

Review

The Growing Problem of Textile Waste Generation—The Current State of Textile Waste Management

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Abstract: The textile industry is global, and most brands export their products to many different markets with different infrastructures, logistics, and regulations. A textile waste recovery system that works in one country may fail in another. European Union legislation (Directive (EU) 2018/851) mandates that post-consumer textile waste must be separately collected in all associated countries. This directive has also stated that, in January 2025, the rate of textile waste recycling in Europe should be increased. Local governments will be under pressure to improve the collection, sorting, and recycling of textiles. Supporting local governments could be part of a more long-term approach to managing high-value textile waste by implementing Extended Producer Responsibility, which would increase the recycling rate of textile companies. This would enable reuse of over 60% of recovered clothes, recycling into fibers of 35%, and only throwing away 5%. Today, most textile waste (85%) is disposed of as solid waste and must be disposed of through municipal or local waste management systems that either landfill or incinerate the waste. To increase reuse and recycling efficiency, textile waste should be collected and sorted according to the relevant input requirements. The dominant form of textile waste sorting is manual sorting. Sorting centers could be a future solution for intensifying the recycling of textile waste. Advances in textile waste management will require digitization processes, which will facilitate the collection, sorting, and recycling of textiles. It is very important that digitization will help to guide used products to recycling and encourage manufacturers to participate in the use and collection of product data. Currently, both the digitization of textile waste management and fiber recycling technologies are at the level of laboratory research and have not been implemented. The aim of this publication is to analyze the state of textile waste management, especially the various forms of recycling that involve a local governments and the textile industry.

Keywords: post-consumer textile waste; sorting; recycling; reuse; the recycling rate of textile waste; natural and synthetic fibers



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1. Introduction

1.1. Bibliometric Analysis

The current review paper examines the directions and recent advances in research on textile waste management, with an emphasis on sorting, recycling, and reuse, using a bibliometric analysis of scientific publications published since 2000. The search strategy that was used in the present study was based on the methodology presented by Abrha et al. [1]. The main objective was to analyze changes in research concerning textile waste management and the share of articles covering this subject. On the basis of keywords related to the textile industry and its management, both the major foci of studies and changes in research focus over the years were analyzed.

A total of 2066 research articles related to textile waste management and published in the years 2000 to 2023 were retrieved from Scopus. The general trend in the number of

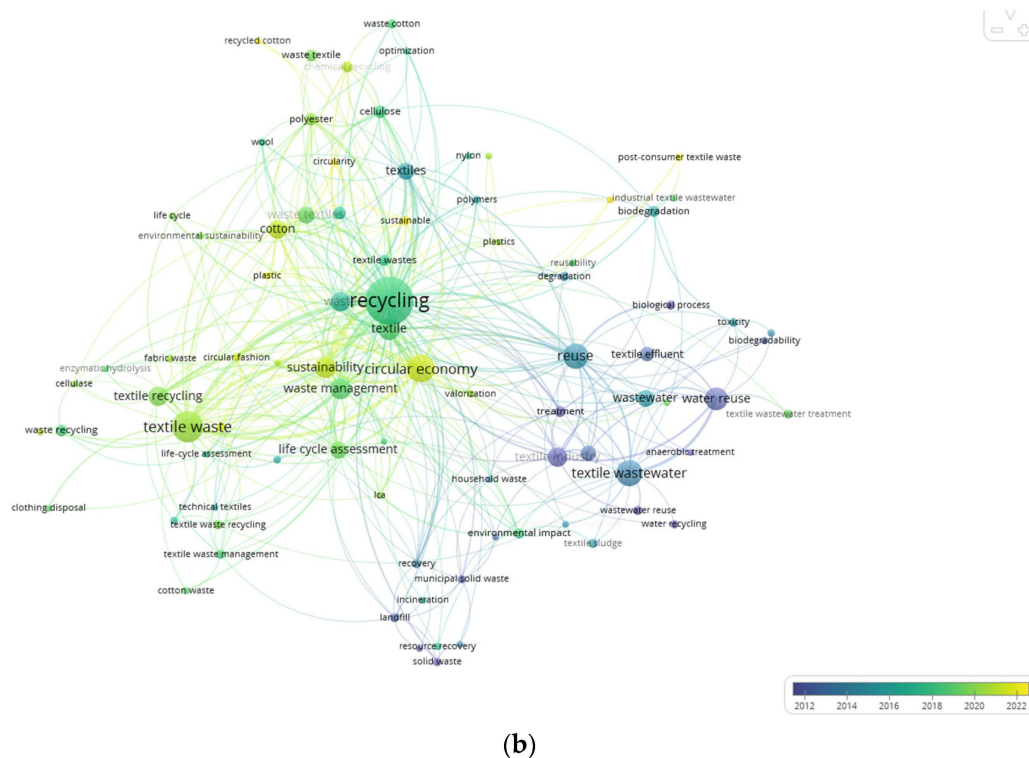


Figure 2. Network visualizations of co-occurrence of author keywords in articles on textile waste management: (a) classification into main clusters, (b) changes in major study direction over the years.

1.2. Textile Waste Management Background

The sources of most materials used in the fashion, textile, and clothing industries can be found in the agricultural and oil industries. Natural, man-made, or regenerated fibers are the basis of all textiles. Natural fibers range from animal hair and wool to crop fibers, such as cotton and hemp. Synthetic fibers are made by polymerizing smaller molecules into larger ones [2]. Man-made fibers account for 75% of all fibers produced in the world and about 80% of those in Europe, including Turkey. World production of these fibers was 113 million tons in 2021. The most important synthetic fiber for clothing production is polyethylene terephthalate (PET), which by far accounts for the largest share (54%) of total fiber production [3]. Regenerated fibers are made of natural polymers that are unusable in their original form, but can be regenerated to produce usable fibers. One of the first regenerated, from wood pulp, was rayon (also named viscose or viscose rayon).

Harmsen et al. [4] have classified fibers on the basis of the chemical bonds and groups in their constituent polymers. Polymer structure in fibers has also been used as the basis for textile recycling. Classification by chemical groups enables recycling of polyester, polyamide, and cellulose mono-material streams. However, textile blends can present problems because, even though blends of fibers within a single polymer group can be recycled, mixes of polymers from different groups can be problematic.

Textile waste can be defined as used or undesired materials created by producing and using fibers, textiles, and clothing. It is typically categorized as pre-consumer, post-consumer, or industrial waste, and fashion industry textile waste includes all three categories [5]. The first category is a byproduct of fibrous material production, and it is considered clean waste. Pre-consumer textile waste also includes unsold inventory and returns from sales. This waste consists of fabric scraps, fiber fluff, fiber waste, and yarn waste, which are biodegradable. Thus, they can either undergo recycling to create new raw materials, or they can decompose under natural conditions.

The second category, post-consumer textile waste, consists of clothing that has been discarded and home textiles, such as pillowcases, sheets, and towels, that are no longer

considered to be valuable because they have deteriorated. Finally, industrial textile waste, which can originate from commercial and industrial sources, is considered dirty waste. This waste is created when producing fibers, yarns, fabrics, and clothing, and the composition of its fibers as well as the dyes, chemicals, and finishes that were used during its production are usually known.

According to Domina and Koch [6], the various forms of solid textile waste are divided into two categories: unsold goods and pre-consumer waste, which are generated by retailers and can be simply reintegrated by sales outlets, jobbers, or non-profit organizations; the other consists of post-consumer fiber waste (yarn, fabric scraps, garment cuttings) generated mainly by fiber producers and fabric and garment manufacturers. The variety and quantity of textile waste and its ever-decreasing durability cause problems with the management of this waste.

The total textile waste in the EU, such as clothing and footwear, home textiles, technical textiles, and post-industrial and pre-consumer waste, in 2019 amounted to 12.6 million tons (Mt). The clothing and footwear waste amounted to 5.2 Mt (12 kg/(person-year)) [7]. As some literature data report, the annual cost of textile collection and disposal in the US increased from ca. USD 2.2 billion in 2000 to ca. USD 4.5 billion in 2020. Moreover, this cost increased from USD 46 million in 2005 to USD 103 million in 2020 only in New York City [8]. Textiles are one of the most resource-intensive sectors that do not fully adhere to the fundamental principles set out by the waste hierarchy, which require the prioritization of waste prevention followed by preparation for reuse and recycling. Legislative provisions supporting the introduction of the 3R rule (reduce, reuse, recycle) are important in waste management. For sustainable and circular textiles in the EU, the Parliament made recommendations for the bloc's strategy on 1 June 2023. The goal is to make textiles more durable and to make it easier to implement the 3R rule. The document also stated that textile production should be consistent with maintaining and respecting the environment, animal welfare, and labor, social, and human rights. Members of Parliament also called for "fast fashion" to end [9]. New rules to support a circular economy regarding, among others, textile waste management, appeared in February 2024 [10]. They are consistent with the European Green Deal [11] and the Circular Economy Action Plan [12], which call for environmental sustainability of various wastes including textiles causing significant negative environmental impact. Hence, the present article points out problems related to textile waste management and presents potential solutions that have already been implemented or are still at the laboratory research stage.

2. Collection for Disposal and Collection for Recycling and Reuse

Textiles are usually collected by private companies and charities, not by municipalities. Only a few countries, for example Germany, have organized collection and recycling systems for textile waste [13]. The last decade has seen the emergence of businesses that collect secondhand clothing using publicly available drop boxes, customized resale markets, retail collection boxes, curbside recovery programs managed by the municipality, etc. The problem with textile waste has led to innovations in collection systems for recycling, an online marketplace for surplus yardage from fabric mills and clothes producers, a repair store whose list of corporate repair customers continues to grow, and resale, which is a new approach to traditional retail. This is also having an impact on other textile industries, including home textiles and upholstered furniture, as in Ikea's resale and furniture reuse pilot program, currently offered in select Ikea stores, e.g., in Spain [14]. Some hotels already offer bedding and towels for rent. Textiles bought by consumers have another life to offer and there is growing evidence of the financial benefits to brands and retailers of offering recyclability and reusability [15]. Separate collection from other types of waste is essential for textile waste reuse and recycling.

Collection systems of textile waste should be designed so that different groups of recyclers have access to textile waste. Textile waste collection consists of two elements: (i) collection for disposal and (ii) collection for recovery. The first involves the disposal of

the majority of textile waste as garbage, which is disposed of either in a landfill or in an incinerator. The annual cost of textile waste collection and disposal in the US was estimated to be USD 4 billion only in 2020 [16].

Recycling and reuse ensure that textile waste that is not sent to landfills goes through a recovery network. There are many practices for textile recovery and reuse, such as used textile drop-offs, pawn shops, garage sales, clothing swaps, and peer-to-peer selling platforms. One of the first organized ways to institutionalize clothing recovery and reuse was via charities and thrift stores. According to Nonprofit Source, in 2018, 52% of Americans donated clothing, personal items, and food [17]. Charities have been collecting textiles for reuse for years. For example, in Sweden, people donate 3 kg/(person·year), a total of 26,000 tons/year. Of this amount, 73% is sent abroad as relief goods or sold for export, 12% is sold in Sweden, and 15% is disposed of [18]. To increase the amount of textiles collected, there is a need to establish a collection system based on collaboration between government organizations, municipalities, businesses, charities, and advocacy groups/organizations.

The selective collection of packaging waste is usually financed under what is called Extended Producer Responsibility (EPR). In the waste management sector, the collection of textiles is not covered by the EPR system and is financed by revenues from the sale of used clothing. To increase the amount of textiles, underwear, and footwear collected, the introduction of EPR will be needed. EPR extends producer responsibility for the product to the post-consumer phase of the textile product life cycle [19].

The number of collection bins and their accessibility must be improved. In cooperation with charities, municipalities should place collection bins for clothing and textiles where there are already bins for recycling for example paper, glass, plastic, and metal (recycling stations), as well as in other accessible locations. Collection bins could also be placed in multi-family housing and near residential areas. The challenge is to find optimal locations for the bins and to obtain permission from property owners to place them. Therefore, the distance between the home and the drop-off location should be short [20]. Waste accumulates in different bins at an irregular rate, which leads to large fluctuations in the length of time before they are full. Due to these fluctuations, as well as some seasonality, the frequency of bin emptying is inefficiently high to avoid overflowing bins. Monitoring the bins will improve the efficiency of textile collection supply chains, which play an important role in ensuring high collection rates of used textiles. To this end, modern technologies, therein the Internet of Things (IoT) and artificial intelligence (AI), provide new possibilities for increasing collection efficiency [21].

Sensor technologies support decision making for route planning and anticipating the accumulation of waste in bins. The introduction of smart bins for textile waste collection can be combined with a route optimization system to improve the efficiency of the overall system. The use of sensor-based collection reduces costs by 7.4% compared to a conventional system, and CO₂ emissions by 10.2% [22].

Textile technology [23] has unveiled a working solution for textile waste collection: containers for textile collection equipped with fill-level sensors (Deutsche Telekom). These sensors measure and transmit the fill-level data to the cloud. Then, the data are processed and displayed on a web portal. This smart solution optimizes collection cycles for the textile containers.

E-textiles consist of electronic components placed in the textiles. They are a fast-growing group of materials for which extensive testing is being conducted worldwide for, among others, fashion and military applications. The recycling of e-textile waste is said to be more challenging than that of typical textile waste [24]. The significant challenge here is the collection of e-textiles. If they are exported, before baling, flammable components, e.g., batteries must be removed from them. Similarly, if e-textiles are processed on mechanical fiber reclamation machines, any electronic devices or components must be separated. Additionally, the lack of standardization of e-textiles and their waste management is a significant barrier for the industry to enter the mass market [25].

Waste collection involves energy consumption, which depends mainly on population density. In the case of household waste, diesel consumption is reported to be up to 10 L/ton [26], which corresponds to about 0.35 GJ/ton. For comparison, the total energy demand for second-hand textiles (therein transport, sorting, packaging, etc.) is in the order of 6 GJ/ton [27]. However, this is negligible compared to the energy demand required for its production, which reaches up to 330 GJ/ton.

3. Sorting of Textile Waste

Textile waste sorting is primarily qualitative sorting that entails manual sorting, image recognition, and/or artificial intelligence; among these, manual sorting predominates. The sorting process begins when garments are loaded onto a conveyor belt. Firstly, coarse sorting takes place, where large and heavy items (coats, curtains, blankets) are sorted out. In the second sorting stage, other easily identifiable items (e.g., shirts, jeans, household items) are sorted. Sorting used clothing also includes sorting according to market demands. It is not uncommon for more than 400 styles to be sorted at one time. Sorting categories include old clothes exported to developing countries, old collections, fabrics, and items for upcycling and further processing, including clothing yarn [28].

The Ellen MacArthur Foundation [29] analysis shows that sorting companies receive material from a variety of collection systems. A sorting company is one that sorts and classifies used clothing by quality, condition, size, and type. Forty-five percent of the incoming material is sold for reuse, 30% as household rags, 20% to the darning, shoddy, and yarn fiber industries, and 5% is unusable due to contamination or other reasons. Only less than 1% is processed into fiber used in the production of new textiles.

The target solution for textile waste management is recycling centers with an automatic and manual sorting system. Textile sorting centers should be an integral part of the textile waste management system. There are two reasons for this: (i) most of the collected textiles are sorted in these facilities, and (ii) facilities' performance determines the amount of collected textiles that can be reused/recycled. Quality sorting would separate materials by grade sorters and possibly sort by brand for delivery directly to branded resale channels. A proportion of the recyclable textile materials would go into the sorting partner's inventory.

Nørup et al. [30] conducted an analysis of textile material flows at a sorting facility covering the period 2015–2017. It was shown that of the textiles sorted at this facility, 74.9–79.8% were reusable, 12.9–17.3% were recyclable, and only 5.4–6.4% were classified as waste. Between 2015 and 2017, the percentage and quality of reusable textiles decreased, while the percentage of recyclable textiles increased, as the market for low-quality reusable textiles shrank and the market for recycling increased. The quality of textiles has declined over the past decade, and this has led to a decline in the percentage of the highest-quality textiles that are sorted multiple times. In 2015, nearly 33% of reusable textiles were sorted, but in 2017, only 29% were sorted.

Most textile detection devices work on the principle of spectroscopy, and near-infrared (NIR) automated sorting technologies are fully compatible with operating conditions in waste sorting. The materials used in textiles are chemically similar to those used in packaging. NIR-based automatic sorting identifies materials based on their electromagnetic spectrum. This technique can distinguish even fabrics with very similar chemical compositions, e.g., viscose and cotton were correctly identified and sorted at a good rate, although both are pure cellulose-based fibers, and non-blended cotton and polyester with refractory finishes [31]. A combination of NIR and mathematical processing of spectra by convolutional neural networks (CNN) was used to separate pure samples and blends of the most common textile fibers [32]. CNN was initially used to classify textile samples. The results were very promising (100% and 90–100% correct classification of pure fibers and binary blends, respectively). NIR spectroscopy (1000–1650 nm) has been used to obtain information on the composition of cotton, silk, viscose, and certain blends thereof, using two different devices: a hyperspectral imaging platform (HSI) and a portable spectroradiometer [33]. The proposed methodological approach, thanks to its ease of use and quick

detection, can be used for quality control in textile recycling in the industry and/or in the laboratory.

However, a limitation of NIR spectroscopy is that it analyzes only textile surfaces [34]. This becomes apparent when testing textiles with coatings, some functional finishes, and multi-layer materials. Multi-layer materials can hide materials in the core or under the visible surface, leading to false positives. Problems also arise with very thin and loose materials as the NIR sensor measures the spectrum of the background material. For some fiber-level mixtures, accurate detection is difficult. Moreover, aging has been shown to cause changes in chemical structure and spectra, especially in cotton, which make detection difficult. To control the proportion of rejections during the detection process, the tolerance detection classes can be adjusted. Additionally, if a small proportion of mixed materials is deemed acceptable, performance improvements are possible.

Blanch-Perez-del-Notario et al. [35] evaluated the suitability of hyperspectral imaging (the visible and near-infrared portion, VNIR) for sorting pure and blended textiles. They also tested the capability of this method to discriminate between denim and non-denim textiles, which is required before decolorization. The authors used a sensor in the 450–950 nm range. VNIR range offers a higher spatial resolution, is cheaper, and uses more compact cameras than the traditional short-wave infrared (SWIR) range. In addition, the VNIR range enables sorting of blue denim, an abundant textile waste, which is difficult to sort in the SWIR range due to the strong color interference of these textiles.

Echeverria et al. [36] indicated that sorting textile waste is still problematic, mainly due to unknown fiber blends. In addition, the composition of post-consumer textiles that have been finished or consisted of multiple layers is often unknown, which makes it difficult to sort these fabrics to ensure the homogeneity of the fiber blend.

The waste sorting process could be improved by incorporating a variety of technologies, especially if the technologies are integrated with information systems, i.e., the IoT [37]. These technologies include blockchain, digital product birth certificates, product passports, nanoscale trackers, molecular labelling, NFCs (Near-Field Communications), QR (Quick Response) codes, and RFID (Radio Frequency Identification). RFID is a method based on radio tags that allows information to be stored and retrieved remotely. RFID tags are implanted into products, and they usually contain an identifier that allows one to find certain information about the product thanks to an external database (serial number, date of manufacture). Information on these tags could allow textiles to be reliably and quickly sorted by composition and color. Thus, RFID tags can enable simple and inexpensive material-sorting technology. Using technologies like RFID to help classify blends of fibers and provide other information on the composition of textile waste could help to guide improvements in the textile sector, infrastructure, and recycling technologies.

4. Reuse of Textile Products

Reuse of a product delays its ultimate disposal. Products can be reused for the same purpose, or one that is different from the one originally intended. Textiles can be formally reused, for example, in thrift stores; semi-formally reused, as occurs when they are sold on websites like Blocket or Ebay; and informally reused, as when clothes are passed on from older children to younger ones or given to relatives and friends [38]. Woolridge et al. [27] quantified the benefits of reusing 100 T-shirts and 100 pants made of 65% polyester and 35% cotton by the end-of-life clothing industry versus direct disposal. Reuse of the T-shirts reduced the amount of waste that was generated by 30%; reuse of the pants reduced the amount of waste by 25%.

Another solution related to textile waste reuse is the collective consumption business model [39]. An example of this model in the garment industry is a clothing library where people can borrow a certain number of garments over a period of time, usually for several weeks, in exchange for a monthly membership fee. Attempts are being made to mitigate the impact of fast fashion on textile waste management, and sharing is one of those attempts. Collective consumption can also supplement targeted materials in the effort to eliminate

conflicts between recyclability and other desired/necessary attributes of textiles, such as durability, stretchability, light weight, etc. [40]. However, the environmental impact of more frequent merchandise transactions (e.g., related to transportation and/or packaging) under such a model could be greater than the benefits of reducing production impacts [41].

Upcycling is defined by Caldera et al. [42] as the transformation of waste material into a value-added product through unique, creative crafting methods. Todor et al. [43] pointed out that upcycling is materially equivalent to reuse in the already known waste hierarchy (reduce–reuse–recycle). However, it is not the direct reuse of the same product, but rather the reuse of the products in an equally useful way. Upcycling, then, means transforming waste into (i) new materials/products of equal or better quality or (ii) new materials/products with greater environmental value. In addition, the use of existing materials reduces the consumption of new materials needed for new products. Therefore, upcycling is an even greener, more environmentally friendly, and more cost-efficient method of recycling. Unfortunately, it remains unclear for many businesses how exactly to use upcycling for better management of waste, so this practice is still a niche.

Despite this, brands have begun to invest in textile recycling to improve the life cycle of garments. According to Xie et al. [44], recycling methods can be categorized as: (i) online recycling, (ii) brand-led recycling, and (iii) government-led recycling. This proposed classification of recycling largely refers to reuse and upcycling, and it describes the role of brands in textile waste management. Internet-based recycling uses the Internet as a platform for recycling old clothes. Lascity and Cairns [45] showed that there are two forms of brand-based recycling: fashion brands take responsibility for recycling themselves, or recycling of used clothing is overseen by dedicated recycling brands. In the first form, fashion brands extend their services to include recycling-related business and reuse of recycled clothing. In the second form, recyclers, in order to build public trust, show the public where the waste clothes go.

5. Mechanical Recycling of Textile Waste

Mechanical recycling converts materials from their original form and function into other forms and functions without changing the basic molecular structure of the material. This is accomplished by garning, shredding, cutting of rags and wipes, and mechanical recycling of PET bottles into fibers. The recovered synthetic fibers are melted, extruded into pellets, and reprocessed into fibers in an extrusion process, just like new fibers.

Blended fabrics cannot be effectively recycled due to the variety and number of different fiber materials they contain. Examples of mechanically recycled polymers include acrylic, nylon, and polyester. The inputs to the process are post-consumer textile waste, selvages, and fabric or garment cutting waste. The most common refill materials are plastic bottles and textile waste. The feedstock for mechanical recycling can be filament yarn, staple fiber, or pellets (chips) [3].

Mechanical recycling involves the conversion of synthetic fibers/materials and cellulosic fibers into pulp and then into fibers. The input materials are textile wastes from plant raw materials (e.g., cotton, man-made cellulose (MMCF)). Cellulose pulp is converted into filament yarn or staple fibers, such as acetate, Cupro (rayon–copper), rayon, viscose, Lyocell, etc. [3].

During shredding, a part of the mechanical recycling process, there are losses of material as well as fiber length, evenness, and uniformity. To ensure the quality and integrity of new garments, at least 50% virgin cotton must be blended in.

If the textiles are mechanically unraveled, the fibers that are separated can be reprocessed into yarn. As fiber length is key for strong and durable textile production, fiber length loss during tearing should be minimized. Aronsson and Persson [46] investigated how the fiber length distribution changes after tearing different cotton wastes (denim and a single jersey) and with different degrees of wear. The fiber length decrease was greatest for the single jersey and the barely worn fractions. These results indicate that significant wear does not preclude mechanical recycling.

Fibers recovered from waste can be used, in various proportions, to produce blended yarns, i.e., waste and virgin fibers. These fibers can be used for both open-end spinning and friction spinning, and recently, ring spinning trials have also been undertaken. However, the final products can contain only a small share of the recovered fibers, mainly due to quality requirements. For example, Bhatia et al. [47] reported that, in the rotor spinning process, only up to 20% of the recovered fibers can be mixed with the raw material without noticeable changes in quality. The authors stated that, in general, it appears that blending 15% and 25% recovered fibers with cotton has no effect on the strength, irregularity, and elongation of the rotor yarn.

Yarn obtained from 50% recovered cotton is 33.5% cheaper compared with that made from 100% raw cotton. The characteristics of this blended yarn, such as non-uniformity and lower tensile strength, caused it to be recommended for denim fabrics [48].

The post-consumer textile wastes can be processed into nonwovens. The waste is cut and completely shredded by rollers rotating at high speed [49]. Nonwovens can be used for disposable products such as handkerchiefs, diapers, and sanitary napkins.

Much work remains to be carried out to develop mechanical recycling technologies. According to Kazancoglu et al. [50], the main barrier to building a supply chain for textile companies is the lack of technical knowledge about recycling. There is also a lack of theoretical knowledge on waste textiles, which hinders the development of recycling technologies.

6. Chemical Recycling of Textile Waste

Chemical recycling requires pure fractions, which means that developing processes of separation is a key factor for progress in textile recycling. The focus has been on separating polyester and cotton fiber blends, as these are widely preferred in the apparel industry [51]. There are three categories of chemical recycling, depending on the degree of decomposition of the plastic waste: (i) solvent-based cleaning, in which the plastics/materials are degraded to the polymer stage; (ii) chemical depolymerization, in which the plastics/materials are converted back to monomers through a chemical reaction; and (iii) thermal depolymerization (pyrolysis and gasification), which in some cases, can be considered chemical recycling because the polymers are broken back down to monomers and then to hydrocarbons. Thermal depolymerization can also be used to produce fuels [52]. Research directions in chemical recycling are mainly related to the recovery of polymers and monomers from mono- and blended textiles. Cotton textiles are the most promising material for efficient recycling, as they consist entirely of cellulose, which can be used in different ways, from reinforced composites to completely different products. The attractive properties of cellulose make it possible to recycle cotton waste that no longer serves a purpose into various value-added products [53].

Sanchis-Sebastia et al. [54] tested acid hydrolysis for the chemical recycling of cotton-based textile waste by converting it to glucose, which can be further converted into valuable chemicals or fuels. To achieve high glucose yields (approximately 80–90%) in the recycling process, it was necessary to use concentrated sulfuric acid and less-degrading dilute sulfuric acid in separate stages. The efficiency of the process also depended on the ratio of dry textile waste to sulfuric acid solution.

Liu et al. [55] chemically recycled post-consumer cotton waste. To regenerate the fibers by wet spinning, sodium hydroxide/urea and lithium hydroxide/urea were used. Using this method, fibers can be produced with tensile properties comparable to rayon fibers made from wood pulp, and dyes from original cotton waste can be reused.

The most commonly used natural and synthetic fibers are cotton and polyester (in the form of PET/PES). Palme et al. [56] processed textiles containing these fibers by degrading PET to terephthalic acid (TPA) and ethylene glycol (EG), thus generating three product streams: TPA, cotton, and a filtrate that contained the process chemicals and EG.

As the solvent for textile waste separation, ionic liquids are often used, which can deal with recalcitrant natural biopolymers that present problems when recycling via melt spinning as this produces hazardous byproducts or gas discharges [57]. For ex-

ample, Lv et al. [58] demonstrated an effective procedure for dissolving fabrics in 1-allyl-3-methylimidazolium chloride anionic liquid and separation by filtration. The cotton cellulose dissolved in this ionic liquid while the fibers of nylon 6 remained. Mixed waste nylon and cotton fabrics were efficiently regenerated with a high recovery rate of both regenerated fibers, i.e., cellulose and nylon 6.

Sun et al. [59] tested 1-butyl-3-methylimidazolium chloride ([BMIM][Cl]) and 1,3-dimethylimidazolium dimethyl phosphate ([MMIM][DMP]) (with water for coagulation) for the regeneration of several types of natural polymeric products, therein cellulose fiber, regenerated cellulose microspheres, cellulose/wool keratin composite hydrogel, and freeze-dried wool keratin hydrogel. They found that the suitability of the ionic liquids varied depending on the type of polymer. For example, waste acrylic fabric after regeneration with [BMIM][Cl] became brittle after drying. In contrast, [MMIM][DMP] efficiently regenerated cellulose/wool keratin composite.

The development of methods of chemical recycling of textile waste is progressing, but currently only a few of them are promising in terms of commercialization of the technology. This is mainly due to the heterogeneous nature of post-consumer waste; thus, post-industrial waste is currently often the best choice for recycling. In addition, various pre-treatment processes need to be carried out to remove chemicals and impurities from textile wastes, resulting in higher costs.

7. Conclusions

This analysis of textile waste management has revealed the following problems:

- Lack of implementation of Extended Producer Responsibility, which would increase the recycling rate of textile companies and brands;
- Lack of selective collection, sorting, and recycling, as well as problems of uniformity and standardization are major obstacles to efficient textile waste management;
- The textile reuse and recycling system does not include collection systems and regional facilities of textile sorting that generate data on the quantity and composition of materials, as well as mechanical and advanced recycling technologies;
- Emerging end markets and branded companies that support the national recycling economy are not integrated with the textile waste management system;
- There is a need to introduce innovative technologies that increase the recycling of both pre-consumer and post-consumer textile waste and reduce landfilling of textile waste.

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