back into production and upcycling them in-house or recycling.

Under the European Green Deal, electronics, furniture, and textiles are now Ukraine's top priorities due to their significant environmental impact and potential for circular use [24].

The European Green Deal is crucial to the EU's goal of achieving net zero emissions in Europe by 2050. Ukraine is working to align its domestic policies with European standards and has formed an interdepartmental working group for the European Green Deal. The country has initiated a targeted dialogue with the EU through the EU-Ukraine Green Deal Task Force to collaborate on climate issues. According to this, Ukraine will introduce new textile legislation as part of the European Green Deal. These changes aim to shift from traditional resource depletion to a circular and Zero-waste approach [25]. However, there is a lack of official statistical data in Ukraine regarding the textile industry's impact on the environment.

Due to Ukraine's extensive territory and the ongoing war, solving this problem requires a regional approach. The Khmelnytskyi region is located in the West of Ukraine. It has a significant presence of clothing manufacturers, accounting for 6% of Ukraine's total before the war. Moreover, Kharkiv, Odesa, and Dnipro clothing manufacturers have relocated to the Khmelnytskyi region. Thus, the Khmelnytskyi region presents an opportunity for further growth and development in the clothing manufacturing sector. So, it is crucial to implement innovation and technology to drive competitiveness and sustainability. The Khmelnytskyi region's strategic location and emerging role as a hub for the industry make it an attractive for an excellent case of regional circular economic development.

According to the information [26], the total number of sewing enterprises in the Khmelnytskyi region is 1173. On the other hand, the number of officially registered sewing enterprises in Khmelnytskyi city is about 683 [26], more than half of regional SMEs. Most clothes manufacturers use imported fabrics and primary raw materials to produce goods [27]. Only 32% of needed textiles are made by Ukrainian producers. Garment production efficiency is only 60% of India, China, England, and China's total production capacity. The main reasons are the ineffective garment production organization and older manufacturing technology [28].

Ukraine's textile and apparel industry is dominated by small and medium-sized enterprises (SMEs), many of which are micro-enterprises. According to [28], more than 92% of companies in the industry have fewer than ten employees.

Developing a circular economy policy in Ukraine requires taking several steps. These include creating transparent and competitive markets for secondary raw materials, improving and harmonizing Ukrainian legislation with relevant international laws, and reducing waste. It is possible to integrate Ukrainian clothing manufacturers into global value chains by digitalizing production, adapting industrial clothing manufacturing to international environmental requirements, implementing resource-efficient technologies, and providing comprehensive support for environmentally efficient businesses by the state [25].

Auditing existing garment production is essential to understand the amount of textile waste created after manufacturing. Analyzing this data will help identify areas where innovative solutions can effectively address the current textile waste issue [29-30]. Implementing an effective waste recycling model in the garment industry, preventing textile waste through the sustainable design of textile products, implementing eco-design for products, and promoting their consumption based on the principles of a circular economy are all very relevant. Therefore, it's crucial to establish the necessary conditions for sewing enterprises to transition to zero-waste production.

The lack of up-to-date statistical information on the volume of clothing production and the size of test waste in the production process requires conducting such studies. In the future, the expansion and digitization of similar statistical datasets will need high quality for application in circular business models. This involves opening up the data for financial institutions, research centers, and universities and harmonizing the methodology and information standards with the relevant EC standards [25].

Thus, the main goals for establishing the implementation of sustainable clothing production are:

- Study of volumes of post-production textile waste in separated regions;
- Determination of stakeholders' characteristics producing post-production textile waste capacity and production volumes;
- Establishing the raw material composition characteristics of textile waste for the processing technology selection;
- Definition of the stakeholders' behavior in textile waste management to form a mutually beneficial action plan for the circular economy.

METHODOLOGY

Due to advancements in sorting and mechanical recycling of textile waste, a decrease in the costs of secondary raw materials for textiles will be expected. This achievement appears to be a realistic possibility due to the establishment of a comprehensive action plan for textile waste recycling. For this, we needed to collect data on textile waste generation in garment enterprises in Khmelnytskyi.

The first step to a sustainable growth strategy for Ukraine's sewing industry involved gathering and analyzing waste data from stakeholders. At the same time, we have used scientific theoretical research methods, such as analysis, synthesis, comparison, generalization of data on the problem, explanation, classification, and a systematic approach, as well as empirical methods like experiments, observation, and description.

Initially, stakeholders were divided into eight main categories: (S1) clothing manufacturers; (S2) manufacturers of other textile goods; (S3) government representatives; (S4) public figures; (S5) mass media; (S6) activists; (S7) public and environmental organizations; and (S8) consumers of goods and services. Relevant categories for conducting interviews were identified through the stakeholder selection process. These categories were further grouped into direct and indirect stakeholders based on their impact on post-production textile waste and management. The relevance of direct stakeholders was determined by their involvement in waste generation or management - (S1) and (S2). This approach allowed the inclusion of key decision-makers such as company directors and the production department head. They have direct involvement in textile product manufacturing and managing textile waste.

Two stages involved collecting waste data from direct stakeholders based on activity garment manufacturing indicators. In the first stage, respondents prepared for the survey by looking at and analyzing the company's data on crucial factors in the generation of textile production waste (Fig. 1).

In our survey, the key factors contributing to post-production textile waste included:

- A one-year time frame with high textile procurement indicators (1);
- The annual volume of garment production and, consequently, the annual volume of textiles (2);
- The proportion of different raw materials concerning the total annual textile quantity (3);
- The percentage of each clothing category to the total garment quantity (4);
- And the city area where the company is located, which is convenient for waste disposal (5).

Following this preparation, the survey was conducted in the second stage. We used a 17-question questionnaire with three question blocks according to the research goals (Table 1).

Two survey questions, QN7 and QN8 in QB2, had a branched structure consisting of a Textile raw classification (Table 2) and a Garment classification. We classified two key factors (raw materials - QN7 and clothing category - QN8) according to the standard classification of raw materials, process categories, product categories, and product details [31].

This classification can help select suitable textiles for procurement, inventory management, and product research and development. It ensures that materials and processes meet specific quality assurance standards. The Textile raw classification (Table 2) consists of 13 options for Material composition, which sewing enterprises used over one year. The Garment classification was based on the assortment manufactured by company respondents and included 10 Product categories.

RESULTS AND DISCUSSION

General information about the company (QB1)

During data collection, we contacted 45 heads of sewing companies, but only 30 provided data. Therefore, over 60% of sewing companies support textile waste recycling cooperation. The survey results were analyzed using Microsoft Power BI.

A survey revealed that 51.85% of sewing companies have a small capacity, 37% have a large capacity, and 11.12% have a medium capacity [32]. Some of our information about the company's capacity, including the use of an automatic cutting system and the percentage of textile leftover, was described in [32].

Our research found that 4883 tons of textiles are used, and these thirty sewing companies produce 778.11 tons of textile waste annually (Fig. 2). The survey also found that 44.93% of the waste created is from fabrics, and 55.07% is from knitted materials.

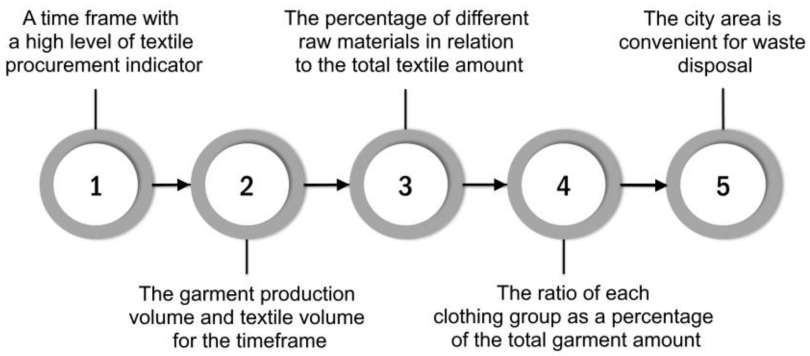

Figure 1. Procedure of data preparation about the generation of textile production waste.

Table 1. Sample interview questions for direct stakeholders (S1) and (S2).

Question block	Question Number (QN)	Sample Questions
General information about the company (QB1)	QN1	General information about a company
	QN2	Average production volume (units/year)
	QN3	How many seamstresses are there?
	QN4	The average volume of knitted materials (kg) used during the year
	QN5	The average volume of fabrics (per m) used during the year
	QN6	Is there software used to lay out the cut?
The characteristics of raw material composition textile waste and assortment (QB2)	QN7	How many materials of different raw materials do you have in manufacturing?
	QN8	How many types of products are there in your production?
	QN9	Is your clothing production seasonal?
	QN10	Is waste accounting kept?
	QN11	Average percentage of waste (approx. if no records are kept)
Stakeholder behaviour in textile waste management (QB3)	QN12	What does the company do with production waste?
	QN13	Are you ready to sell textile waste?
	QN14	Are you ready to sort textile waste by raw material?
	QN15	Are you ready to use containers for textile waste?
	QN16	Are you ready to pay for the service of collecting textile waste?
	QN17	Specify an area of the city convenient for unloading the company's waste

Table 2. Textile raw classification [31].

Product category	Product detail	Material composition
Dyed fabrics (PC0025) Greige fabrics (PC0026) Undyed fabrics (PC0027)	Terry fabrics (PD0060) Denim fabrics (PD0061) Woven fabrics (PD0059) Knitted fabrics (PD0058)	Cotton 100% (RM0102 100%)
		Cotton 90%, other fibres (RM0102 90%, RM0262 10%)
		Cotton 75%, other fibres (RM0102 75%, RM0262 25%)
		Polyester 100% (RM0186 100%)
		Polyester 80%, other fibres (RM0186 80%, RM0262 20%)
		Polyester 30%, mixed fibers (RM0186 30%, RM0258 70%)
		Polyamide 100% (RM0182 100%)
		Polypropylene 90%, polyamide 10% (RM0202 90%, RM0182 10%)
		Linen up to 92%, other fibres (RM0108 92%, RM0262 8%)
		Linen 30%, viscose 70% (RM0108 30%, RM0238 70%)
		Linen up to 30%, mixed fibers (RM0108 30%, RM0285 70%)
		Wool 40%, acrilic 60% (RM0077 40%, RM0156 60%)
		Wool 30%, acrilic 70% (RM0077 30%, RM0156 70%)

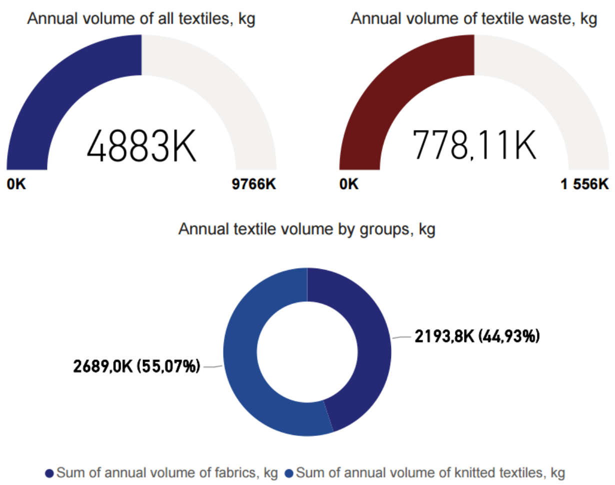

Figure 2. Annual textile volumes and waste by category.

Characteristics of raw textile waste (QB2)

The survey included a question about the types of products produced by sewing companies. The results showed that the most common types of products are knitted clothes (40.85%), sports clothes made of synthetic fabrics (15.21%), and clothes made of light woven fabrics (12.5%).

Annual textile waste volume by enterprise capacity and raw material composition is shown in Table 3.

Small sewing businesses accounted for the highest annual post-production textile waste, nearly 33.2%. Meanwhile, 23.9% of respondents did not disclose their enterprise capacity for various reasons.

The percentage of different raw materials in the total textile is shown in Fig. 3.

Material composition ratios in textile waste reveal that 42.14% of post-production textile waste contains more than 75% cotton, and 32.45% contains more than 80% polyester.

It has been determined that out of 327,888.94 kg of cotton textile waste, 56.92% (186,843.8 kg) is 75% cotton (RM0102 75%, RM0262 25%), and the lowest amount is 13.92% pure cotton (RM0102 100%) (Fig. 4).

Table 3. Annual textile waste volume by enterprise capacity.

Material composition (code)	Annual volume of textile waste by enterprise capacity [kg]				
	small	medium	large	not defined	total
Cotton 100% (RM0102 100%)	13 201.25	5 950.00	26 503.88	0	**45 655.13**
Cotton 90%, other fibres (RM0102 90%, RM0262 10%)	47 945.00	12 590.63	34 851.88	202.50	**95 590.01**
Cotton 75%, other fibres (RM0102 75%, RM0262 25%)	37 460.63	1 328.13	28 717.50	119 137.50	**186 643.80**
Polyester 100% (RM0186 100%)	34 366.88	6 693.75	27 366.75	1 260.00	**69 687.38**
Polyester 80%, other fibres (RM0186 80%, RM0262 20%)	63 393.75	4 743.75	53 473.13	61 200.00	**182 810.60**
Polyester 30%, mixed fibers (RM0186 30%, RM0258 70%)	19 202.50	0	11 350.00	0	**30 552.5**
Polyamide 100% (RM0182 100%)	14 589.38	0	5 407.50	4 050.00	**24 046.88**
Polypropylene 90%, polyamide 10% (RM0202 90%, RM0182 10%)	13 087.50	90 131.25	618.75	0	**103 837.50**
Linen up to 92%, other fibres (RM0108 92%, RM0262 8%)	6 264.38	0	6 481.25	0	**12 745.63**
Linen 30%, viscose 70% (RM0108 30%, RM0238 70%)	3 168.75	0	3 490.63	0	**6 659.38**
Linen up to 30%, mixed fibers (RM0108 30%, RM0285 70%)	2 681.25	0	6 391.25	0	**9 072.50**
Wool 40%, acrilic 60% (RM0077 40%, RM0156 60%)	1 657.50	0	4 760.00	0	**6 417.50**
Wool 30%, acrilic 70% (RM0077 30%, RM0156 70%)	1 318.75	0	3 075.00	0	**4 393.75**
Total	**258 337.52**	**121 437.51**	**212 487.52**	**185 850.00**	**778 112.55**

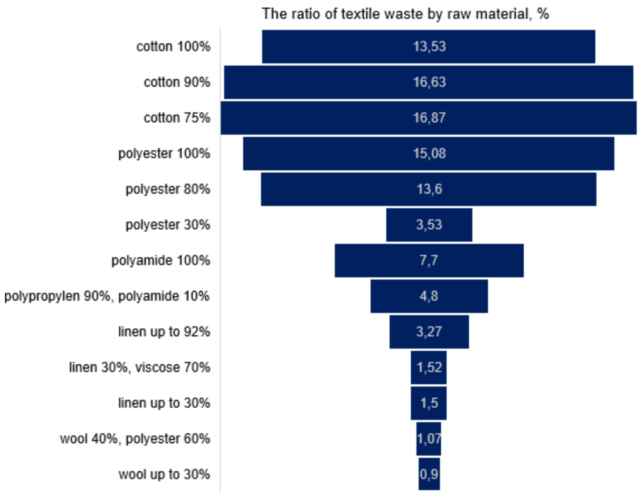

Figure 3. Material composition ratios in textile waste.

The results indicated that most textile waste (64.59%, equal to 182,810.6 kg) comprises 80% polyester waste (RM0186 80%, RM0262 20%). It was determined that 24.62% of the polyester waste, equivalent to 69,687.38 kg, comprises 100% polyester (RM0186 100%). Additionally, in our research, the textile waste of mixed raw materials (30% polyester and mixed fibers – RM0186 30%, RM0258 70%) is relatively tiny – 30,552.5 kg, 4% of the total amount (Fig. 5).

This information offers insights into the annual volumes of textile waste, enabling the development of practical technology and plans for processing the generated textile waste during production.

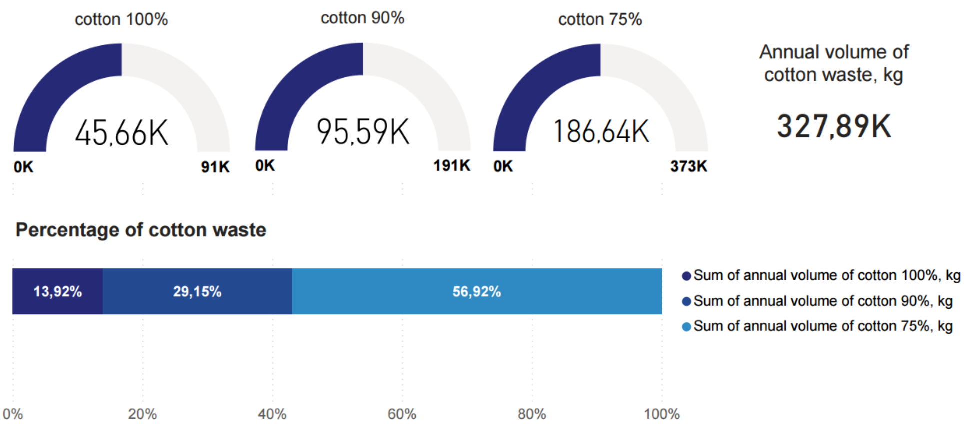

Figure 4. Annual textile cotton waste volume.

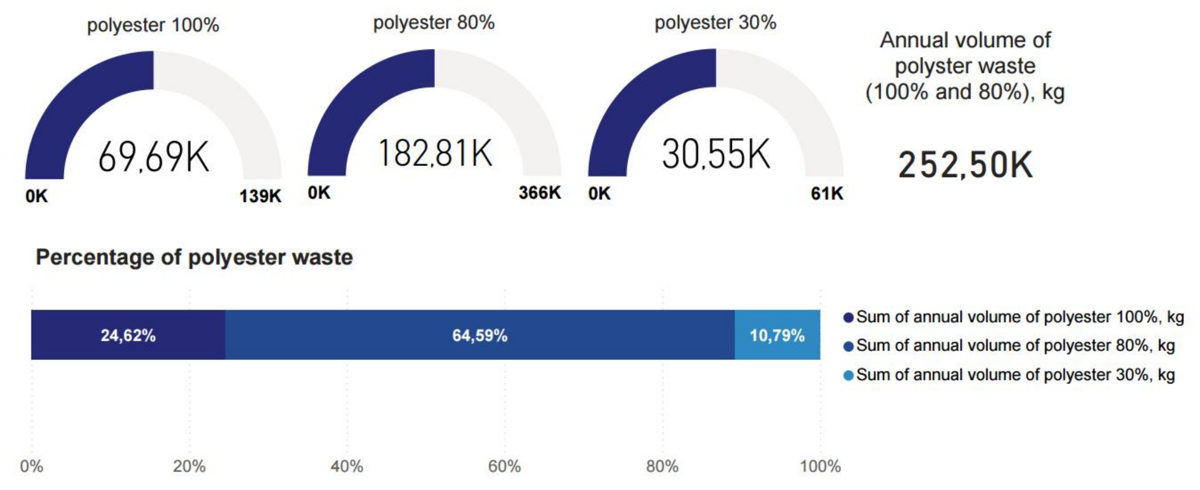

Figure 5. Annual textile polyester waste volume.

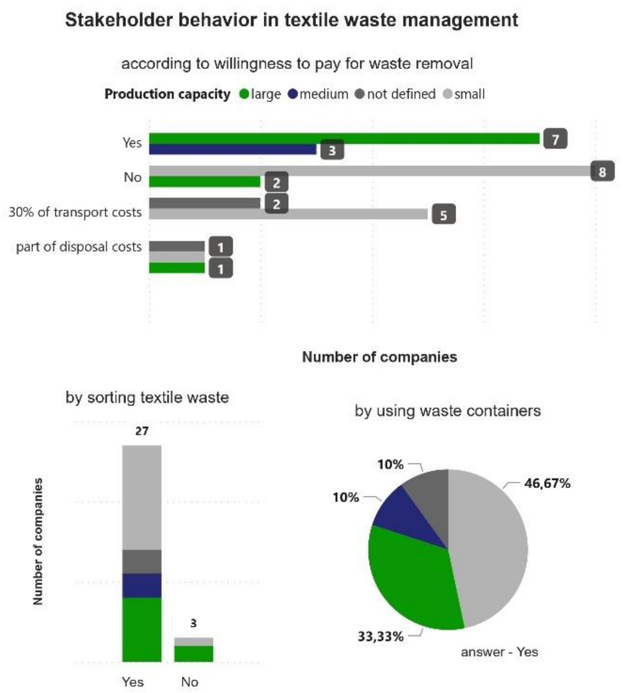

Figure 6. Stakeholder behavior in textile waste management.

Stakeholder behavior in textile waste management (QB3)

It has been found that 90% of companies are prepared to sort the waste generated in the production process, and 50% of companies are willing to pay for waste collection services. Furthermore, all respondents have expressed their commitment to using containers for collecting and sorting waste (Fig. 6).

CONCLUSIONS

Waste management is crucial in achieving a sustainable environment and improving people's quality of life. The research shows that textile waste is a significant issue in Khmelnytskyi, which has over 600 sewing companies. It was determined that only 30 of them could regenerate almost 800 tons of post-production textile waste annually.

Introducing technologies for recycling textile waste as one of the Zero-waste design principles can substantially enhance the region's environmental situation and reduce the volume of waste in landfills. The volume of waste in 30 enterprises allowed for the extrapolation of data for further research and strategic planning. Based on these results, the Textile Waste Roadmap 2030 was created. Among its different actions to introduce sustainability principles into the Ukrainian sewing industry, it has provided gathering and certifying textile waste to determine the raw material and purity composition necessary for the precise selection of the recycling process. It is essential to implement Textile Waste Roadmap 2030 systemically and continually assess outcomes and challenges. That's why we plan to conduct more profound research on post-production textile waste regeneration in the Khmelnytskyi region to determine the most intensive locations for its accumulation and create the logistic collection and sorting system. The involvement of all stakeholders in this process will form an effective waste management policy. This collaborative effort will help establish a closed cycle of recycling textile waste from the garment industry, promote sustainable clothing and textile production in Ukraine, reduce greenhouse gases, and conserve primary planet resources.

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