Chapter

Textile Wastes: Status and Perspectives

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Abstract

The world population has grown tremendously in the past few decades, and the same period also witnessed improvements in living standards in general. These two developments have augmented the consumption of textiles, which in turn increased textile production. Global production of all apparel and textile fibers amounted to more than 110 million tons annually, leading to the generation of high amount of textile wastes. In order to ensure sustainability and reduce environmental impacts in the textile and apparel sector, utilizing a circular economy model is of utmost importance. Recycling of textile waste is a requirement for the implementation of a circular model. This study presents a general evaluation of management of textile wastes, in terms of ensuring sustainability and minimizing environmental impacts.

Keywords: textile wastes, sustainability, waste management, recycling, circular economy

1. Introduction

Textile is an ancient industry that goes back to the beginning of the history of humanity, and its products range from products of daily usage to technical ones. All kinds of garments obtained by processing knitted, woven and nonwoven fabrics are categorized as the apparel sector. Actually, textile production is one of the main industries that affect global environmental pollution, as both the production and the processing of the necessary raw materials are contributing factors to pollution. Another important aspect of the problem is the waste that results from both production and consumption of the textile goods. Though technically all waste in the textile and garment sector can be recycled, unfortunately, only a small amount is recycled. As long as the linear system currently utilized in the production goes on, it seems that we will not be able to use the resources efficiently and reduce the environmental pollution.

Given that the current global trends persist, by 2050, the textile sector is expected to represent a quarter of the world carbon budget—26%, to be precise. The figures are colossal: If the current trends do not shift, the textile and apparel sector's nonrenewable raw material usage will reach 300 million tons and the amount of microplastic released to the oceans will reach 22 million by 2050 [1].

One key concept to analyze and understand the situation is the linear economy. As the dominant model of production at least since the Industrial Revolution, linear economy basically works as "subtract the raw material from the source, convert it into a product, sell the product to the consumer, which eventually gets disposed of by the consumer after usage." Under this model, products discarded by

the consumer become waste and are generally disposed of ending up in landfills or by incineration [2].

The basis of the linear economy approach is the consumption of the raw material required for production. It seems that the limited resources available to us in the world will not provide the conditions for the current dominant economic model to go on as today. The actual perception of raw materials is not sustainable. Moreover, linear economy-oriented production and business models become a burden for the environment—the environmental aspect, the damages they cause and the waste that results from them are generally not considered.

An alternative to this traditional production model is what is called a "circular economy": "A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems" [3].

In contrast to the negative aspects of the linear economic approach, the circular economy is seen as a sustainable development model for the future and increasingly stands out as an approach that is becoming widespread in the world. The circular economy is a systems model in which every part of a product is considered as a valuable resource that should be handled with care and resources are circulated again and again through closed loops.

The basis of the circular economy model is to expand the life-span of a product via repair, reuse, remanufacturing and recycling, so that resources are used more efficiently and the need for new products and virgin raw material is reduced or ideally eliminated [2].

In order to ensure sustainability and reduce environmental impacts in the textile and apparel sector, utilizing a circular economy model is of utmost importance. Recycling of textile waste is a requirement for the implementation of a circular model. This study presents a general evaluation of recycling of textile wastes, in terms of ensuring sustainability and minimizing environmental impacts.

2. Fashion and sustainability

Decisions of consumption have obtained a significant role in today's world—the choice of what you eat, where you go, what you wear and so on has become decisive factors of showing who you are and what you want to be, of displaying one's social identity. When one talks about consumer behavior in the textile sector, fashion is the key concept. Fashion presents the markers for social differentiation, mobility and identity, and allows a person to present one's identity—moreover, this dynamism and speed of fashion allow people to change their conceived identity [4–6].

Certain historical, social and cultural changes can be said to have shaped contemporary fashion. The first big leap was the Industrial Revolution—the possibility of producing *en masse* made it possible for the consumers to pick their desired products from a much wider range at lower prices, which, in turn, meant that a wider portion of the society could afford to have the pleasure of purchasing the desired products. In other words, "...fashion, which had been the epitome of luxury, was democratized and consumption behavior began to change" [7]. Industrialization also triggered changes in the economic structures: Autarky lost ground and urbanization has become a widespread phenomenon. The fact that an increasing number of people started to move into cities enhanced the commercial activities. Starting with the 1900s, new types of trade companies and retail shops emerged in the cities. Consumption, which was mainly a subject of certain periodical trade events, has become a fundamental part of the daily routine of the people. The new shops enabled people to buy clothes any given day. This new dynamism of fashion

provided retailers and marketers with new commercial opportunities, as "being fashionable" became an important aspect of consumer behavior [7, 8].

Although the modern concept of "consumer culture" goes as far back as three centuries, the last few decades have witnessed unprecedented growth of purchasing and disposal of textile goods. The emergence of fashion as a defining force in consumer behavior resulted in overconsumption. The logic of fashion constantly pushes forward the need for change, which results in generating more and more requests to supply newer, fresher and more contemporary goods [9, 10]. Until the 1990s, the general tendency of fashion retailers was to release two main collections—spring/summer and autumn/winter—each year; however, during the 1990s, drastic changes occurred: The so-called era of "super cheap and super fast" arrived [11]. The increasing ability to outsource production to low-cost regions of a globalized world and thus to produce much cheaper clothes, combined with the inherent dynamism of fashion, paved the way for the emergence of what we nowadays conceive as the "modern fashion business" [12].

This fundamental role of dynamism inevitably positioned time as a crucial factor for the competitiveness of fashion companies. Consumers are conditioned to expect newness; thus, brand new products need to arrive at the stores with short time intervals constantly. This objective is accompanied by limited ranges and rapid stock turnaround for the companies [13].

The dominance of fast fashion and just-in-time production in the textile industry has led to more frequent seasons and minicollections in-between seasons, which has led to the arrival of new cheap items to the stores every week, even, in some cases, every day. It is a chain reaction: increase in the creation of new fashion trends, desires to experience the new spurring out of control, consumers buying more and more, and eventually overconsumption. This new concept of seasonal new collection brings about more incentives of buying for the consumer and, thus, increases the rate of textile consumption. However, the fashion industry not only has an impact on people but also has a big impact on the environment [10, 14].

The concerns about the environment are rapidly growing in today's world and are shared by the fashion firms and the consumers. Textile production is an important source of human-made adverse impact on the environment, as the sector uses huge amounts of water, pesticides and chemicals. Attempts to establish guidelines for sustainability in the production phase, such as ISO 14000, are a reflection of this fact, and this aspect is quite relevant for fashion firms. On the other hand, the consumers are getting more and more conscious about the social and environmental problems, which have a direct effect on the consumption choices of the consumers, as in eco-fashion consumption [15–17].

Even though this burning issue is gaining more importance in all sectors, it can be said that textile lags behind other sectors, for example the industrial design, in terms of research and development about modes of production that would be more efficient for the conservation of the environment or ways to get the consumers more engaged in topics of sustainability. The industry needs more innovation in the aspects of design, manufacture, consumption and business within a sustainable framework [18, 19].

Sustainability is indeed a burning issue, and the following data demonstrate how important it is for the world to achieve greater success in the textile sector. Textile production, a sector that goes back to ancient times and has always maintained its pivotal role in human life, still has a paramount place in industry if one takes a look at the global output and employment numbers [20]. According to the Zion Market Research's report, the textile market was approximately valued at USD 858 billion in 2018 globally and is estimated to generate around USD 1207 billion by the year 2025, at a CAGR of around 5% between 2019 and 2025 [21]. The global garment and

textile industries employ 60 million to 75 million people worldwide [22]. The total volume of the production of the sector around the world is expected to exceed 99 million tons annually. These numbers are evidence to the importance of the applications of the industry for environment [23].

Clothing is an essential human need, and the textile and clothing industry delivers goods to satisfy this basic necessity. But this vital sector presents serious social and ecological problems in many instances of the supply chain—from fiber production, spinning, fabric production, dyeing and finishing, to clothing production [24, 25]. However, the increasing price pressure over fashion companies in the last decades does not help the companies in developing more sustainable production models. The price pressure has led many textile companies to outsource their production, which caused the bulk of the European and US clothing production shift to developing economies in Asia. The part of the value creation chain that remains in the Western countries is mostly limited to value-added services such as design and overall brand management. This production shift, with the relocation of a big part of the value chain in lower labor cost countries, presents a new challenge for sustainability, as the surveillance and control over labor and ecological practices in the production sites of the supply chain have become much more complicated [25, 26].

Sustainability, a word more frequently used every day nowadays, may sound very familiar, but it is difficult to define, understand and adopt in industrial practices. An apt definition for the term sustainable development, coined by Brundtland (formerly the World Commission on Environment and Development), is as follows: "The development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [27]. Below is a list of the main obstacles for an environmentally sustainable textile and apparel sector:

2.1 Consumption of water

Studies show that, in terms of consumption and pollution of clean water, textile and related industries are only surpassed by agriculture [28]. The sheer amount of water used during textile production, especially wet processing, tells a lot: to process a kilogram of fabric, 80 to 150 liters of water is used, along with other chemicals [29]. About 4% of global freshwater withdrawal, which corresponds to 93 billion cubic meters of water, is utilized annually by the textile sector, if cotton farming is included. Clothing is responsible for more than 60% of this amount [1].

2.2 Global warming

The average temperature on Earth is constantly increasing, but especially since the Industrial Revolution, the rate at which the average temperature on Earth has been rising is too rapid—the phenomenon known as global warming. Various estimates put the rise at 0.6–0.8°C, which corresponds to a rise 10 times faster than the calculated normal. This man-made global warming is due to the amount of greenhouse gases released, such as carbon dioxide and chlorofluorocarbon, of the use of fossil fuels as well as of other developments [30].

Textile and apparel production has a major role in this global phenomenon. In 2015, greenhouse gas (GHG) emissions from textile production were responsible for 1.2 billion tons of CO_2 equivalent of greenhouse gas (GHG). This figure exceeds the emissions that result from all international flights and maritime shipping combined—two fundamental means of transportation [1]. Transferring final products produced in developing countries to the shops in the developed ones necessitates

long-distance maritime transportation, which further increases the total consumption of nonrenewable fuel [31].

Given that the actual trends of the sector do not alter, by 2050, 26% of the carbon budget and 300 million tons of crude oil will be consumed by the textile industry—a significant change compared with 2% and 98 million tons, respectively, in 2015 [1].

The textile industry utilizes much energy with little efficiency. The chemical processing leg of the production mostly utilizes thermal energy to heat water and dry fabrics, while spinning and weaving legs of the production mostly utilize electrical power [32, 33]. The consumption of electricity to produce 60 billion kilograms of fabrics worldwide per year is calculated to be nearly 1 trillion kilowatt hours [30].

Textile manufacture is also a source of NOx and SOx emissions, solvent release during drying of coatings or cleaning operations and volatile organic compounds (VOCs) [31].

2.3 Environmental pollution

About a quarter of chemicals produced globally are used in the textile industry [34]. Numerous chemicals are used for textile production, mainly in the wet processing. Of these nearly 2000 different chemicals, many have adverse impacts on health. Some chemicals evaporate, while others are dissolved in treatment water—which ultimately goes back to the environment—and some chemicals remain in the product [31]. Cotton clothing, which, after all, is regarded as particularly natural and healthy, calls for cotton farming, which currently needs 0.2 million tons of pesticides and 8 million tons of fertilizer globally. Although cotton cultivation accounts for only 2.5% of worldwide agricultural land, it is responsible for 16% of global pesticide utilization. Furthermore, the physical health of cotton farmers gets negatively affected from the chemicals used for cultivating cotton, and cases of acute poisoning from pesticides among cotton farmers are commonplace. About 4% of all nitrogen and phosphorus fertilizers used around the world go to cotton production, and these chemicals are a main source of clean water pollution. If merged into the rivers, these chemicals can lead to algal blooms, which starve the river of oxygen. Producing cellulose-based fibers also necessitates large amounts of chemicals and some of the chemicals used are sources of concern. However, the agricultural part of textile production is not solely responsible for the chemical use of the industry. Producing the fibers requires using chemicals too, for example for dyes or finishing treatments. This part of the production is estimated to use approximately 43 million tons of chemicals globally [1].

The microplastics contaminating the oceans are attracting more and more attention from concerned scientists, even though we still do not fully understand its long-term impacts. Microfibers discharged from textiles during washing processes add to the increasing plastic pollution in the oceans [1]. George Leonard, Chief Scientist for The Ocean Conservancy, estimates that the amount of microfibers on seafloor could have reached to the sheer figure of 1.4 million trillion [35].

The waste generated by producing and consuming textiles is another major concern. Textile consumption around the world is calculated to be over 100 million tons [23]. However, the rate of recycling is rather low: Barely 13% of the total material input is in some way recycled after usage. Of this recycled 13%, a minuscule part is used to produce new clothing—less than 1%. The rest is recycled into other, lower-value items such as insulation material, wiping cloths or mattress stuffing [1].

Additionally, odor problems and noise pollution are also negative effects of the textile industry on the environment. Odor pollution is an indicator of

environmental change that affects health and human well-being. Odor impacts people by strong, unpleasant or offensive smells that can interfere with one's enjoyment of life especially if they are frequent and/or persistent [36]. When it comes to noise pollution, there are different processes in the textile chain that can produce noise level above 90 dB(A), the allowed limit, and can cause problems especially for the workers. The dry processes produce more noise than the wet processes, due to the fast-moving parts in the processing machines, which is another danger for the workers along with the hearing problems [37].

3. General outlook of the current situation of the textile fibers

The world population has grown tremendously in the past few decades, and the same period also witnessed improvements in living standards in general. These two developments have augmented the consumption of textiles, which in turn increased textile production [38]. The effect of the rising living standards can be seen in the fact that the worldwide consumption of textiles is growing faster than the world population. The demand is expected to grow from around 30 million tons in 1980 to more than 130 million tons in 2025. The figure translates into a growth of over 400%—or an average annual growth rate of 4.3%. In the same period, the world population has been growing by only 1.7% [39].

Global production of all apparel and textile fibers amounted to 110 million tons in 2018, according to the Discover Natural Fibers Initiative (DNFI). This number points to an increase of 4 million tons compared with the previous year and of 35 million tons compared with a decade ago. Natural fibers represent 29%—a 12% decrease since 2008. In 2018, cotton represented 81% of natural fiber production by weight, which overshadows the share of jute, coir and wool, which account for 7%, 3% and 3%, respectively. Cellulosic fiber production represented 6%, synthetic filament 45% and synthetic staple 20% of the total production in 2018. Polyester is the leading synthetic fiber, which represents almost 90% of world filament production and 70% of world synthetic staple production. The rest of the synthetic fibers are mostly composed of nylon, acrylic and polypropylene. However, the figures do not translate into a plunge in the production of natural fibers. The share of natural fibers in total fiber production has decreased in the last decade because the production of polyester has increased exponentially. Synthetic filament production, which is mainly used for the production of fast-fashion apparel, has risen from 26 million tons to 50 million in a decade after 2008, almost doubling in size. During the same period, synthetic staple production increased from 15 million tons to 22 million. Natural fiber production also increased from 2008 to 2018, but the rate was nowhere close to the others: from 31 million tons to 32 million [40].

The global market is prevailed by two types of fibers: polyester, a synthetic fiber, and cotton, a natural fiber. The trend mentioned in the previous paragraph is clearly reflected when the figures for these two fibers are examined. The demand for polyester has doubled—a significant rise that resulted in the fact that polyester has succeeded cotton, the most widely used fiber until the 2000s. Polyester fiber production is estimated to increase to be 3 times more than cotton production in order to meet the still-growing demand, while the production of cotton fibers remained stable. Increasing the production of cotton depends on the land and water resources, which are limited, and the fact that the opportunities to increase yields of cotton cultivation are narrow does not help either. These constraints on cotton production are very significant to understand the growth of the synthetic fiber market [39].

Still, it is important to point out that, despite the growth of synthetic fiber production, cotton, a product with very good fiber characteristics, remains to be

considered as the most popular fiber. It is not expected that cotton would largely be replaced or eliminated in the short or medium term from the textile production. Thus, sustainability strategies for cotton will persist to be paramount for the conservation of the environment [25, 41].

Synthetic polymers are mainly produced from petroleum—a nonrenewable resource. But this is not limited to synthetic fibers: Renewable natural polymers such as cotton also depend on nonrenewable resources, because their production needs energy and chemicals that are actually produced from nonrenewable resources. The petroleum reserve of the world might last for several more centuries if the current consumption rates continue, but it does not change the fact that petroleum—like many other natural resources—cannot be replaced in practical terms [42]. Therefore, deciding if natural fibers or manufactured fibers are more eco-friendly is impossible. The production of all types of fibers comes with its own challenges. Some fibers need a lot of water, while others demand lots of energy to produce. The synthetic fibers are not fully biodegradable like the natural and cellulosic fibers, which broadens the waste aspect of the problem. Synthetic fibers are generally petroleum by-products, which makes them nonrenewable materials; however, this gives them the advantage to get conveniently recycled into a good-quality material like polyester—a contrast with cotton, which generally gets down-cycled. But recently, the market has also started to receive recycled, high-quality cotton [19, 20].

Made-By, a nonprofit organization, carried out a study called "The Environmental Benchmark for Fibres." The study focuses on the prevalent fibers in the clothing industry and compares the environmental impact of the production of these materials. The production of the fibers is analyzed from the raw material up until the preparation of the fiber to be spun, thus excluding the later stages, such as spinning itself, fabric manufacturing, dyeing and finishing, garment making, transportation of the product and consumption. The study lists 28 fibers from Class A to Class E (Class A being the most benign) not regarding their quality, durability or performance, but their direct effects on the environment: greenhouse gas emissions, human toxicity, eco-toxicity, energy input, water input and land use [43].

The results demonstrate that all mechanically recycled fibers and organic fibers score "positively," while both natural and synthetic fibers obtained by conventional production methods are far behind in sustainability ranking. Class A materials include mechanically recycled nylon, mechanically recycled polyester, organic flax (linen), organic hemp, recycled cotton and recycled wool, while Class E materials include bamboo viscose, conventional cotton, cuprammonium rayon, generic viscose, rayon, spandex (elastane), virgin nylon and wool [43].

To protect not just human life on Earth, but Earth itself, we have to use the natural resources adequately. The rates at which natural resources are generated and consumed have to be appropriate for the sustainability of the planet. The 2011 annual report of the United Nations Environment Programme (UNEP) predicts the rate of consumption to triple the current rate by the year 2050 [44]. One alternative way to approach the solution of this problem is gradually replacing the traditional linear economy model—which relies on extraction/cultivation of raw materials, use of the product and disposal of the waste in landfills—with the circular material flow—which focuses on reusing and recycling.

4. Textile wastes and recycling

Consumption of textile products has two main aspects that trigger environmental change: the pollution and waste brought about, and the natural resources

expended. Pollution is generated not only during the production phase but also during the consumption of the products. The Earth has a natural system that can naturalize pollutants and stabilize a natural equilibrium to a certain extent, but the rate and degree of the release of man-made pollutants into nature challenge this natural equilibrium of the planet [45, 46].

The second factor is the depletion of limited natural resources of the planet through the consumption of goods. Conventional modes of production and consumption dictate utilizing both renewable and nonrenewable resources. Manufacturing processes required during production need natural resources such as fossil fuels (coal, oil and natural gas) to generate energy and raw materials for the actual products (as in the example of plastic, which generally is produced from petrochemicals). Furthermore, in most cases, more natural resources are used up to consume the products themselves. Unfortunately, the utilization of both nonrenewable and renewable resources has a major impact on both localized and global environmental change. As a result of the depletion of resources and generation of pollution, both producing and consuming goods by humans are important sources of environmental change [45, 46].

A significant amount of research has been conducted and published on the environmental impacts of the production and consumption of textiles. The research has helped to inform policy-makers and the public on reducing toxicity of chemicals in production stages, creating industry standards for production and promoting more sustainable ways of cleaning textiles. However, sustainability of the disposal of textiles was not paid much attention until recently.

Textile production is a burden for the environment. Textiles cost significant amounts of natural resources, and the use of toxic chemicals and generation of large quantities of carbon dioxide further augment the problem. However, despite this huge cost, millions of tons of textile products are disposed of every year. In Europe and America, 10 million tons of disposed textile products are predicted to be disposed of, while the estimation for China is double this amount. This textile waste pollutes our environment and clogs landfills around the world on top of all the natural resources used for their production.

Western lifestyle, with its dependence on the culture of consumption, amplifies landfill waste. Not only is the consumption at a high level, but also products are generally overpackaged in the West, which translates into more waste—and to the consumption of natural resources required for packaging. Landfill capacity is not growing at the pace of the increase of the generation of waste, which inevitably means that the cost of waste disposal rises further. This is a major concern for businesses as they need to reduce the overhead costs [38].

The disposal of textile wastes is crucial for the textile industry globally. Tons of textile products get discarded by the consumers and end up in landfills all over the world. Estimates suggest that a vast majority, as high as 95 percent, of the discarded product could in fact be used again—re-worn, reused or recycled, depending on their condition. Indeed, the conditions are pushing the trend, because, as natural resources are limited and cost of waste disposal is increasing, more waste is getting recycled or reused [47].

Textile wastes account for almost 5% of all landfill spaces, according to the US Environmental Protection Agency (USEPA); however, the recycled postconsumer textile wastes are barely 15% annually, and thus, a huge 85% of the waste ends up in landfills. Certain organizations, including the Council for Textile Recycling (CTR), are endeavoring to raise consciousness about keeping the postconsumer textile wastes out of the solid waste streams, with the aim of reaching the level of zero textile waste going to landfills by 2037 [44].

Textile waste is produced through a number of streams including the fiber, textile and clothing manufacturing industry, consumers and the commercial and service industries. CTR categorizes textile recycling material as pre- or postconsumer waste [48, 51].

Preconsumer textile waste, according to CTR, is the waste generated during production—by processing fibers, and the production of finished yarns and textiles, technical textiles, nonwoven, garments and footwear, including offcuts, selvages, shearings, rejected materials and/or B-grade garments. Preconsumer textile waste is usually what is considered as "clean waste." Preconsumer textile wastes are produced by the original manufacturers and never make it to consumers [44, 48].

Postconsumer textile waste refers to textile products that the consumer disposes for any reason—they might be run-down or not liked by the consumer anymore. Generally, postconsumer textile wastes tend to be of good quality, which can be recovered or reused as second-hand clothing, and are generally sold to poorer regions of the world. Even the textile products that will most likely not be used by the consumers can potentially be shredded into fiber to be reused for manufacturing [48].

The fast fashion era has skyrocketed the rate at which textile products are discarded, as "going-out-of-fashion" has become one of the main reasons for "not liking the product anymore." The implementation of a convenient recycling regime can turn these wastes into raw materials to be used in producing future, value-added products. This is the current aim for the ongoing development of textile waste management systems, which seek to produce value-added products through recycling [44]. Textile waste treatment strategies include reducing, reusing and recycling, as shown in **Figure 1**. The first and most preferred approach, reducing, is aimed at, if possible, avoiding any waste entirely. The second approach, reusing, aims literally for the item to be reused by a consumer after it has been discarded by another. The third and last approach is recycling: the materials of discarded items are transformed into new products [49]. Wastes can be recycled to products for the same purpose with their first use, or they can be upcycled or downcycled. In upcycling, wastes are converted into high-value products with different purposes than the original use, while in downcycling, valuable products are converted into lower-value materials [50].

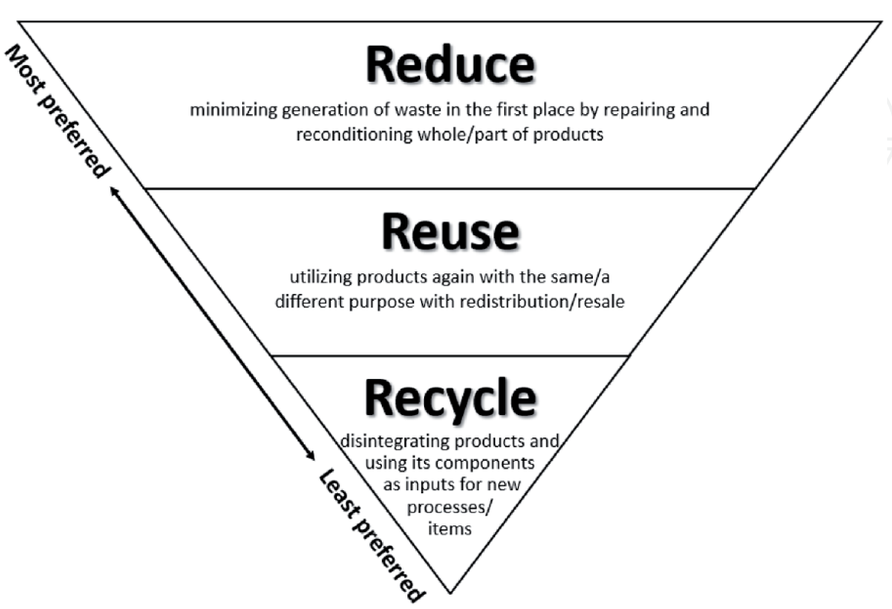

Figure 1.
Textile waste treatment strategies 3R concept.

Sustainability aspires to derive maximum benefit from products by extending their life. Studies conducted by economists and environmentalists on technical and economic requirements for sustainability reveal that it is imperative to reduce waste generation and increase recycling. Below are a few reasons why recycling is important [51, 52]:

- Economical reasons: recycling programs cost less than waste disposal programs. The high water, energy and manufacturing consumption makes it much cheaper to recycle than to produce some new textile products. Recycling can be made financially rewarding, as people can receive money for turning in certain recyclable products.

- Social reasons: recycling creates jobs. Recycling centers create four jobs for every one job in the waste disposal industry. The method can also create opportunities for small businesses.

- Environmental reasons: recycling conserves natural resources such as water, oil and natural gas; saves energy as it requires less energy compared with manufacturing brand new products; produces less greenhouse gases; and prevents the destruction of natural habitats.

Recycling and recovery of textile products are not as common as the material groups such as glass, metal, plastic and paper and product groups such as electronic, packaging and automotive. Recycling activities related to the textile sector are mainly focused on the treatment of chemical wastes and polluted water—problems that arise during production processes. The number of scientific or practical studies on the recycling of solid wastes is extremely limited [53].

Even though the textile and apparel sector is one of the most intense consumption sectors, implementation of recycling throughout the sector is not satisfying. However, parallel to the increasing global awareness of environmental problems, the awareness of consumers about sustainability has also started to increase. Consumers are now demanding recycled textile products and manufacturers are seeking ways to meet this demand [53, 54].

The waste generated by the textile sector contributes to land, water and air pollution. Decomposing textiles generate greenhouse gases and thus air pollution. The vast amount of chemicals used for producing textile goods unavoidably pollutes the rivers. And discarded textile products fill up landfills, which are already scarce. All these wastes are resources that could have been used to create value-added products. Not only this potential is lost, but also more raw materials are required to be used, which in turn results in more energy to be consumed [55].

Wasted materials can be recovered through reusing a product as is and converting the waste into a product. A material should get to be reused as much as possible and the consumer finally decides to discard it, and then recycling would be a good alternative to reduce the carbon footprint [56].

Recycling technologies tend to be divided into primary, secondary, tertiary and quaternary approaches, and all these four methods are applicable to recycle fibers. Primary approaches refer to the process of recycling a material to what it was originally. Secondary recycling means melt processing a plastic product into a lower-quality but nevertheless a new one. Tertiary recycling refers to processes that convert the plastic wastes into basic chemicals or fuel, such as pyrolysis and hydrolysis. Quaternary recycling involves burning the fibrous solid waste and converting it into a source of energy exploiting the heat generated through burning [38, 57].

Obviously, the most fruitful method of recycling is the primary approach. This approach, also called closed-loop recycling, is only applicable to man-made fibers such as PET or PA. This primary approach includes collecting textile waste discarded by the user and using this in new clothing as material for the production of yarn. The most common method of recycling actually is what is called open-loop recycling. In this method, the output material does not have a high-enough level of quality to produce new clothes; thus, it gets downgraded. The study on cotton fibers by Ütebay et al. demonstrates the deterioration in fiber quality. Downgraded material can be used as mattress upholstery or isolation material in cars. Through open-loop recycling, some value is recuperated from the textile waste, which would otherwise have been incinerated. However, this does not help to reduce the necessity of raw materials to produce clothing. Therefore, closed-loop recycling remains to be an attractive alternative. A closed-loop supply chain provides the advantage to recover more value from used products [56, 58, 59].

The most recycled textile waste is thermoplastic polymer-based fibers because they are easy to process and can be given different forms and shapes afterwards. Nevertheless, natural fibers such as cotton, wool and silk are also finding their ways into the recycling stream through downcycling or upcycling [44].

Recycling of textiles today is not a wide industry. The number of companies that offer services of recycling of textile fibers is limited because it is economically not beneficial and technologically not advanced. The lack of technological innovation and the continuing supply of cheap fabrics into the markets hinder the motivation for research, development and application of recycling techniques; however, it does not totally block the development of new technologies for recycling textile waste. Soon, certain obstacles will need to be faced and resolved to further increase textile waste recycling [10, 60].

In terms of technology, the fundamental question is the fiber composition of textile materials. The current garments in today's markets vary more in terms of design and fiber content than in the past. The other compounded factors are issues/difficulties in separating the blended components, efficiency of separation, quality of separated material and hence the recycled material's quality and so on. As recycled fibers and fabrics still provide a low level of quality, virgin natural and synthetic fibers remain to be popular options [10, 38, 56].

There are some recycling technologies available on the market today. Others are on the way, albeit few. Other changes need to accompany these research and trial endeavors—in terms of economy, processing costs should be reduced; in terms of policy, relevant standards should be implemented; and in terms of governance, textile waste should be recollected much more efficiently. Apart from increasing the efficiency of recycling methods and processes, the market for recycled products should grow. In short, recycling needs more encouragement, wherever it is economically and technically feasible [47].

There are important benefits of recycling textiles, both environmental and economical. It reduces the need for landfill space, consumption of already scarce virgin resources, pollution as well as water and energy consumption and the demand for dyes and fixing agents [61]. However, even though recycling offers ways to reduce environmental negative impacts, it is not exempt from certain problems. Wang [38] lists the following as challenges:

- The mechanical, chemical or biological processes to recycle waste still require a certain amount of energy.
- The recycling processes continue to require new raw material input.
- The recycling processes still generate emissions into air, water and land.

Evidently, recycling is not always the preferred approach, when not only the environmental context but also the competitiveness of the final product in the market is taken into account. The existing recycling technologies need to get better, cleaner, more energy efficient and less costly [38].

Textile recycling, a key concept for sustainability, currently faces hurdles related to cost, time and technology. But as sustainability becomes more and more important, more initiatives are getting incentivized and sponsored by both manufacturers and other organizations in the textile sector to help advance the results of textile recycling. This tendency can be seen through the fact that certain textile recycling companies have shown promising growth. Different strategies and policies were coined in different regions to promote an efficient way of recycling for conserving the environment more and increasing the economic efficiency [38].

Many voluntary and nonprofit organizations run campaigns to conserve natural resources by creating awareness of both downcycling and upcycling recycling

Figure 2.
Labels for recycled products.

concepts. The campaigns aim to convince the consumers that using recycled products is an esteemed way of adding value to oneself, the product and the world.

Examples of commercially available labels for recycled products are given in **Figure 2** [62–68]. All these initiatives are expected to promote environmentally appropriate, socially beneficial and economically viable management systems [44].

In addition to these certifications, some standards such as Social Responsibility Standard (ISO 26000), Environmental Management System (ISO 14001), Occupational Health and Safety Management System (ISO 45001) and Energy Management System (ISO 50001) also support sustainability and social responsibility practices and contribute to their dissemination [69–72].

An unsustainable consumption of textile goods ensures the deterioration of the environmental degradation. To achieve environmental integrity and sustainability, incentivizing the textile companies to produce more environment-friendly products is not enough—the behavior of consumers also needs to change, creating more awareness toward the conservation of the environment [45]. In this context, Connolly and Prothero [73] write: "Rather than focus on the issue of whether green consumption can work as a strategy, we should perhaps try to gain a greater understanding of the process that has led people to believe that they, as individuals, can help solve global environmental problems."

5. Conclusion

The fibers obtained by recycling are generally evaluated in the production of lower-value products (downcycling) compared to the original product. However, nowadays, recycling fibers have started to increase their evaluation in high value-added products (downcycling). On the other hand, the perspective that focuses only on the cost aspect of the production of recycled garments is not correct. Considering water consumption as well as pesticides and artificial fertilizers used, the textile industry is known to be one of the most polluting and waste-generating sectors. From this point of view, recycling of textiles and garments is of great importance in terms of reducing the use of natural resources (e.g., water used to grow seeds or oil used in the production of synthetic fibers) and CO_2 emissions. Recycling will also save energy and chemicals to produce new textiles, as well as prevent pollution from the production process. In this context, it is important for the future of our world to review all production and consumption processes and supply chains in the focus of circular economy and sustainability. Therefore, the recycling of textile industry waste is very important.

The future of textile recycling mostly depends on its implementation in the industry and gaining more experience and grounds for more innovative methods. Clothing retailers are key actors on this front, as they are uniquely positioned to be able to influence and improve consumers' approach in favor of sustainability. Not only do clothing retailers have the potential to influence consumer decisions, but also they are in a position to alter consumption patterns. People can learn the importance of recycling as well as reuse and resales by the help of companies, and this is not limited to developing countries. Through such actions, consumer awareness about sustainable consumption would increase, leading to less environmental damage in the future.

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