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# CIRCULAR ECONOMY — CHALLENGES FOR THE TEXTILE AND CLOTHING INDUSTRY

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***Abstract:***

*The circular economy model has recently gained a lot of attention worldwide from scientists, business people and authorities. The importance of the transition towards a more circular economy has also been noticed in the European Union. The new regulations provide the enabling framework for the circular economy to flourish. At the same time, although there is no standardized approach to creating a circular economy, while defining appropriate policies, care must be taken that they are suitable for particular industries. The limits of the present linear economy model (take-make-waste) are extremely apparent when examining the textile and clothing industry. The transition to a circular economy requires significant changes in both production and consumption models. This article uses a literature review and industry examples to identify and evaluate challenges faced by the clothing and textile industry in adapting to the circular economy model.*

***Keywords:***

*Circular economy, recycling, closing the loop, textile and clothing industry*

## 1. Introduction

It is becoming increasingly obvious that the present linear (take-make dispose) model of economy has slim chances of effectively adopting sustainable development principles. Consequently, the circular economy (CE) model is gaining more and more attention. It is defined as an industrial system that is restorative or regenerative by intention and design, uses and reuses natural capital as efficiently as possible, and finds value throughout products' life cycles [26,29]. It also involves the introduction of principles such as sustainable design strategies, zero-waste design, product-life extension, resource recovery, repair and remanufacture services [4]. We could say that the CE framework is shaped by the 3R (reduce, reuse, recycle) principles that should be applied throughout the whole cycle of production, consumption and return of resources and the circular model requires the engagement of all market the participants [20].

The importance of the transition towards a circular economy has been noticed in the European Union (EU). A major momentum of this transition was the creation of the Circular Economy Package and its adoption by the European Commission on December 2, 2015. With a view to closing the loop of product lifecycles, the package was provided with an Action Plan to support the circular economy in each step of the value chain. The European Commission will continue to deliver on the Circular Economy Action Plan, setting very concrete targets for the Member States and their industries that will have to be met in the near future. Moving away from the "take, make, use and dispose" paradigm towards the circular one involves the replacement of the end-of-life concept, restoration of resources, the use of renewable energy, the elimination of toxic chemicals from use, and the elimination of waste through the superior design of materials, products, systems and business models [29]. In designing the transition towards the circular economy, one has to bear in mind that the process has not been standardized and the policies making the circular economy more implementable must be appropriate for particular industries. The limits of the present linear economy model (take-make-waste) are well illustrated by the textile and clothing sector, an essential consumer goods industry. The necessity to move towards the circular model of economy is also indicated by the industry experts and practitioners. In a recent document "Strategic Innovation and Research Agenda for the European Textile and Clothing Industry" released by the European Technology Platform for the Future of Textiles and Clothing, the theme "Circular Economy & Resource Efficiency" was highlighted as one of the four strategic innovation areas that have special importance for further development of the European textile and clothing industry. The textile research, technology and industry experts from across Europe working on the document also named three powerful innovation trends that will impact the industry in the coming years, all of which are very closely related to the new circular economic model. These are [27]:

1. **digitization** of products, their design, manufacturing, distribution and retail processes, consumer/end-user interaction, factories, workplaces and supply chains

2. **sustainability, circularity and resource efficiency** of materials, processes and overall business operations; this trend requires transparent supply chains meeting the environmental, health and social legislation standards

3. **new business and consumption models** based on the sharing of productive resources and final products, servitisation, pay-per-use or subscription models, all moving us towards collaborative or sharing economy

The rise of these new, very broad and potentially far-reaching trends brings both challenges and opportunities for the textile and clothing industry.

Based on literature review and industry examples, this article aims to identify and evaluate the challenges that the clothing and textile industry will face in adapting to the circular economy model.

## 2. The limits of the current linear model of production and consumption in the textile and clothing industry

Textile and clothing production is a major component of the European manufacturing industry. According to Euratex [31], in 2016, 177,700 textile and clothing companies (EU-28) with employment of over 1.7 million people had a turnover of €171 billion and invested €4.8 billion. The industry accounts for a 3% share of the value-added goods and a 6% share of the employment in the total manufacturing in Europe. With nominal sales of over $450 billion globally, the industry is also one of the biggest [24] and unfortunately, one of the most harmful to the environment [24,1]. The environmental issues are typically related to the use of energy, water and chemicals, direct $CO^2$ emissions and solid waste [24]. Their environmental footprint has different intensity depending on the stage of the textile or clothing product life cycle (Table 1).

The section below presents the main factors that, in recent years, significantly contributed to the aggravation of environmental problems in the textile and clothing industry. It also outlines the trends that expose the limits of the present linear economic model and explains why efforts should be made to move towards the circular one.

The direct or indirect sources of most of the ecological concerns that beset the T&C industry are related to surging consumption and fast fashion that comes with it [17]. The fast-fashion business model emerged in the 1980s; then, 5–10 years later, the ever more aggressively priced fast-fashion discounters came and gradually began to affect customer expectations with their ability to undercut traditional clothing retailers by 50% or more [16]. Clothing companies aggressively cut costs and streamlined their supply chains. This caused clothing prices to fall relative to the prices of other consumer goods and made clothing more affordable [23]. Shorter production lead times made it possible for clothing brands to introduce new lines more frequently. Today, Zara offers 24 new clothing collections each year and H&M from 12 to 16 and refreshes them weekly. Among all the European apparel companies, the average number of clothing collections has more than doubled, from two in a year in 2000 to about five in a year in 2011 [23]. Consumers responded to lower prices and greater variety of clothing by buying more items. Consequently, from 2000 to 2014 the number of garments purchased each year by an average consumer increased by 60 percent [26]. Large increases in clothing sales were especially observed in the emerging economies, where more and more people enter the middle class [26]. The authors of the recent McKinsey report predict that if consumers in developing-countries will buy more clothing as their purchasing power increases, clothing sales may rise significantly in the future. According to their estimates, if 80 percent of the population in emerging economies achieves by 2025 the same clothing-consumption level as the Western world, and the apparel industry will not become more environmentally efficient; the industry's environmental footprint will grow much stronger [23].

The Europeans consume substantially more clothing today than they did two decades ago. In 2012, clothing spending in EU-28 accounted for 4.2% of total household expenditures. The volume of clothing purchases increased from 1996 by 40% [8]. Additionally, today clothes are made to be used for a comparatively short time and then disposed of, as the ubiquitous linear models of consumption dictate [12]. McKinsey asserts that across nearly every apparel category, consumers keep clothing items about half as long as they did 15 years ago. Industrialization ushered in consumerism with its throwaway attitude. Economic growth began to depend on the ongoing promotion of new products and the disposal of old ones, which were branded useless simply because the stylistic norms emphasized their obsolescence [7]. Today, many consumers tend to purchase more than they really need and treat the lowest-priced garments as nearly disposable. Some estimates indicate that such garments are likely to be discarded after just seven or eight wears [26,23,10]. Another negative consequence of these consumption patterns is that the opportunities for reuse of low-value clothing at the end of its

**Table 1.** Major environmental issues related to product life-cycle stages

| Environmental problems | The most impactful stages in product life cycle |
|---|---|
| Energy consumption | Production of man-made fibers, yarn manufacturing, finishing processes, the washing and drying of clothes in the use phase |
| Water and chemicals consumption | fiber growth, wet pre-treatment, dyeing, finishing and laundry |
| Solid waste | Mainly the disposal of products at the end of their life, textile/clothing manufacturing |
| Direct $CO_2$ emissions | Transportation within globally dispersed supply chains |

Source: created by the author based on [24].

useful life are few, if it quickly goes out of fashion, or has poor appearance retention, dimensional stability, or durability [12].

Falling costs, streamlined operations, rising demand and consumer spending contributed to a significant growth of clothing production,[23] which doubled between 2000 and 2014 when it exceeded 100 billion items for the first time (nearly 14 items of clothing for every living person on the earth) [23].

The growing world population and expanding middle class, as well as the rising standards of living, mean that this trend will continue [19].

A natural consequence of the current apparel production and consumption patterns is the steadily increasing demand for fibers and the swelling amounts of textile waste [6]. According to Lenzing' preliminarily estimates, in 2016, the world fiber consumption reached 99 million tons. Most of the fibers were oil-based synthetic fibers (62.7%) followed by cellulosic and protein-based fibers (with cotton content of about 24.3%), wood-based cellulose fibers (around 6.6%), other natural fibers (around 5.3%) and wool (around 1.1%) [28]. Seeking to meet the demand, the global fiber production continues to set new records. In 2013, it was around 85.5 million tons and is expected to grow by 3.7% per annum reaching 130 million ton in 2025 [8,30] (Figure 4). Global production of cotton and polyester, the two key fibers for the textile industry, is predicted to grow by 40% in the next 5 years [10]. In the past two decades, the production of cotton rose steadily, but at a slower rate than the production of polyester that now dominates the global fiber production [6]. Cotton accounts for nearly 33% of global textile production, synthetic fibers (including polyester, acrylic, nylon (polyamide) and polypropylene) for about 60%, other cellulosic for almost 4%, and wool and flux (linen) for 2.1% and 1.0%, respectively [19].

The Circle Economy [6] estimates that an 84% increase in the demand for textile fibers in the next 20 years will stretch resources to their breaking point. Shrinking resources and growing production of textile fibers will put more and more strain on the environment. Cotton and polyester production has a huge environment footprint [25]. Polyester fiber and other fibers made from non-renewable fossil fuels require significant energy inputs and large amounts of crude oil to be manufactured and result in significant emissions of greenhouse gases. Moreover, the by-products of polyester production (e.g., volatile monomers, solvents, etc.) are discharged by manufacturing plants with wastewater. Finally, because polyester is not biodegradable, it takes centuries to decompose in the environment [19,7,6].

The environmental footprint of cotton, the second biggest textile fiber with an annual production of about 25 million tons, is also significant [19,6]. Growing cotton takes a lot of water, land, pesticides, and fertilizers [26]. The Circle Economy estimates that 10% of the world's pesticides, 25% of insecticides, and as much as 2.5 percent of all the world's water are consumed by cotton, even though it takes up only 2.4% of total arable land. Cotton is also the 3rd biggest contributor to pesticide-illness in farmworkers [6]. Cotton is a biodegradable fiber, but the chemicals used in the finishing and dyeing processes impair the quality of soil and groundwater upon disposal [19].

All these negative environmental impacts could be significantly mitigated if the textile and clothing sector chose to replace the take-make-dispose model with a circular one. Wearing clothes longer, effective recycling of textile waste and reusing it as raw materials could largely reduce the demand for the end products and fibers. Textile and clothing companies can no longer ignore the fact that the present linear model of economy has become dysfunctional, as evidenced by limited supply of raw materials and resources, and increasing disposal costs pointing to declining landfill capacity [1]. Figure 2 identifies interacting trends that have brought the textile and clothing industry to the limits of the linear "take-make-dispose" economy model on the one hand and stimulate the transition to the circular one on the other.

## 3. Main challenges faced by the textile and clothing industry in transitioning to the circular economy model

The speed and scale of the transition to circular model will depend on knowledge, awareness and engagement of all

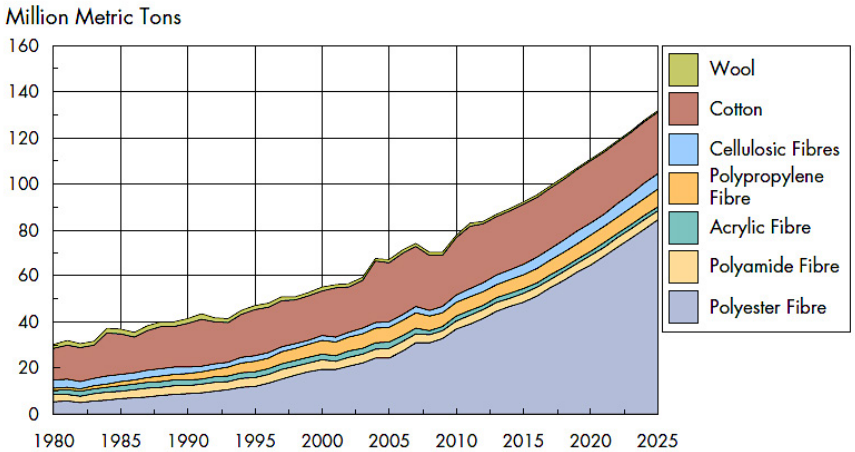


**Figure 1.** World fiber production 1980-2025 Source: Tecon OrbiChem [30]

market participants. In the process, the 3R principles should be applied throughout the whole cycle of production, consumption and return of resources. This means that the challenges for the textile and clothing sector will refer to reduction of material and energy intensity, lower dispersion of toxic substances, enhancement of the ability to recycle, maximization of the use of renewable resources, extension of product durability and increasing the service intensity.

The prevention of waste throughout a product life cycle and the elimination, or at least minimization, of the percentage of waste ending up in landfills are one of the biggest challenges that the textile and clothing industry will have to confront while transitioning to the circular economy. Its success will depend on the adoption of a completely new approach to the way products are designed, produced and consumed [10]. Effective waste management will significantly influence all the 3Rs by reducing virgin raw materials, reusing textile and clothing waste and recycling them. However, effective waste management strongly depends on the initial phrase of product design and development. Below, the main challenges, barriers and risks related to closing the loop in textile and clothing industry and the transformation to the circular model are presented more in detail.

### 3.1. Waste creation

The current linear model of textile and clothing production and consumption (fast fashion) leads to enormous quantities of textile waste, because clothes are discarded after being worn for a relatively short time. There is also the issue of overproduction; only 30% of the clothing produced today is sold at the recommended retail price, another 30% goes in the sales and 40% remains unsold or even fails to reach the shops [9].

Textile waste can be generally divided as per its source into three main types (Figure 3):

1. **Post-industrial waste** – a side-effect of clothing manufacture;
2. **Pre-consumer waste** – inferior quality garments at the manufacturing site or a retailer's distribution center, unsold merchandise at the retail store;
3. **Post-consumer waste** – generated by consumers themselves: worn out, damaged or unwanted clothing.

The key challenge in handling the three types of waste is to reduce their amounts and to minimize waste that is now being incinerated or landfilled. In Graph 3, the red denotes the flows of textile waste that has to be eliminated or minimized, as well as the necessary activities; the grey represents stages that the author deems crucial for the process to be successful.

In its most recent report, the Global Fashion Agenda and The Boston Consulting Group predicts that if the current level of solid waste generated by production processes and end-of-use continues into the future, the fashion industry's waste will increase from 2015 to 2030 by about 60%, as a result of additional 57 million tons of waste being generated annually. Consequently, the total level of fashion waste will rise to 148 million tons by 2030, which amounts to 17.5 kg per capita annually across the planet [13].

According to the Eurostat statistics, the top ten producers of textile waste in the EU in 2014 (tons; all NACE activities plus households) were Italy, Germany, the UK, Poland, Belgium, France, Spain, Netherlands, the Czech Republic and Portugal (Figure 4).

Most of the countries managed to reduce their textile waste levels from 2004. The exception is Poland, Belgium and Germany, where the volumes of textile waste increased between 2004 and 2014 (Table 2).

The rankings look somewhat different when the generation of textile waste is considered in per capita terms. In this case, the unquestionable leader is Cyprus with 32 kg of textile waste per

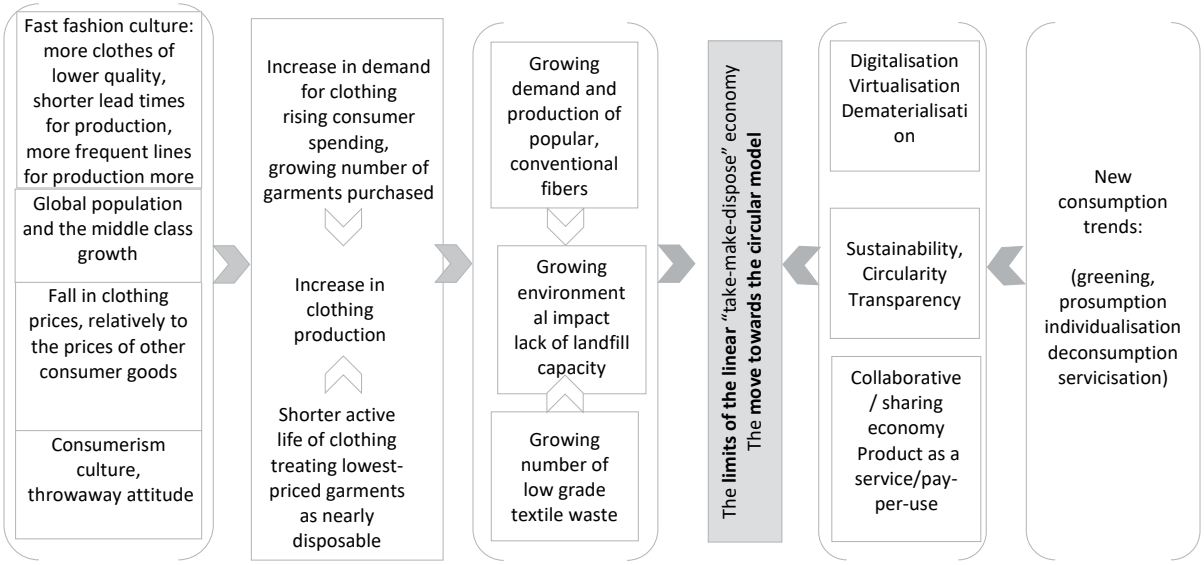


**Figure 2.** Trends in the textile and clothing industry pushing the move towards circular economy

inhabitant in 2012, followed by the UK (19 kg) and Belgium (16 kg). These numbers contrast sharply with the EU average of 6 kg per capita (Figure 5).

The data in Table 3 below reveal that in the years 2004—2012 textile waste production significantly increased in the UK (from 4 to 19 kg per capita), Germany (from 2 to 4 kg) and Austria (from 4 to 5 kg). In the same period, some of the EU leaders in textile production managed to substantially reduce textile waste. For instance, in Romania, its level dropped from 12 kg per capita in 2004 to 1 kg per capita in 2012, in Portugal from 45 kg to 6 kg, in Belgium from 59 kg to 16 kg, and in Italy from 14 kg to 7 kg (Table 3).

The problem that waste poses today lies not only in the number of its streams, but also how it is treated. The typical end-of-life options for textile and clothing products are the following[12,5]:

- reuse (repair, resale)
- recycling (high value recycling, up-cycling, down-cycling)
- incineration (without energy recovery, with thermal energy generation), and
- landfill disposal

Only 20% of clothing waste is collected globally for reuse or recycling. The remaining 80% is landfilled or incinerated, which results in a great loss of energy and raw materials.[18,9] Therefore, let us try to identify the main causes of this situation.

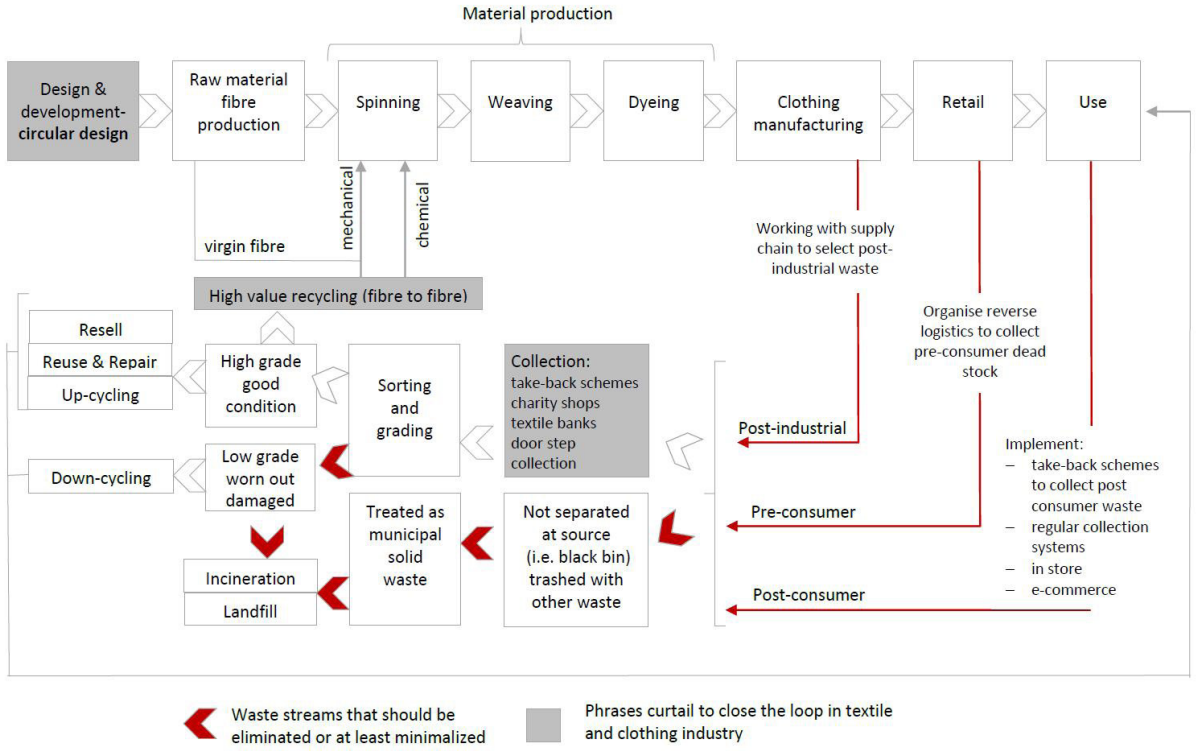


**Figure 3.** Closing the loop in the textile and clothing industry — a way to zero waste supply chain Source: created by the author based on [8,19,20]

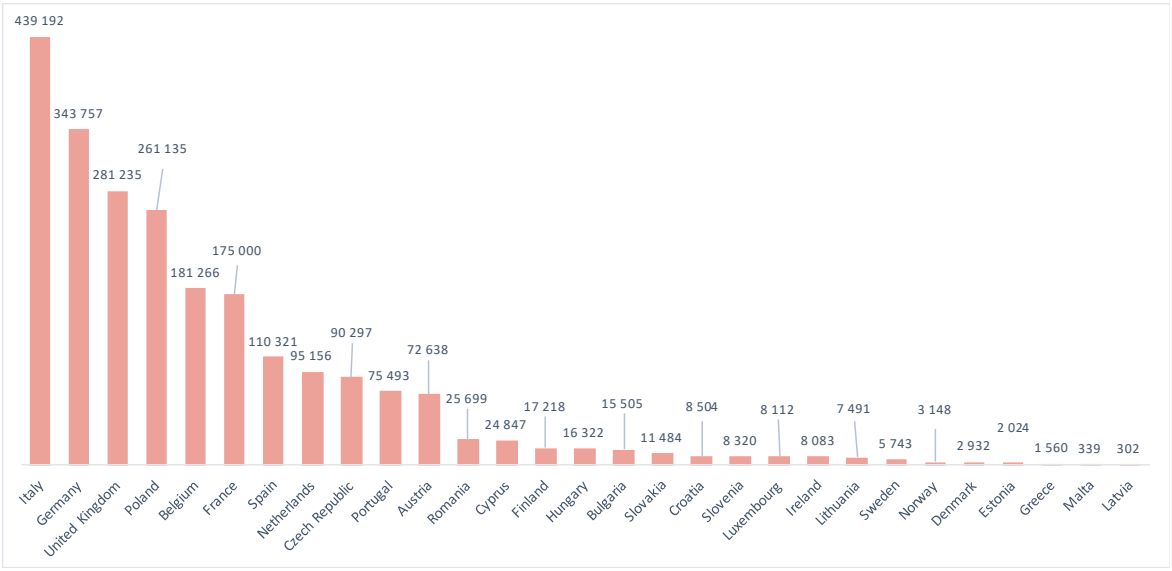


**Figure 4.** Textile waste (all NACE activities plus households) in EU countries; tons, 2014 Source: created by the author based on Eurostat data

**Table 2.** Change in textile waste in EU countries from 2004 to 2014

| Textile waste All NACE activities plus households | 2004 [tons] | 2014 [tons] | Change [tones] | Change [%] | Ten-year change |
|---|---|---|---|---|---|
| European Union (28 countries) | 4 430 000 | 2290000 | | -48% | ↓ |
| Poland | 79 402 | 261 135 | 181 733 | 229% | ↑ |
| Belgium | 106 766 | 181 266 | 74 500 | 70% | ↑ |
| Germany | 222 336 | 343 757 | 121 421 | 55% | ↑ |
| Turkey | 260 549 | 214 324 | -46 225 | -18% | ↓ |
| Netherlands | 115 935 | 95 156 | -20 779 | -18% | ↓ |
| United Kingdom | 378 233 | 281 235 | -96 998 | -26% | ↓ |
| Spain | 188 762 | 110 321 | -78 441 | -42% | ↓ |
| Italy | 753 187 | 439 192 | -313 995 | -42% | ↓ |
| Austria | 138 121 | 72 638 | -65 483 | -47% | ↓ |
| France | 489 600 | 175 000 | -314 600 | -64% | ↓ |
| Czech Republic | 310 438 | 90 297 | -220 141 | -71% | ↓ |
| Romania | 261 032 | 25 699 | -235 333 | -90% | ↓ |
| Portugal | 963 633 | 75 493 | -888 140 | -92% | ↓ |

Source: created by the author based on Eurostat data

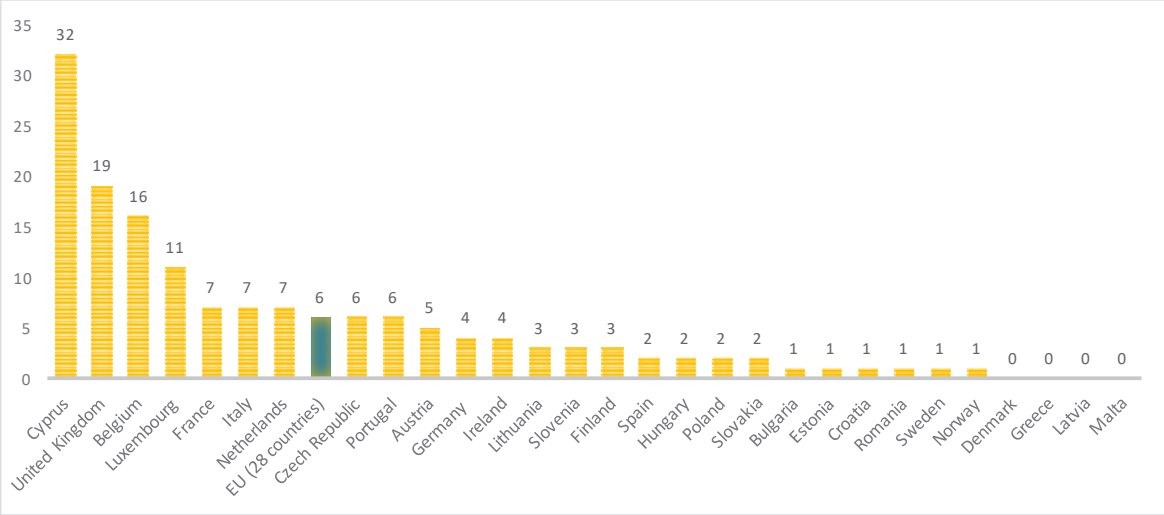


**Figure 5.** Textile waste (all NACE activities plus households) in EU countries in 2012, kg/per capita. Source: calculated by the author based on Eurostat data

## 3.2. Determinants of the effectiveness and economic viability of textile recycling

The practical and economic viability of textile and clothing recycling depends on many factors, including the availability of appropriate infrastructure, the type of textile product and its physical condition, the degree of wear, fiber composition, finish, garment construction, logos and emblems, accessories, the manner of labelling, and, last but not least, how the garment has been disposed of [12]. The factors can be divided into three groups (Figure 6) with respect to the phase in the textile product life cycle (marked in grey in Figure 3).

### 3.2.1. Product design and development

In the circular economy, product performance (determined by its durability, recyclability and reparability) will be defined as early as the design stage. Decisions being made then will influence all the subsequent phases of a garment's life-cycle (from the specification of raw materials and the selection of dyes, solvents, finishing processes, garment construction, accessories, and labelling methods to the disposal of the garment by the consumer), thus determining the range of end-of-life options [12,10,29]. They will also make garments last longer and be less likely to end up in landfills at the end of life [12].

The designers and engineers will face a real challenge of combining optimal recycling options and sustainability with product desirability, because designing sustainable, fully recyclable products that appeal to no one, falls short of success.

In trying to achieve this, they will have to solve a sort of a catch-22 problem; although many fibers and fiber blends present in finished products cannot be effectively separated for recycling unless complex processes are applied, they cannot be given up because they give fabric qualities appreciated by consumers, such as softness, breathability, ease of care, comfort, appearance, drape, handle, color fastness, functionality and so on.[12] A case in point is the blend of cotton and polyester. It is inexpensive for clothing manufacturers and offers consumers the desirable performance and care features (breathability and softness of cotton is enhanced by polyester properties such as color stability and resistance to abrasion and repeated washings), but recycling it is a challenging task. [13,6] This inevitably implies that the circular economy will need new design philosophies and interdisciplinary teams capable of coming up with circular, resource-efficient solutions acceptable for customers.

**Table 3.** Change in textile waste levels in EU countries from 2004 to 2012, kg per capita

| TEXTILE WASTE | 2004 [kg per capita] | 2012 [kg per capita] | Change [%] |
|---|---|---|---|
| **EU-28** | **8** | **6** | **-25%↓** |
| United Kingdom | 4 | 19 | 375%↑ |
| Germany | 2 | 4 | 100%↑ |
| Austria | 4 | 5 | 25%↑ |
| Cyprus | 32 | 32 | 0% |
| France | 7 | 7 | 0% |
| Spain | 2 | 2 | 0% |
| Poland | 2 | 2 | 0% |
| Italy | 14 | 7 | -50%↓ |
| Sweden | 2 | 1 | -50%↓ |
| Belgium | 59 | 16 | -73%↓ |
| Norway | 4 | 1 | -75%↓ |
| Portugal | 45 | 6 | -87%↓ |
| Romania | 12 | 1 | -92%↓ |
| Greece | 1 | 0 | -100%↓ |

Source: calculated by the author based on Eurostat data

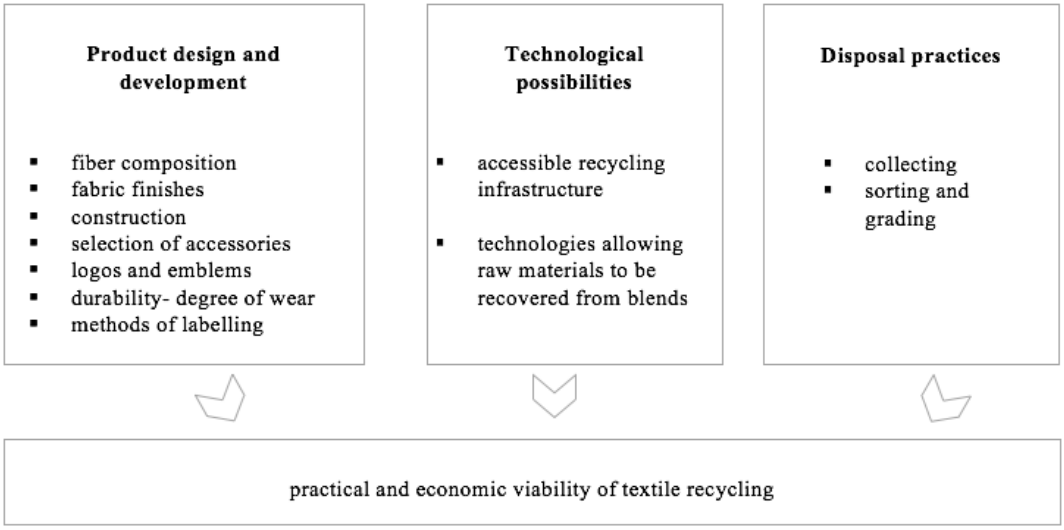


**Figure 6.** Main factors likely to influence the practical and economic viability of textile and clothing recycling in the future

### 3.2.2. Disposal practices and recycling technologies

Another crucial and challenging stage in the development of a circular textile system is finding an answer to the question about how textile waste should be collected and sorted. For the process to be successful, recovery and reprocessing infrastructure is necessary, as well as effective communication across the supply chain.[4] As it seems, closing the loop in textile and clothing industry is hindered by three main types of barriers (Tables 4):

- consumer disposal practices – behaviors and education
- producer disposal practices and possibilities – infrastructure and processes for waste collection and sorting
- recycling technologies – operable in practice

Consumers appear to know less and be less aware of the need and ways of dealing with end-of-life garments and textiles than they are in the case of glass, paper or plastics.

A lack of up-scaled efficiency in collecting and sorting textile and clothing waste is also a problem. Due to this, low-quality materials and blends dominate in the recycling market and puts a strain on the commercially viable recycling technologies for low-grade textiles and blends.

As a result, only 15 to around 20% of all textiles (depending on the region) go to recycling, while the rest of it is landfilled or incinerated. The EU-27 rate for reused or recycled clothing is only 18%, which in the US is even worse.[19] They clearly contrast with the rates for other products (in the case of packaging it is 98% in Germany and 79% in Belgium).[13]

The mainstream recycling technologies and structural solutions that could eliminate barriers to the introduction of a global closed loop in the textiles industry are still few. To cope with this problem, the industry, research institutions, academia and NGOs have intensified their efforts aimed to develop effective solutions through research projects and programs, and to introduce new business models and technologies. Some examples of such initiatives are presented in Table 5.

**Table 4.** Barriers to closing the loop in textile and clothing industry

| Consumer behavior and education | Disposal practices, collection and sorting infrastructure and process | Recycling technologies |
|---|---|---|
| - Poor consumer demand for recycled textile products, which tend to be perceived as lower quality<br>- Consumers' unawareness that textiles should be recycled and how they can be disposed of in the most responsible manner | - Collectors focus on "re-wearable" textiles, while neglecting streams of waste that require more costly recovery solutions<br>- Lack of mainstreamed, up-scaled processes and know-how to collect and sort textiles by fiber type<br>- Low availability of infrastructure on local and regional levels | - Lack of commercially viable recycling technologies for low-grade textiles fraction<br>- Lack of mainstreamed, up-scaled processes and know-how to separate fiber types from the mixed blends and composite structures<br>- Costly recovery process<br>- The recycling end-market dominated by low quality materials and blends<br>- Costly logistics and low availability of textile recycling plants on local and regional levels |
| - Lack of traceability in the global waste chain<br>- Policy frameworks in which collectors, recyclers and waste managers operate | | |

Source: created by the author based on [20,10].

**Table 5.** Examples of the activities facilitating the transformation towards circular economy model in textile and clothing industry

| Company/ Area of action | Aims | Actions | Results |
|---|---|---|---|
| BIONIC® [21,3]<br><br>**Recycling technologies** | To use innovative technologies to transform recycled plastics into innovative raw materials and high-performance textiles, and to achieve new standards in aesthetics and functionality<br><br>To supply the consumer and industrial markets with fully traceable, high-grade textiles and polymers made with coastal and marine plastic. | Production of POLYMER: **BIONIC®** Polymer: a hybrid of recovered Marine and Coastal plastic available as Polyethylene terephthalate (PET) and High-density polyethylene (HDPE) for injection and blow mould applications with customizable pellet color and physical properties<br>Production of FIBRES - offer a range of three yarns, each with a different structure and proportion of recovered plastic, from 40% up to 100% of recycled content: (**DPX®**., **HLX®** ,**FLX®** ) | Bionic Yarn estimate that in three years they have pulled 7 million plastic bottles from shorelines around the world to produce yarn, thus helping to protect marine ecosystems. |

| Company/ Area of action | Aims | Actions | Results |
|---|---|---|---|
| Tonlé [15] **Zero-waste design and production model** | To use all pre-consumer textile waste to make fashionable clothing | Creation of zero-waste fashion collections out of surplus fabric from larger manufacturers, who usually scrap about 11% of the fabric through inefficient cutting patterns. Tonlé achieves zero-waste by combining creative pattern-making with a process of generating new garments from the surplus fabrics. Tonlé utilizes more than 97% of the fabric it receives and turns the excess into paper instead of discarding it. Workers are paid well above the minimum wages and are offered a comfortable and safe working environment. | In 2014, Tonlé succeeded in diverting 10 tons of textiles from landfilling. 90% of the fabric it uses is pre-consumer textile waste and the remaining 10% is composed of the up-cycled components of local garment waste. By using recycled raw materials rather than virgin materials. |
| Mud Jeans International BV [15] **Recycling technologies based on a "lease a jean" consumption model** | To promote usage over ownership and to facilitate the transition to a circular economy in the fashion industry by leasing jeans and recycling or upcycling materials. | After a year of leasing a pair of jeans, customers may keep it, switch it for a new model, or send it back for reuse or recycling. Mud Jeans sells the used clothing as vintage items or recycles the fabrics into new products. The manufacturing process itself is socially responsible and respects workers' rights. | The clothing manufacturing process uses far less water and does not need chemicals then conventional jeans |
| G-Star and Circle Economy pilot project with Wieland Textiles and Recover [5] **Waste collection & recycling technologies** | To re-introduce denim goods returned to G-Star and to create new denim fabrics that can compete with virgin cotton denim on price, quality and aesthetics. To try and prove the business and environmental case for high value (textile-to-textile) recycling of denim. | G- Star selected one of their top selling denim fabrics and set out to incorporate recycled content in the making of that fabric. The intent was to extend the future impact of this project beyond a single capsule collection and make recycled denim part of the sourcing strategy in the long term | Recycled denim fabric has a price premium of 12.5% compared with virgin equivalents. A maximum of 30% of recycled fibers can be used in the recycled yarn to make sure that it retains the needed strength for weaving and finishing. A recycled denim fabric with as little as 12% of recycled content has a much lower environmental impact than its virgin equivalent: water consumption can be reduced by 9.8%, energy consumption by 4.2% and CO2 emissions by 3.8%. |
| ReShare – a division of a Salvation Army: Project partnered with Circle Economy and Recover [6] **Recycling technologies** | To recycle used workwear of the Dutch military into new textile products to show the market that used workwear can be transformed into new, high quality products, while achieving significant environmental savings. | Development of a sustainable and safe solution for approximately 600 tons of old military workwear donated by the Dutch Ministry of Defence Used workwear of 50:50 cotton/ polyester average composition was mixed with virgin PET (polyester) fiber and mechanically recycled into new yarn to make blankets for humanitarian aid. | Several tons of old Dutch navy and army uniforms were transformed into new yarns that were used to produce humanitarian aid blankets. The Life Cycle Assessment of the yarns made with 80% recycled military uniforms showed a reduction in water consumption by 87%, decreased energy use by 42%, and a reduction in CO2 emissions by 33%, when compared with a non-recycled yarn. |

| Company/ Area of action | Aims | Actions | Results |
|---|---|---|---|
| ReBlend, a Dutch circular fashion & textiles agency [22]<br><br>**Product design +recycling technologies** | To show that mixed post-consumer textiles can be recycled into new high-quality products, thereby making the case for closed loop textiles | No longer wearable, post-consumer textile waste (>70%) were used in an ecologically friendly process (no water, no additional chemicals, no dying) to make yarn and textiles with a minimal negative ecological impact<br>In the project 100% recycled yarns for a new collection of knitted and woven fashion and upholstery products were produced | In the project, almost 7 tons of post-consumer garments were processed to produce 6 tons of new 100% recycled yarns. Four different color yarns were made with 70% recycled post-consumer garments and 30% RPET<br>The LCA analysis of one of the recycled yarns showed a decrease in energy use by 33%, a reduction in water consumption by 62%, and a decrease in greenhouse gas emissions by 18% compared with a virgin yarn of similar composition. |
| H&M<br><br>Collection + recycling technologies [13] | | The brand has partnered with I:CO, a solutions provider for clothing and footwear reuse and recycling. Its facility in Germany receives 25 to 30 truckloads a day from collection bins at H&M stores. The brand has similar facilities in the US and India. | In 2016, H&M collected nearly 16,000 tons of garments, a 29% increase from the previous year.<br>The collection program quickly became the sustainability initiative with the highest awareness amongst customers<br>Many stores reported positive feedback, both in terms of handling processes and customer reactions. |

## 4. Conclusions

Recent years have made it apparent that the linear economy model (take-make-waste) underlying the textile and clothing sector is nearing its end. There are several intertwined trends that have brought the sector to this point: fast fashion and consumerism with its throw away attitude and shorter active life of clothing, expanding global population and middle class, and the falling prices of clothing. The trends have almost naturally entailed an increase in the demand for relatively inexpensive textile and clothing products and conventional fibers, as well as contributing to an increased amount of low grade textile waste, a lack of landfill capacity and higher disposal costs. At the same time, new trends are emerging towards the circular economy: digitalization, sustainability, an emphasis on transparency, as well as the adoption of new business and consumption models based on sharing economy.

With the rise of those new, very broad and potentially far-reaching trends, the textile and clothing industry faces new challenges, several of which have been addressed in this article. A transition towards a circular economy should start with waste prevention and the minimization of landfilled waste. This process has three phases that are crucial for the circular economy model: product design and development, waste collection and sorting and effective recycling. Each of them comes with barriers and difficulties, but also offers ample opportunities.

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