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Turek-Rahoveanu, Petruța Antoneta

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THE IMPACT OF TEXTILE WASTE ON THE ENVIRONMENT

Petruta Antoneta TUREK RAHOVEANU

Research Institute for Agricultural Economics and Rural Development - Bucharest *Corresponding author email*: turek.petruta@iceadr.ro

Abstract: The expansion of the textile industry and consumer trends have led to a rapid global increase in textile waste in the municipal solid waste (MSW) stream. Worldwide, 75% of textile waste is landfilled, while 25% is recycled or reused. Landfilling textile waste is a prevalent option that is considered unsustainable. This paper aims to present various technologies (anaerobic digestion, fermentation, composting, fiber regeneration and thermal recovery) of reuse and recycling for better waste management. Applying extended producer responsibility and a circular economy system involves a holistic consensus among major stakeholders.

Keywords: *textile waste; reuse, recycling; durability* **JEL Classification:** A10, D04, O13, Q01, Q53

INTRODUCTION

In the value chain of the textile industry, waste is produced especially from the fashion industry which is the most unsustainable of the industries. Textile waste can be pre-consumer (remnants of material,) and is recycled and requires less logistics process in collection and sorting.

American legislation has required manufacturers that exceed 10% waste from used textile materials to develop recycling and recovery programs. Another category of waste is post-consumer waste resulting from the last stage of the value chain, those that can no longer be worn/used.

Globally there are regulations on waste collection but there is no producer approach to the responsibility they should have.

At the European level in France there is legislation for these producers, with a good yield, and the main collection channels are the NGOs, the collection being carried out in stores (take back type program) or street containers. Following these collection actions there are advantages and disadvantages, the difference lies in the method that can affect the quality of the textiles.

Sorting by categories is performed according to the degree of degradation and is essential in this process, but more labor is required as it is a manual activity. Depending on the size of the organization, sorting can be done up to 300 items or categories (by color, size, type, etc.), or between clothes that can be worn or not and stored as waste.

Globally, only 20% is collected separately from the rest of the waste. This separation activity must be carried out in fractions made up of pure materials. According to information from the Association for Textile Reuse and Recycling (ARETEX), approximately 160,000 tons of textile waste are thrown away in Romania annually.

According to the data, about 6-10% are recyclable from the total waste generated, depending on the conditions imposed by the legislation and the market. This percentage would be possible to increase up to 25% if the selection, reuse and recycling industry is also developed with large amounts of sorting by quality and composition starting from the support of the manufacturer with extended responsibility in the textile industry.

Currently, the vast majority of the amount of textile waste is distributed to the landfill, respectively it takes the path of energy recovery.

MATERIAL AND METHOD

The study is based on primary research to identify textile waste reuse and recycling technologies with the help of specialized literature.

RESULTS AND DISCUSSION

Sustainable practices and recycling transform textile waste into valuable resources. In order to be able to recycle on a large scale it is essential to achieve a mixture of fibers as low as possible, being a difficult and expensive recycling process. Companies that carry out these actions often face obstacles in fiber-to-fiber recycling processes when reusing mixed textiles to design new clothing fabrics. Starting from 2011, the European Commission defined its medium and long-term objectives regarding the transformation of the European economy into a sustainable and competitive economy at the same time.

Within the policies adopted, the central pillar for sustainable development is the circular economy, which assumes a production and consumption model that involves extending the life cycle through the collection, reuse, repair, renovation and recycling of materials and products.

In support of accelerating the transition to a sustainable economy, the European Council adopted on May 22, 2018, the package of laws on waste: Directive (EU, 2018) 2018/851 of the European Parliament and of the Council of May 30, 2018 amending Directive 2008/98/ EC (EU, 2008) on waste, it sets new rules on waste management and new recycling targets. Member States will have to achieve a recycling rate for municipal waste of 55% by 2025 followed by sustained growth to reach 65% by 2035. In addition to the separate collection that already exists for paper, cardboard, bottles, metals and plastic, the member states will establish, by 1 January 2025, the separate collection of textile products and hazardous waste from households.

Textile waste can be classified into two categories:

- pre-consumption resulting from the technological manufacturing processes related to the subsectors of the textile industry, such as waste from spinning mills, weavers, from the manufacturing and finishing processes of textile products.

- post-consumer are textiles in the finished stage, in the form of clothing or other products collected from the population and institutions, with different degrees of wear.

Of the 2.1 billion tons of waste produced annually worldwide, 4%, or 92 million tons, is produced by the fashion industry, according to Boston Consulting Group analysis (Eder-Hansen et al., 2017). More than 35% of pre-consumer waste is produced in the primary processing phase of the raw material. Of this waste, 9% comes from fiber manufacturing and 91% comes from product manufacturing process operations such as weaving, knitting, textile manufacturing and spinning. This analysis also demonstrates that the processing and recycling of post-consumer textile waste has quantitative and technological limitations. In this case, only 25% of post-consumer waste ends up in incinerators and landfills.

At the present time, processing technologies have as a result five challenges that they face, namely:

- From a commercial point of view there is a lack of feasible recycling methods especially for lower quality textiles;

- The absence of integrated, progressive processes and the need to expertize the entire process to separate the fibers from the mixtures by types and compositional structures;

- The association of high costs in recovery processes;

- Predominance of lower quality materials on the final recycling market;

- Limited availability of regional and local recycling facilities as well as expensive logistics operations.

Also, recycling techniques must pass life cycle assessment to ensure ecological viability. The essential aspect of the supply chain assessment emphasizes both the recycling technique, the transport between the recycling plant and the waste storage areas and the energy consumption.

The methods used to recycle textile waste are classified as follows (Ellen MacArthur Foundation, 2017):

- Mechanics - the transformation of waste into new products (threads for fabrics, knitwear and non-woven materials by cutting, shredding and defibrating down to the fiber level, without affecting the basic chemical structures. It is recycling that covers the multitude of fibers, regardless of how they are: synthetic, animals or plants.

- Chemicals – decomposition of textiles to the level of monomers, oligomers or basic chemical elements. Through this recycling process, high-quality products can be obtained, because they are identical to the original constituents that were used to obtain the products subject to recycling (synthetic fibers, cellulosic fibers).

- Thermal – the process of transforming PET flakes into fibers by extruding the melt.



Figure 1. Textile waste recycling route (Sandin & Peters, 2018)

From the point of view of the textile waste recycling itinerary, recycling can be classified into upcycling or downcycling (Figure 1):

- Closed-loop recycling is the process of transforming textile waste into products identical to the original ones. (Ekström & Salomonson, 2014; Khan & Islam, 2015).

- Open-loop recycling or cascade recycling refers to the transformation of textile waste into products distinct from the original ones (Echeverria et al., 2019).

Reuse involves extending the life of textiles with or without modifications to other owners.

Technologies, currently, are diverse to facilitate the recycling and recovery of textile waste. Methods and techniques such as anaerobic digestion, fermentation and composting are part of textile waste biotechnology (Shrestha, B, 2020), (Ariunbaatar, J.,2014) Anaerobic digestion is the most used technology for biodegradable treatment of organic waste in order to produce biogas. Cotton is a potential substrate for biological conversion and contains 50% cellulose (figure 1). Studies on anaerobic digestion using cotton as waste (cotton stalks, cotton husks, seeds and cotton oil) for biogas production show that they are rich in solid powder and cellulose content. (Isci, A.; 2007)

Waste from spinning mills is a basic source for anaerobic digestion (Chockalingam R.S,2009)

This pretreatment process before the anaerobic digestion of waste containing polyester (40%) and cotton (60%) or pure cotton at a temperature of 1500C results in a high methane productivity (361.1 mL CH4/g VS). Also, for methane, a comparable maximum production rate of 80% was obtained by digestion in reactors (one or two stages) using polyester/viscose or polyester/cotton fibers with 20g/L added cellulose. (Hasanzadeha, E., 2018)



Figure 1 Cotton waste parameters (Chockalingam R.S,2009)

From the specialized literature studied, in table 1, it can be seen as a summary, the ideal, optimal operating conditions, using the anaerobic digestion process

Cotton waste stream	PRE treatment	Operating Temp. (°C)	Digestion Time (Days)	CH4 Yield (mL/g VS)	CH4 (%)
Cotton waste of which: cotton stalks (Isci, A.,2007)	-	35	23	65	60
- cotton seed husk	-	35	23	86	60
- cottonseed oil cake	-	35	23	78	60
Cotton waste from spinning mills (Chockalingam R.S.,2009)	-	30-32	50	-	77
Medical cotton waste (Zainab Z. Ismail,2016)	Na ₂ CO ₃	55	90	37,6	60-70
Waste jeans (60% cotton) Cotton waste (100%)	0.5 M/ Na ₂ CO ₃ at 150 °C for 120 min	37	40	328.9 (60% cotton); 361.08 (pure cotton)	-

Table 1. Ideal operating conditions using the batch anaerobic digestion process

Cotton waste stream	PRE	Operating	Digestion	CH4 Yield	CH4
	treatment	Temp. (°C)	Time (Days)	(mL/g VS)	(%)
Cotton textile waste (100% cotton)	0.5 M Na ₂ CO ₃ at 150°C	37	15	306,7	>50

> Fermentation process of cotton textile waste

The fermentation process of textile waste for ethanol production is carried out by:

- chemical dissolution (the process by which natural fibers can be recovered separately from synthetic ones and transformed into new raw materials);

- incineration (energy recovery process)

Synthetic fibers are being recycled less and less. Instead, natural fibers, especially cotton and wool, being produced from consumer sources, are more available on the market.

Studies investigating cotton waste began in 1979 in Texas Tech University, and looked at the use of textile waste to produce ethanol (Hamawand, I., 2016)

Technological processes result in waste classified into two categories:

- Recoverable waste: results from fiber mixtures resulting from knitting factories, spinning mills, weavers that can be exploited by making non-woven textiles, insulating materials, geotextiles (materials that can be permeable made of polypropylene, polyester or polyethylene used in special works of constructions in contact with the ground (approx. 60% of recovered sewage)

- Non-recoverable waste: textiles incinerated or thrown in landfills.

The process of pre-treating cotton and polyester textiles has had an essential impact in increasing ethanol production. After pre-treatment with /urea, the ethanol yield determined by the simultaneous fermentation and saccharification process was 70%. (Gholamzad, E., 2014)

Also, jeans waste (40% cotton and 60% polyester) was investigated for the production of ethanol through the enzymatic hydrolysis process that transforms cellulose into fermentable sugars (Raj, C.S., 2009)

Following the studies, it was observed that the effect of pre-treatment of non-mercerized and mercerized cotton textiles increased ethanol and glucose yields. In table 2, the optimal operating conditions for ethanol production based on the studied literature are summarized.

Technological flow of cotton waste	Pretreatment	Hydrolysis	Fermentation conditions	Glucose yield	Ethanol yield
Textile waste consisting of cotton and polyester (Gholamzad E.,2014)	NaOH/uree,	Cellulase and β-glucosidase enzyme, pH 4.8, 45°C, 72 h	36 °C, 72 h	91%	70%
Bleaching and mercerising cotton textiles (100% cellulose) (Nikoli, S,2017)	Pre-tratarea prin mercerizare [*]	Celluclast enzyme, 50 °C, 8 days	pH 5, 30°C, 100 rpm	0.94 g/g	0.9 g/L∙h
Jeans waste (60% cotton) (Hasanzadeha, E.,2018)	1 M Na ₂ CO ₃ , 150°C,120 min	45 °C, 72 h, 120 rpm	36 °C,72 h	81,7% cotton 88% cotton pure	59,5% cotton 69,4% cotton pure

Table no. 2. Ideal operating conditions for ethanol production using cotton waste.

* the process of treating cotton threads or fabrics with a solution of sodium hydroxide to make them smoother, silkier, more compact and more durable

The process of composting textile waste

Composting textile waste (cotton) is a biodegradation process, under anaerobic conditions bringing a surplus of nutrients for the soil. At the same time, it is a biological-oxidative process that reduces the volume of organic waste by 50%. Currently, the disposal of textile waste has become a major problem, and the composting process is designed as an alternative method to direct disposal in the landfill. The biotechnological composting process using earthworms called vermi-composting consists of turning waste into compost containing a rich density of isolated bacteria. (Selvi, 2015)

From the bibliographic studies, it appears that cotton waste has been used for pig manure loading in different proportions of pig slurry and cotton waste (4:3, 3:4). (Santos, A., 2016)

The conclusions show that: the thermal properties of zootechnical agents were determinants in the temperature increase and the aeration process; the highest proportion of compost sludge resulted in high nutrient concentration.

As early as 1978, researchers Chang, S. T. and Hays, W. A. showed that the new technology of composting cotton can be used in the cultivation of mushrooms as a substrate with a yield of 65.1% compared to the traditional fermentation technology with a yield of 43.6%. In conclusion the use of cotton residues is more effective in matching the moisture content correctly.

Sustainable utilization of textiles through recycling and reuse

A topology of recovery and reintroduction of textiles into the economic circuit refers to extending the life of items by passing them on to other owners with or without repairs. (Fortuna and Diyamandoglu, 2017) This method can be done through exchange, loan, inheritance, market or thrift store, online, charitable donations. In the academic literature, the concept of reuse has been interpreted as a collaborative consumption, product-based service system, or access-based business system. In general, textile recycling produces materials of lower quality with the exception of combination with natural fibers or fiber-to-fiber sorting (pure materials). Therefore, in the textile industry, recycling and reuse are essential concepts, with a positive impact on the environment and the economy. While the act of recycling involves changing used materials into new ones, reuse focuses on the reuse of clothing and textiles without processing. The distinction between the two concepts depends on several factors, including the condition of the material, economic viability and ecological impact.

Ecological impact

The act of recycling textiles can reduce the amount of waste by helping to recover energy, but also landfills, minimizing pollution and saving natural resources. Through the transformation process into new products, the need for new raw materials can be reduced, which has a positive impact on the environment.

From the point of view of reusing textiles and clothing, the advantages are quick in terms of resource conservation. Donating used clothing items, in good condition, can extend their life but also have a minimal impact on the environment.

In perspective, the reuse of textiles and clothing presents many advantages over recycling because the cost of their collection, processing and transformation are significantly reduced.

CONCLUSIONS

The proliferation of textiles made from fiber blends – such as cotton and polyester or elastane – poses significant challenges when it comes to recycling post-consumer textile waste. This is due to

the labor-intensive process of separating different types of fibers and the different conditions required for chemical and mechanical recycling. Chemical recycling technologies can help overcome the complications associated with mechanical textile recycling, and there are several innovative startups working on solutions to create high value possible fiber mix recycling.

The EU Action Plan for the Circular Economy and the EU Strategy for Sustainable and Circular Textiles confirm a particular interest with ambitious objectives and measures until 2030.

Due to the increase in the global population, the textile industry is in continuous development, therefore the increase in the standard of living has determined a high consumption of textiles (fibers).

Although the application of the EPR (extended producer responsibility) policy in textile waste is still limited, it is considered essential in promoting a circular economy system. Extended Producer Responsibility (EPR) makes manufacturers responsible for the overall management of textile waste from collection to disposal at the end of the product's life cycle.

In addition to EPR, there is a holistic approach involving major stakeholders (industry, government, private agencies and consumers) who must work in unity to promote a dynamic circular system. Emerging textile economies should take the lead in moving from a linear to a circular economy.

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