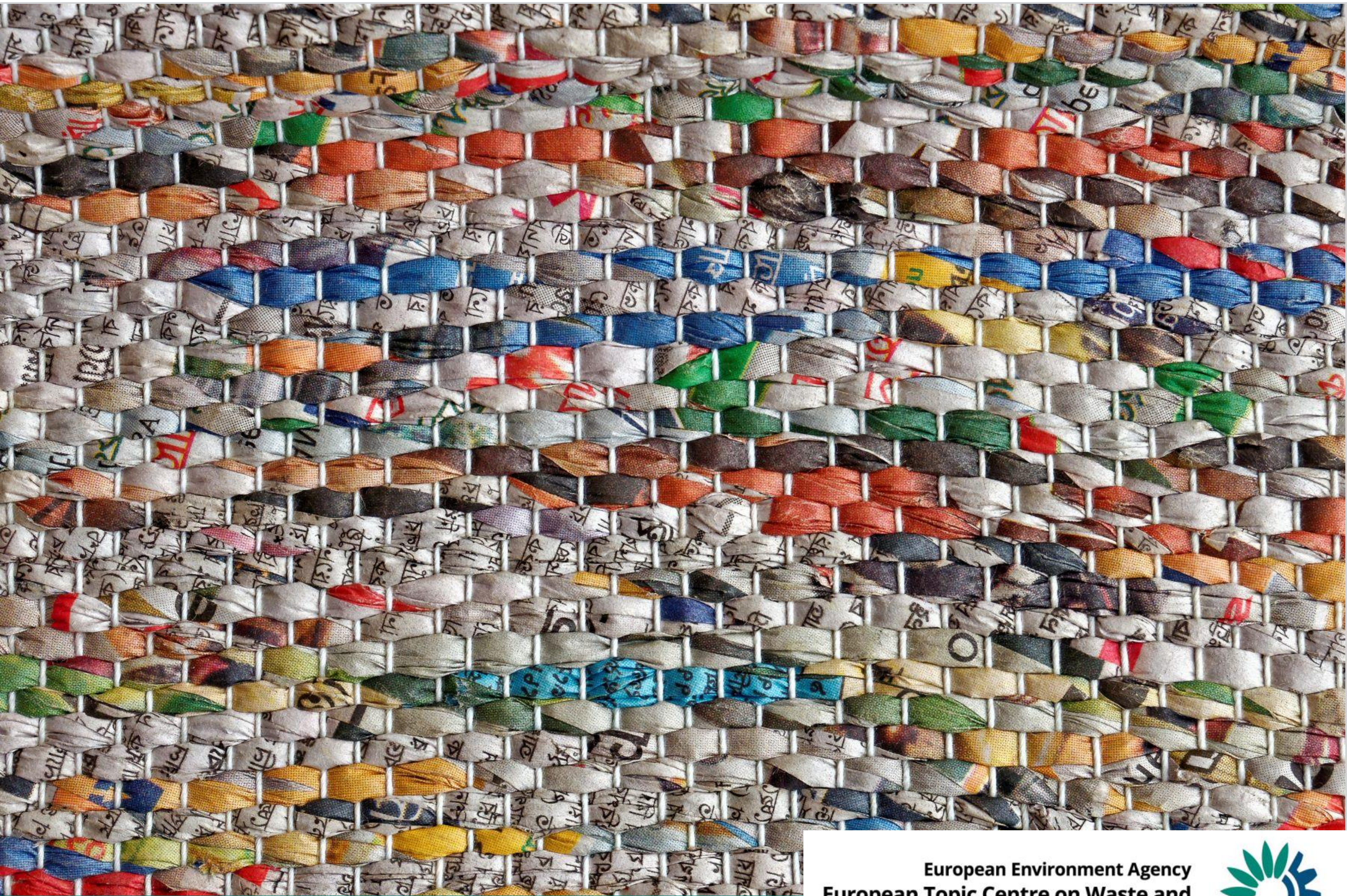
Eionet Report - ETC/WMGE 2019/6

Textiles and the environment in a circular economy

November 2019



European Environment Agency
European Topic Centre on Waste and Materials in a Green Economy

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Acknowledgements

The report has been produced within the task on 'Textile products and the environment' of the 2019 ETC/WMGE work program. Lars Mortensen (EEA) has been the project leader and Saskia Manshoven (ETC/WMGE) has been the task leader.

The authors are grateful to the following experts and organisations for their comments that substantially improved the quality of the report: Marco Manfroni (European Commission, DG GROW), Ruben Dekker (European Commission, DG Environment), Josiane Masson (European Commission, DG Environment), Sandra Averous-Monnery (UNEP), Emily Macintosh (The European Environmental Bureau), Arthur Ten Wolde (Ecopreneur.eu), Eline Boon (The Ellen MacArthur Foundation), David Watson (PlanMiljø), John Wante (OVAM), Bente Bauer (Sustainable Apparel Coalition), Bart Ullstein (BCI), Almut Reichel (EEA), Dominik Chadid (EEA) and Ioannis Bakas (EEA). Bart Ullstein (BCI) provided a very careful editing of the report.

1 Introduction: the world of textiles

1.1 Textiles are fundamental to human wellbeing

Textiles are fundamental to the wellbeing of people in Europe and across the world. Textiles provide us with clothing and footwear – it is illegal in most places not to wear clothes – keeping us warm and enabling us to express personality and taste. Textiles are also used to make bed linens and towels, carpets and curtains for our homes, offices and public spaces, as well as providing materials for such other sectors as furniture and transportation, for example for car seats. At the same time, the textile value chain provides jobs to millions of people around the world, contributing to economic growth.

The system of production and consumption of textiles is highly globalised with millions of producers and billions of consumers spread across the world in highly linear value chains involving raw material extraction, production, transportation, consumption and after-use disposal. Although the European Union (EU) is a net importer of textiles, mainly from Asia, it also exports huge amounts to other regions, representing more than 30 per cent of the world textile market (EC, 2019b). In 2018, the textiles sector in the EU consisted of 171,000 companies, employing 1.7 million people and with a turnover of EUR 178 billion (Euratex, 2019b). In 2017, the total consumption of textile products ([1]) by households in the EU27, Norway, Switzerland, Turkey and the United Kingdom was estimated as 13 million tonnes ([2]), with a value of EUR 445 billion (Stadler et al. (2018)).

The textile sector, including the fashion industry, has significant environmental footprint across its value chain. Natural fibres, such as cotton and wool, are produced using vast areas of agricultural land and large amounts of water, energy and chemicals, while the manufacture of synthetic fibres is based on fossil fuels. The use of chemicals and additives in textile production exerts significant impacts on local and regional water bodies. Their global distribution network emits greenhouse gases and generates packaging waste. In the use phase, washing and drying of textiles result in significant water and energy use as well as the release of chemicals and micro-plastics into rivers and the marine environment. The sector is a major contributor to climate change through its energy use and waste management. Apparel and footwear have been estimated to produce as much as 8 per cent of global greenhouse gas emissions through their life-cycles (Quantis, 2018). In 2015, greenhouse gas emissions from textile production amounted to 1.2 billion tonnes of carbon dioxide equivalent (CO_2-eq), more than international flights and shipping combined (Ellen MacArthur Foundation, 2017).

The textile industry can also have huge social impacts, as we were reminded by the 2013 Rana Plaza incident in Bangladesh when a textile factory collapsed killing more than a thousand workers. The payment of extremely low wages and dangerous working conditions are widespread in the industry.

1.2 Towards a circular textiles production and consumption system

A sustainable textile system should bring wellbeing and value to society through the provision of safe, high-quality and affordable textile products and the creation of inclusive jobs with fair wages and working conditions, while at the same time minimising any negative environmental and social impacts, and respecting the carrying capacity of the planet. Across the value chain, pollution and waste should be limited. To ensure the conservation of the value of materials, efficient collection and recycling processes should be put in place, allowing high-quality, clean and safe product and materials cycles.

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[1] Includes the Classification of Individual Consumption According to Purpose (COICOP) domains for clothing (3.1), footwear (3.2) and household textiles (5.2).

[2] Amount calculated for 2017 consumption data, based on 2011 data and conversion factors in EXIOBASE 3.4 This estimate is based on a 30 gram per euro (2017) final expenditure conversion factor, which is derived from EXIOBASE v. 3.4 in combination with Eurostat expenditure statistics [nama_10_co3_p3] and [prc_hicp_aind]. This conversion factor includes the value of the textile product itself, as well as the value of trade and transport activities.

The European Commission has identified textiles, apparel and fabrics, as a priority product category within a circular economy (EC, 2019b). A more circular and sustainable textile system could contribute to the achievement of both EU and global goals. In the EU, it would contribute to economic growth and job creation as well as to meeting the aims of the circular economy and a number of climate, environmental and waste targets. At the global level, this more circular and sustainable system would contribute to many of the UN Sustainable Development Goals (SDGs), including Goal 6: Clean water and Sanitation, Goal 7: Affordable and Clean Energy, Goal 12: Responsible Consumption and Production, and Goal 13: Climate Action.

Textile production in Europe is regulated through a patchwork of EU and national legislation, including on production methods and working conditions, and fibre names, related labelling and the marketing of the fibre composition of textile products (EC, 2019c). Legislation on chemicals, industrial emissions, product safety, etc. also regulates textiles. The production of textiles within the EU, for example, is covered by the EU Regulation on Evaluation and Authorisation of Chemicals (REACH) and the Industrial Emissions Directive (IED). Textiles produced outside the EU are also subject to product regulation, such as EU eco-label criteria and green public procurement criteria for textiles. Furthermore, the 2018 revision of the EU Waste Framework Directive (WFD) includes an obligation for Member States to collect textiles separately by 1 January 2025 (EC, 2019b).

European countries face constraints in influencing production methods and related negative social and environmental impacts that occur elsewhere. As the EU relies heavily on textile imports, there are key challenges when it comes to ensuring that textile products entering the EU are subject to the same standards. Despite such constraints, there are several policy options which can have an effect on production methods in other regions, some of which have already been implemented. Examples are policies related to green public procurement, standards and labelling, and waste management. Transparency and traceability through the value chain are also key.

To move towards a more circular and sustainable system the EU needs to go beyond separate collection of textile waste and recycling. Regulation of textile production and consumption should go hand-in-hand with technological innovation, aimed at favouring renewable fibres and fabrics, product design that facilitates longer use and reuse, and efficient production processes that generate less waste and fewer emissions (Bauer et al., 2018), and phasing-out of hazardous chemicals. Social innovation related, for example, to how consumers interact and share clothing is also needed. To foster profound behavioural change, the scaling of sustainable, circular business models is key (Elander et al., 2017; Watson et al., 2017). The circular management of textiles requires the creation of safe product and material cycles, encouraging reuse and recycling, while avoiding waste incineration and landfilling.

A systemic change is needed, involving more stakeholders than the fashion industry alone, to overcome technological and economic challenges. Among the different textile sectors, the fashion industry is taking initiatives to improve the sustainability of its supply chains and processes. In the short term, focus is primarily on implementing efficiency measures to reduce water, energy and chemicals use, while improving supply chain traceability and working conditions. In parallel, tangible work towards a longer-term objective has to start now, transforming the fashion industry to a circular system, embracing the opportunities of digitisation and the development of sustainable fibres (Global Fashion Agenda, 2019).

Figure 1.1 illustrates a vision of a more circular textile system, including showing how circularity can be improved in each phase of the lifecycle.

This report, which provides the analytical underpinning for an European Environment Agency (EEA) briefing, investigates options for a circular and more sustainable textile production and consumption system.

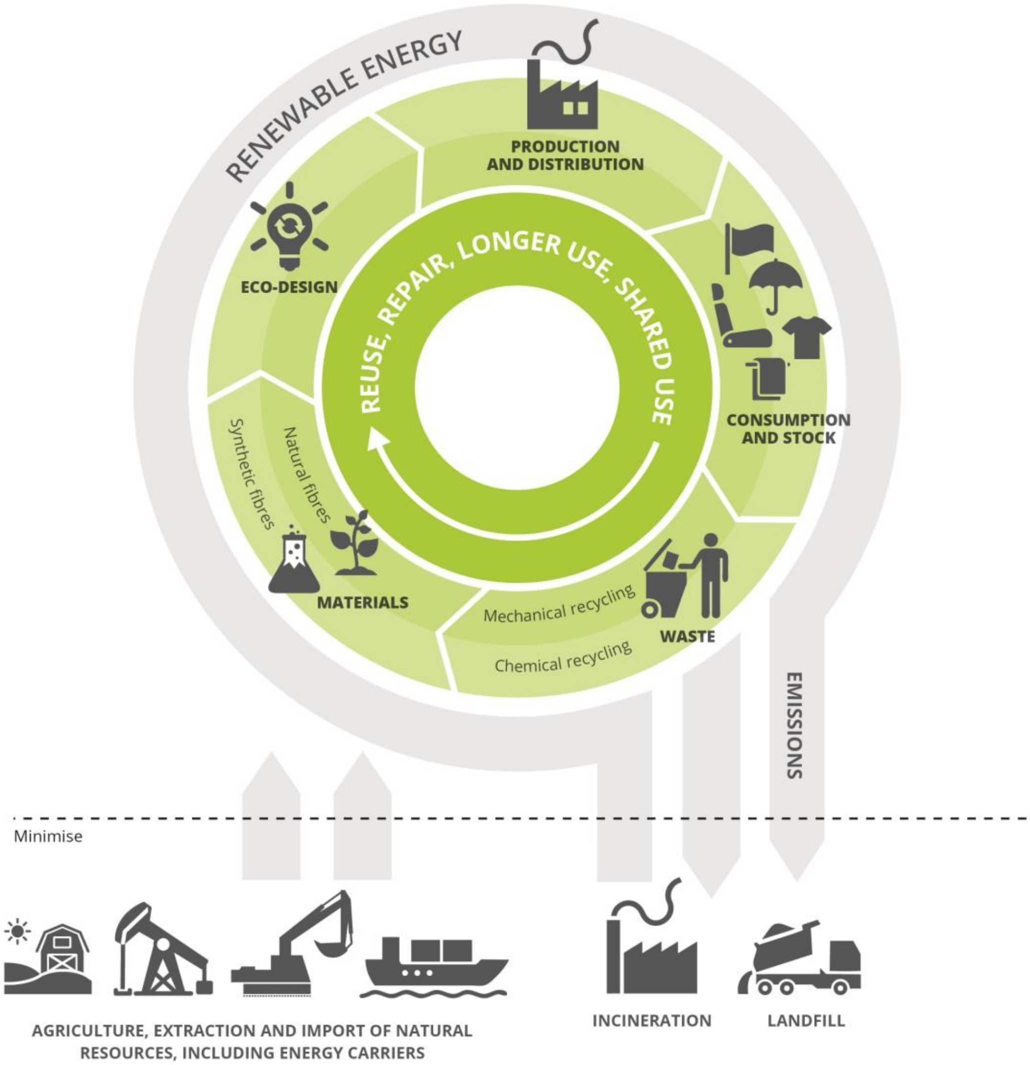
Chapter 2 shows the production and consumption of textiles from a European perspective. It maps textile value chains, including main trade patterns, and discusses the current systems of production, consumption and waste management, including economic and employment trends.

Chapter 3 analyses the environmental and social impacts of textiles. It provides an overview of the impacts of the upstream supply chain of EU textile consumption. The environmental analysis focuses on four particular hotspots: resource depletion of materials and water, land use, climate change and chemicals' toxicity. The social impact assessment discusses working conditions, mainly in the production of textiles.

Chapter 4 provides a more detailed vision for a more circular and sustainable textile production and consumption system. It analyses the potential for various types of new and innovative business models as well as the role regulation can play in supporting innovation.

Chapter 5 concludes the report.

Figure 1.1 Vision of a circular economy for textiles



Source: EEA and ETC/WMGE, adapted from EEA (2016)

2 Trends in the production and consumption of textiles

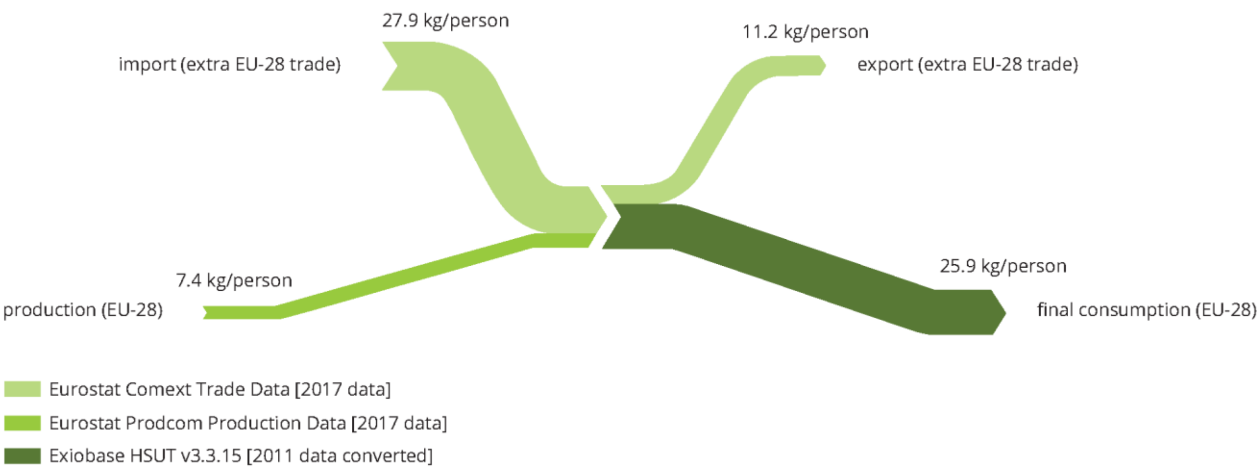
2.1 Production and consumption trends

Textile production and consumption are highly globalised. In 2017, European households consumed nearly 26 kilograms (kg) of textile products ([3]) per person (Figure 2.1). This estimate comes with some uncertainty, as various studies in different countries provide different estimates ranging from 9 to 27 kg per person, depending on the data source and product scope (Watson et al., 2018; Šajn, 2019). An earlier estimate by the European Commission's Joint Research Centre (JRC) calculated the average annual EU consumption of clothing and household textiles at 19.1 kg per person (JRC, 2014).

Only 7.4 kg of textiles per person were produced within the EU itself, making Europe highly dependent on imports to fulfil its consumers' demands. Europe also exports a significant amount of textiles, 11 kg per person. The reason that EU exports exceed EU production is re-export: some textiles are imported, turned into specific products and then re-exported.

The value of imported textiles in European clothing consumption increased by 9 per cent between 2014 and 2018. The net import of textiles into the EU in 2018 sums up to 8.8 million tonnes: 14.5 million tonnes ([4]), with a value of EUR 139 billion, were imported in 2018 while only 5.7 million tonnes, with a value of EUR 61 billion, were exported (Eurostat, 2019a). The export figure includes about 1.5 million tonnes of worn clothing, 3 kg per person, with a value of EUR 1.3 billion. The difference between total import and production versus total export and final consumption is related to stocks that had been built up (Figure 2.2).

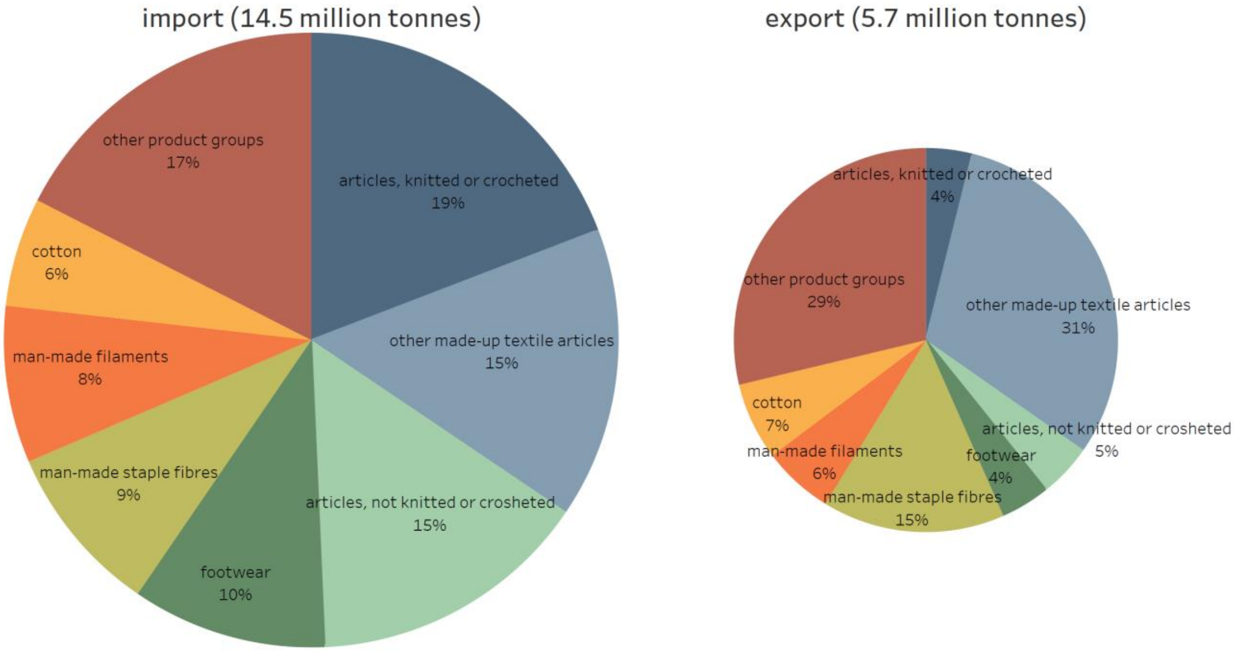
Figure 2.1 Overview of the import, export, production and consumption flows of textile products, EU, 2017, kg per person ([5]).



The types of products that Europe imports and exports are different. Europe mainly imports finished textile products, clothing and footwear products and clothing accessories, while exported textiles are typically intermediate products, such as non-wovens, fibres and technical textiles, and high quality fabrics in which European industry specialises (Figure 2.2).

[3] Including clothing, footwear and household textiles (carpets, curtains, bedlinen, towels, etc.)
[4] Textiles defined by the Harmonized Commodity Description and Coding System (2012) Chapters 50–67 (Sections XI and XII), including fibres, fabrics and finished products, such as clothing, footwear and household textiles.
[5] The waste flow of textiles from stock is not included in this scheme.

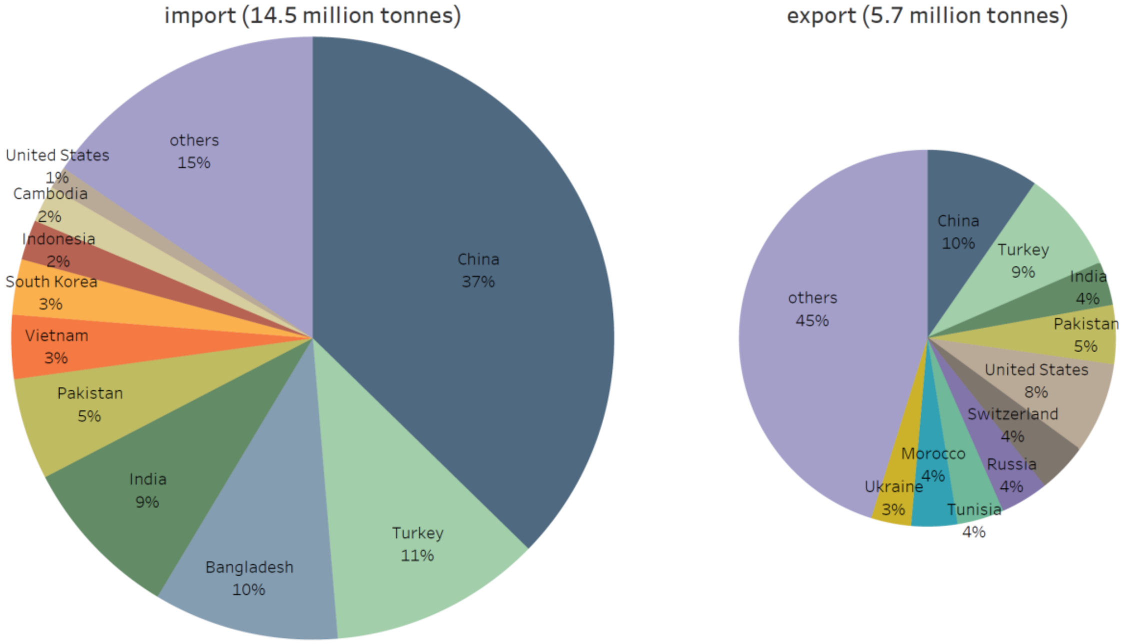
Figure 2.2 Import into and export from EU by product type, including textile fibres, fabrics and articles, footwear and headgear, 2018, per cent



Note: percentages may not sum due to rounding
Source: The Harmonized Commodity Description and Coding System, Chapters 50–67 (2017)

As can be seen in figure 2.3, 85 per cent of the total quantity of textile imports into the EU come from just 10 countries, with 37 per cent coming from China, 11 per cent from Turkey, 10 per cent from Bangladesh and 9 per cent from India. Exports are more fragmented, with the largest 10 destination countries accounting for 55 per cent of total exports by volume, with 10 per cent of exports going to China, 9 per cent to Turkey, 8 per cent to the United States, 5 per cent to Pakistan.

Figure 2.3 Import into and export from EU by country, 2018, per cent



Note: percentages may not sum due to rounding
Source: The Harmonized Commodity Description and Coding System, Chapters 50–67 (2017)

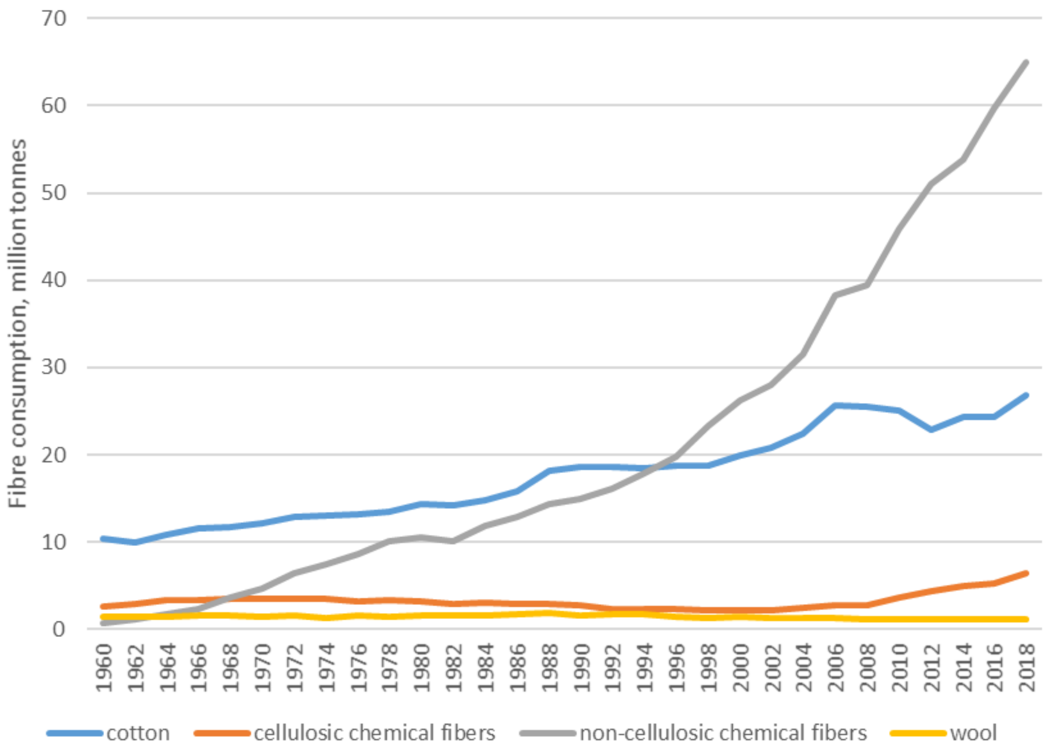
The production of textiles is an important part of the European manufacturing industry, playing a crucial role in the economy and wellbeing in many regions. In 2017, the EU's total textile production ([6]) was 3 million tonnes; production of fibres accounts for 27 per cent of this, yarn production 36 per cent and woven fabrics 37 per cent (Eurostat, 2019c). Natural and synthetic fibres are both produced and processed by the European textile industry.

In 2018, there were around 171,000 companies in the EU's textile and clothing industry, employing about 1.7 million people and generating a turnover of EUR 178 billion (Euratex, 2019b) – the sector is mainly composed of small businesses with fewer than 50 employees (Business Beyond Borders, 2017). European producers are global leaders in technical/industrial textiles and non-wovens – industrial filters, hygiene products, products for the automotive and medical sectors, etc.– as well as in high-quality garment design and production. When it comes to the European clothing industry, the largest producing countries are in Central and Eastern Europe (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Hungary, Moldova, North Macedonia, Romania, Slovakia, Turkey and Ukraine (Luginbühl and Musiolek, 2014)). Worldwide, the number of garments produced annually has doubled since 2000 with, in 2014, 100 billion items being exceeded for the first time, an annual production of nearly 14 new items of clothing per person on Earth (Remy et al., 2016).

The global production of textile fibres has almost tripled since 1975 (Ellen MacArthur Foundation, 2017). When looking at the global textile sector, about 60 per cent of textile fibres produced are synthetic polymers, while 37 per cent is dominated by cotton (Sandin and Peters, 2018; Palm et al., 2013).

[6] NACE Rev. 2 – Division 13

Figure 2.4 World consumption of major textile fibres between 1960 and 2018, million tonnes



Source: ICAC (2019)

The global annual production and consumption of cotton fibres, currently to most prevalent for clothing, more than doubled from slightly more than 10 million tonnes in 1960 to about 25 million tonnes in 2010, and has since remained more or less static (Figure 2.4). Cotton may, however, become an increasingly costly premium product in the future as a result of challenges related to land use and water consumption (WRAP, 2019). According to a study by the JRC (2014) focusing on the EU, about 43 per cent of all clothing is made of cotton, 16 per cent of polyester, and 10 per cent each of acrylic, wool and viscose. About 54 per cent of fibres used in clothing are natural but in household textiles, about 70 per cent are synthetic – overall cotton and polyester at 28 per cent each, are the most prevalent, followed by polyamide at 23 per cent. Acrylic and polypropylene are important fibres in carpet manufacture.

The global consumption of synthetic fibres increased from marginal amounts in 1960 to more than 60 million tonnes in 2016, and continues to rise (Figure 2.4). Polyester, the most commonly used fibre across the world, is a synthetic, non-renewable, petroleum-based fibre made using a carbon-intensive process that requires more than 70 million barrels of oil each year (WRAP, 2019). Polyester fabrics are durable, wrinkle resistant and are used in clothing, home furnishings and variety of industrial applications including cushioning and insulating materials as well as ropes, car tyres and conveyor belts.

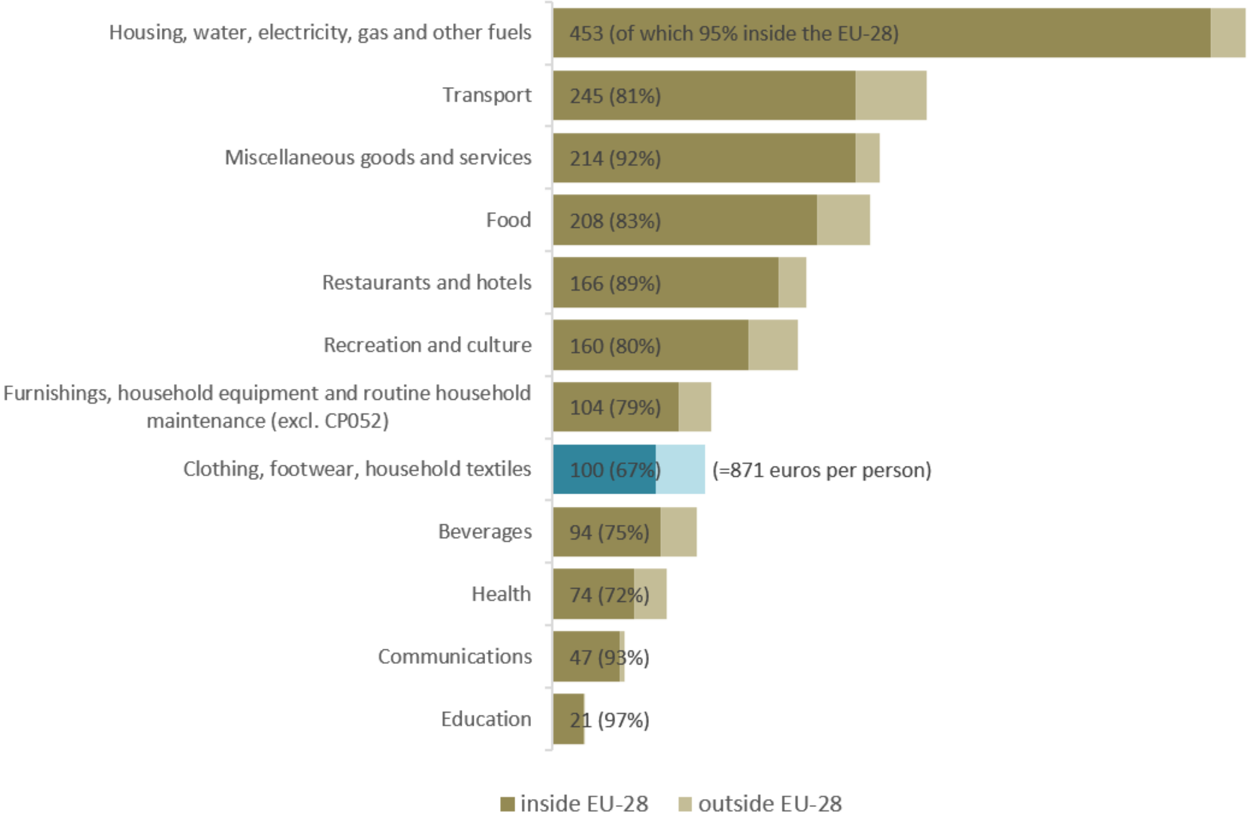
Currently, only 2 per cent of all synthetic polymers is made from bio-based resources. Of this share, 11 per cent is produced for textile applications (Nova Institut, 2021). Production of synthetic cellulosic fibres–lyocell, viscose, etc. – was estimated at 5 million tonnes in 2016. Production is growing and so is the share produced sustainably from certified forests (TextileExchange, 2018).

To create fabrics with improved properties, such as increased breathability and durability, to achieve special colour effects or reduce production costs, different fibre types are often blended into composite yarns. One of the most common textile materials, polycotton, used in most service textiles, such as sheets, towels and workwear, is made of a mix of polyethylene terephthalate (PET) and cotton in varying percentages (Palme et al., 2017).

On average European households spent EUR 871 per person on textile products in 2017 (Exiobase 3.4). The supply chain of textile products bought in Europe is spread all over the world and it is very complex in terms of sectors involved. The global distribution of gross value added and employment related to final consumption of textile products have been calculated by using an extended multiregional input model based on EXIOBASE v.3.4 data (Stadler et al., 2018). In figures 2.5 and 2.6, 2011 Exiobase data were combined with 2017 household consumption data from Eurostat (methodology in annex).

As can be seen in Figure 2.5, 67 per cent of the gross value added in the supply chain of textile products bought by European households is generated in Europe, followed by 23 per cent in Asia and the Pacific. This is much less than other consumption categories, where the gross value added in Europe varies from 80 to 95 per cent. This illustrates the importance of activities outside Europe for textiles. Forty-four per cent of the gross value added is generated in the textile industry; Other important sectors are services, 16 per cent; other industries, 12 per cent; and transport, 11 per cent. The share of agriculture, for the cultivation of natural fibres, in total value added is low at just 3 per cent.

Figure 2.5: The generation of gross value added in the upstream supply chain ([7]) of EU household consumption domains, indexed values with textile consumption equalling 100, 2017.

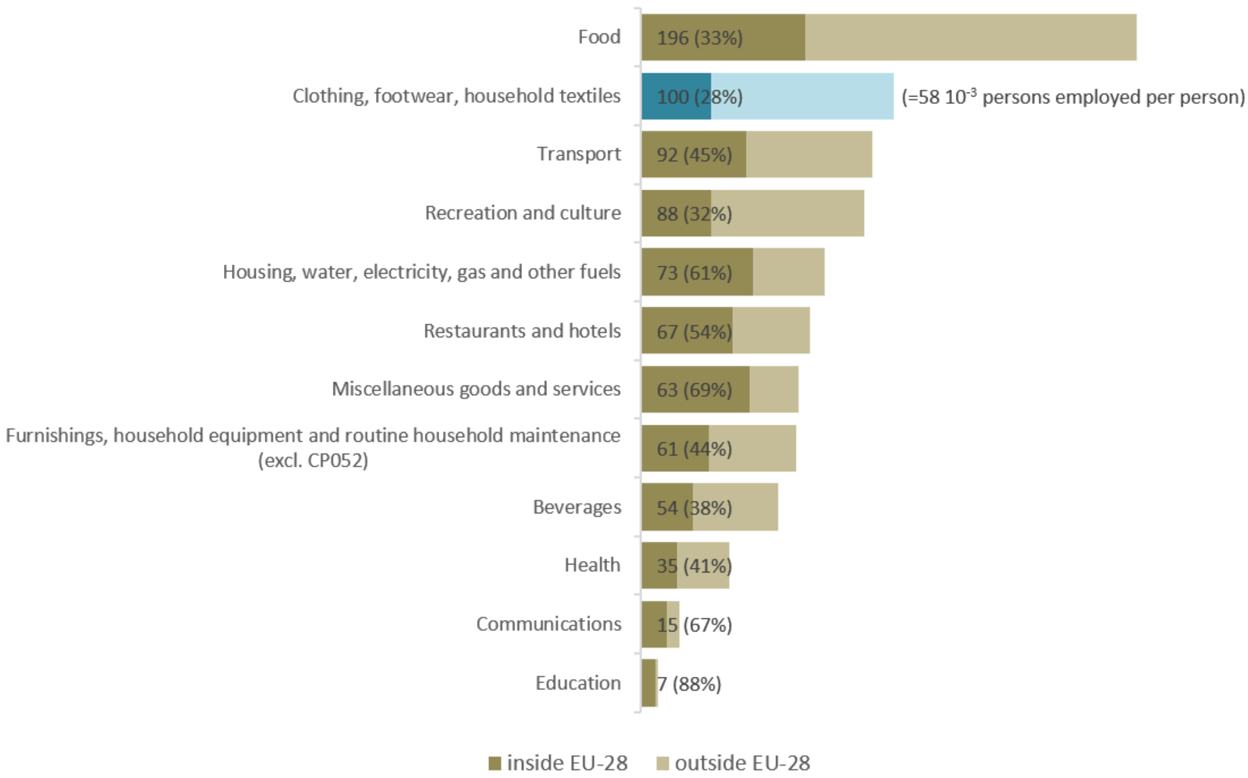


Source: Exiobase v.3.4 (Stadler et al., 2018)

[7] This includes all activities in industrial and service sectors in the production and supply chain of the textile products up to purchase by households. It excludes the use of the textile products and the treatment at end of life.

Looking at **employment in the supply chain of textile products** bought by European households, textiles is the second most important sector after food (Figure 2.6). Labour intensity in agriculture and the clothing industry is an important factor in this context. Only 28 per cent of employment in the supply chain takes place in Europe, which is one of the smallest shares of all consumption categories. Forty-three per cent of working hours are linked to the textile industry, which is in line with the gross value added. Agriculture, however, represents 28 per cent of employment compared to just 3 per cent of value added. The geographical distribution of gross value added differs significantly from the distribution of employment: 56 per cent of the employment takes place in Asia and the Pacific, 28 per cent in Europe and 12 per cent in Africa. According to the Exiobase socio-economic model, 40 per cent of the workforce in the textile supply chain worldwide is female and 89 per cent is low- or medium-skilled. The share of female workers, 50 per cent, is much higher in the textile industry itself compared to the other industries involved in the supply chain, such as agriculture, trade and transport in which it is 22–38 per cent. Due to the prevalence of informal employment in agriculture and the production of textiles, the share of female workers is probably higher in reality, up to 75 per cent globally (EC, 2017). Payment of employees accounts for 52 per cent of the gross value added of the textile industry worldwide, with large differences in the cost of employment between regions: EUR 3.44 per hour on average, with a factor of seven difference between Europe and Asia.

Figure 2.6: The use of employment in the upstream supply chain ([8]) of EU household consumption domains, indexed values with textile consumption equalling 100, 2017.



Source: Exiobase v.3.4 (Stadler et al., 2018)

Worldwide, the consumption of technical textiles – industrial textiles, workwear, etc. – accounted to 33.2 million tonnes in 2015, and is estimated to grow to 42.2 million tonnes by 2020 (TextileToday, 2016).

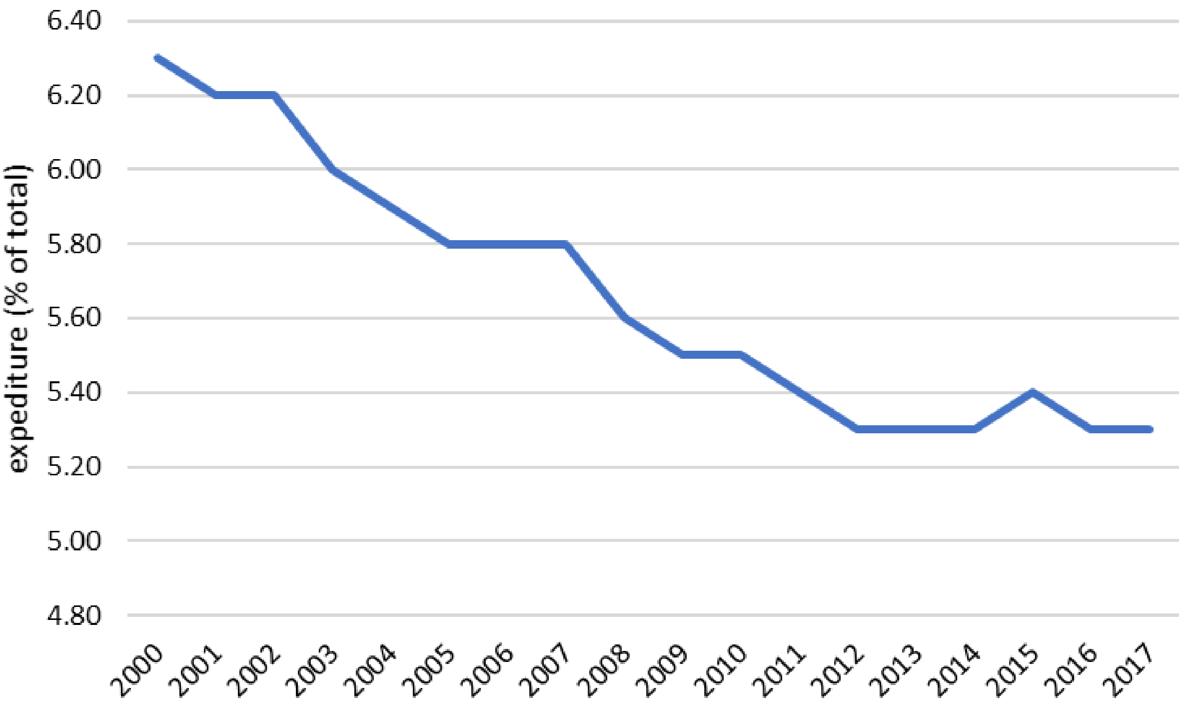
[8] This includes all activities in industrial and service sectors in the production and supply chain of the textile products up to purchase by households. It excludes the use of the textile products and the treatment at end of life.

Technical textiles have a wide variety of uses encompassing civil engineering, agriculture and fishing, construction, the automotive industry, medical uses, protection and machinery. Technical textiles have generally high durability requirements and thus are, to a large extent, composed of synthetic fibres.

When looking at the textile consumption of households, it can be seen that textiles and related products are an important part of current lifestyles in Europe. In 2017, EU households spent 5.3 per cent of their total expenditure on textile products ([10]), representing a value of EUR 445 billion on, of which 74 per cent was on clothing, 17 per cent on footwear and 8 per cent on household textiles (Eurostat, 2020).

When analysing the trends of the total expenditure of EU households, there is a slight decline in the share attributed to clothing, footwear and household textiles, from 6.3 per cent in 2000 to 5.3 per cent in 2017 (Figure 2.7Source: Eurostat (2020)
). Despite this slight decrease in expenditure, the total number of clothing items consumed has increased and is expected to further increase in the coming years. Concretely, there was a 40 per cent growth in the amount of purchased clothes per person in the EU between 1996 and 2012 (Šajn, 2019). In other words, Europeans have been able to buy more pieces of clothing while spending a smaller share of their income on them. At a global level, the consumption of clothing and footwear is expected to increase by 63 per cent by 2030, from 62 million tonnes now to 102 million tonnes in 2030 (Global Fashion Agenda and Boston Consulting Group, 2017).

Figure 2.7 Household expenditure on clothing, footwear and household textiles as a proportion of total household expenditure in the EU, 2000–2017, per cent



Source: Eurostat (2020)

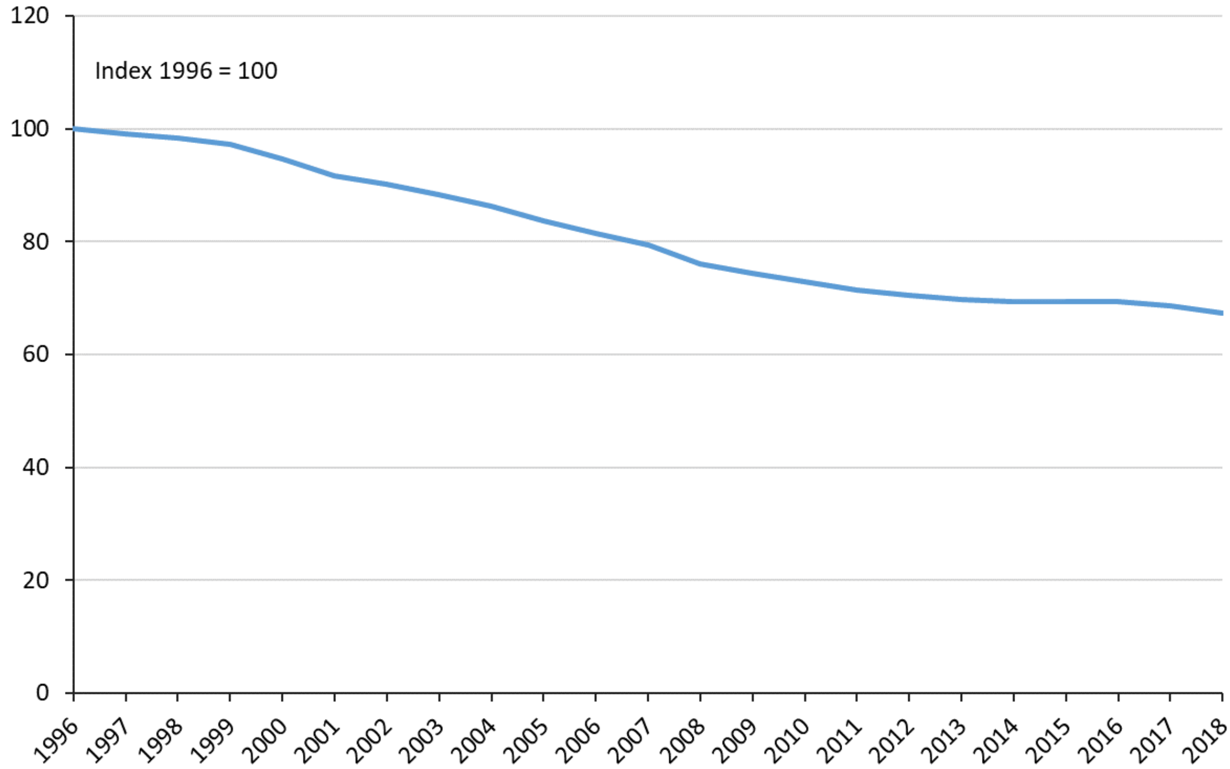
A combination of multiple factors and drivers have led to the increased consumption of clothing. These include production trends based on low-cost and fast fashion and a respective decrease in the price of clothing; the increasing affluence of consumers; further trade liberalisation; and technological

[10] Clothing (CP031), Footwear (CP032) and household textiles (CP052).

advancement (EEA, 2014). Moreover, a general trend can be seen towards a more consumerist mindset, in which consumption is seen more as gratification rather than a function of meeting needs.

Throughout the past years, companies have increasingly invested in streamlining and optimising their supply chain operations as well as in cutting production costs by deploying fragmented, low-tech production systems and using cheaper, low-quality materials (Remy et al., 2016). This process has been driven by the globalisation and industrialisation of the clothing and textile industry as well as the push to improve, gain and/or maintain market competitiveness. These developments, on one hand, have led to lower and more affordable consumer prices (Koszewska, 2018) – for example, between 1996 and 2018, clothing prices in the EU dropped by more than 30 per cent relative to total harmonised index of consumer prices ([11]) inflation (Figure 2.8).

Figure 2.8 Consumer price indices for clothing relative to HICP inflation in the EU, 1996–2018



Source: Eurostat (2019b)

On the other hand, more efficient and shorter (in time) production processes have contributed to the more frequent introduction of fashion and clothing lines and shorter market seasons. Fast fashion aims at consumers who want to follow trends and change their wardrobes frequently. In fast fashion, styles from high-end fashion shows are rapidly delivered to consumers at cheap prices, achieved, in art, by using lower-quality materials. As such, fast fashion encourages over consumption and the generation of waste (House of Commons, 2019). A driver of this trend is a pursuit of added value and growth by continuously promoting the purchase of new products and the disposal of old ones, which are branded as obsolete simply because they are out of fashion. European apparel companies in 2011, for example, released an

[11] The harmonised index of consumer prices (HICP) measures the price change of consumer goods and services over time

average of five collections as opposed to two clothing lines, which was the norm around the year 2000 (Koszewska, 2018). Accordingly, some of the biggest brands mainly targeting young people are releasing between 12, 16 and 24 new clothing collections every year (Remy et al., 2016).

This has led to increased consumption accompanied by a decrease in the lifespan of clothes, which are generally worn fewer times – around seven to eight on average, kept for a shorter period than in the past, and treated as almost disposable (Remy et al., 2016). In Europe, the average lifespan of clothes varies between 2.2 and 5 years (WRAP, 2012; Gray, 2017), with clothing items across various categories being kept by consumers for half as long as they used to be 15 years ago. Garments are prematurely discarded, because of fast-changing trends or their general poor quality. More recently, however, the push model is being challenged by a pull or demand-driven model in which consumers, rather than clothing brands, guide the development of the textile and clothing market, through for example social media, bloggers, influencers and peer reviews. This trend, which is also encouraged by many brands, spurs companies to quickly develop and produce customised items, based, for instance, on consumers' designs or simulations, on demand (Andersson et al., 2018).

Reflecting the complexity of human behaviour, a wide range of factors and drivers are seen to influence consumer purchasing. Across countries, a clear relation exists between income and per person spending on clothing (EEA, 2014). Factors such as product fit, price and value for money, quality, brand, durability, comfort, convenience and latest trends are some of the most frequently mentioned determining factors. Cultural and societal factors, such as social status, identity, social influence or peer pressure also have a role to play, as well as marketing and the influence of retailers (Paras et al., 2018). The cultural context, however, also affects spending on clothing: Italians, for example, tend to spend much more on clothes than people with higher disposable income from other European countries, such as France or Denmark (EEA, 2014).

Hiring or leasing clothes is less common. According to a Waste and Resources Action Programme (WRAP) survey in 2012 in the United Kingdom (UK), the only types of clothes that more than one in ten people hired were formal wear, 13 per cent, and fancy dress, 11 per cent, while only 2 per cent of respondents has leased any type of clothing. Around half the respondents, however, said they would consider hiring clothes more frequently if it were easier to do – for example, through major high-street retailers (WRAP, 2012).

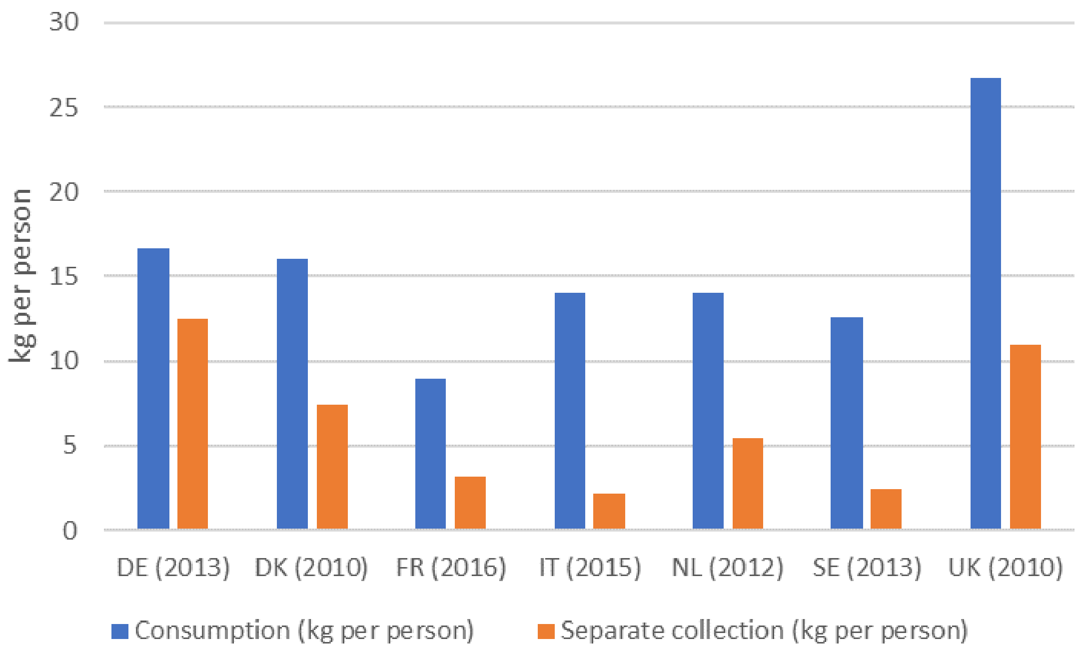
Although European consumers are increasingly aware of sustainability when shopping for clothes, such concerns still have a limited impact in informing consumer decisions (Vehmas et al., 2018). Aspects such as quality, comfort, price and fit score higher in the priority list. According to a recent Cotton Council International and Cotton Incorporated Global Environment survey conducted in China, Germany, India, Italy, Mexico, the UK and the United States, for example, sustainability was mentioned as a behavioural determinant by 60 per cent of respondents, with comfort and price mentioned by 88 per cent, quality by 89 per cent, and fit by 90 per cent (TextileToday, 2018). In another survey conducted by Fashion Revolution (2018) with 5,000 respondents from France, Germany, Italy, Spain and the UK, 38 per cent and 37 per cent mentioned they consider social and environmental impacts, respectively, when purchasing clothes. This rather low prioritisation of sustainability could potentially be explained by the idea that assessing clothing sustainability is very complex due to a lack of transparency about production conditions and impacts (Vehmas et al., 2018).

When it comes to shopping habits, online shopping is growing rapidly with only a small majority of European consumers still preferring to buy their clothes from physical stores (CBRE, 2013). According to a Mastercard (2017) survey, 48 per cent of European consumers purchase clothing and footwear online, which makes online shopping for clothes more popular than for tickets, 34 per cent; electronics, 33 per cent; or books, 31per cent. Online sales platforms are increasingly making it easier for manufacturers to sell and consumers to shop and return products anywhere in the world, eliminating the need for intermediary actors (CBI, 2018). Consequently, the increase in online sales has a large impact on resource use and emissions in terms of packaging and transport.

2.2 Collection, reuse, recycling and waste management trends in Europe and elsewhere

It is estimated that EU consumers discard about 5.8 million tonnes of textiles every year, which equates to 11.3 kg per person (Beasley and Georgeson, 2014). Figure 2.9 shows that separate collection-to-consumption ratios range from 11 per cent in Italy to more than 70 per cent in Germany (Watson et al., 2018). The differences between countries can be partly explained by differences in infrastructure, such as the density of collection points and the intensity of collection activities by charity organisations and private actors. In addition, national policy measures play an important role, such as the availability of subsidies and research and development (R&D) support for sorting and recycling initiatives and the organisation of public awareness campaigns to influence consumer behaviour (Watson et al., 2018).

Figure 2.9 Estimated consumption and separate collection rates for clothing and household textiles in seven EU countries.



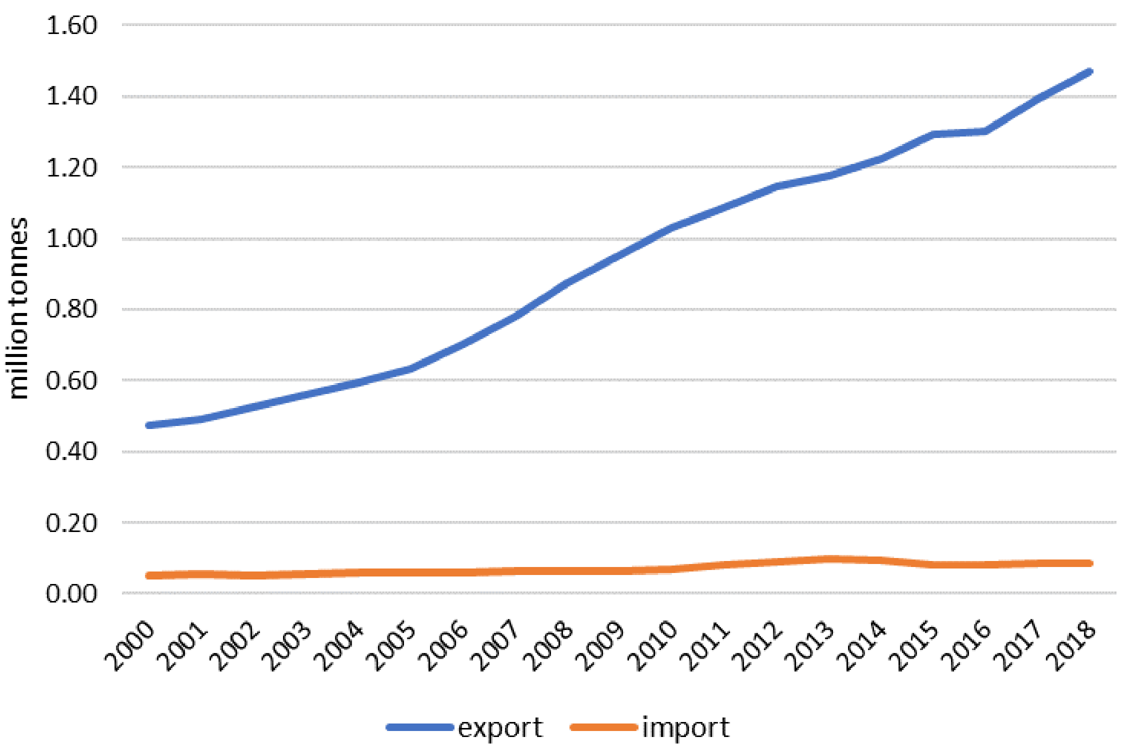
Source: Watson et al. (2018)
Note: Figures for Denmark (DK), France (FR), Germany (DE) and the UK include footwear

Reuse of textiles is much more environmentally advantageous than recycling (Schmidt et al., 2016). Traditionally, the collection of used textiles was dominated by charities along with some private actors (EEA, 2018). More recently however, voluntary take-back campaigns have been set up by larger retailers (Hvass and Pedersen, 2019) and municipalities are also increasingly getting involved (Watson et al., 2018). Gunther (2016), however, pointed out that consumers do not generally return clothes and the participation in companies' recycling efforts is limited, regardless of the incentives.

Apart from the benefit of waste prevention, sorting and reuse also offer opportunities for (low-skilled) employment. Experience from textile collection and reuse schemes in Flanders, the Nordic countries and the UK, however, has shown that on average only about 10 per cent of collected used garments are reused within the same region, with a variation 4–30 per cent (WRAP, 2012; De Kringwinkel, 2017; Schmidt et al., 2016). Results from the European Clothing Action Plan study point to Denmark as a country where buying second-hand clothing is relatively popular, but even there it does not exceed 9 per cent of total purchasing decisions. In the other countries considered – Germany, Italy, Netherlands and the UK – the share of second-hand purchases is typically below 5 per cent (Gray, 2017). At the same time, reuse businesses and peer-to-peer reuse trade are increasing due to ease of marketing through the internet. An important question is whether the purchase of second-hand textile products actually replaces the purchase of new items, and to what extent. Based on a survey among more than 200 consumers in Denmark, Estonia and Sweden, Farrant et al. (2010) estimated that for each 100 second-hand garments purchased, about 60–85 new items would be saved.

In general, a large share of unsorted collected textiles is sent for sorting in Eastern European countries, then exported again for reuse or recycling in Africa and Asia. Figure 2.10Source: Eurostat (2019a)
shows that the export of used clothes from the EU is significant and increasing. Most receiving countries have a well-established second-hand clothing markets: in Uganda, for example, 81 per cent of clothing purchases are of used clothing (Brooks, 2015). Although there are some benefits, such as the creation of local jobs in sorting and selling, and the provision of cheap clothes, there are also increasing concerns that the oversupply of used textiles, together with increased imports of cheap new clothing from Asia may have contributed to the decline of domestic textile industries in sub-Saharan countries (Watson et al., 2016). In January 2018, Burundi, Kenya, Rwanda, Tanzania, South Sudan and Uganda all announced that they intended to stop importing used clothes from Europe and the United States by 2019 in order to support their own textile industries (Gittleson, 2018), but as a result of political pressure, only Rwanda remains committed to this policy (News24, 2018).

Figure 2.10 Export and import of worn textiles, 2000-2018, EU



Source: Eurostat (2019a)

The 2018 revision of the WFD includes an obligation on Member States to collect textiles separately by 1 January 2025 (EC, 2019b). Since global markets for used clothing are becoming saturated, however, finding suitable outlets for increasing volumes of collected textiles will be a challenge (Ljungkvist et al., 2018). It will, therefore, be important to make progress in textile-to-textile recycling. Currently, the nonreusable fraction of collected textiles is mostly downcycled into industrial rags, upholstery filling and insulation, or is incinerated or landfilled. Less than 1 per cent of textile waste is recycled into new fibres for clothing as technologies for processing textiles to recycled fibres are only starting to emerge (Ellen MacArthur Foundation, 2017). Textiles that are currently made from recycled content often rely on polyester fibres made of waste plastic bottles and cannot be recycled themselves with the current technology. As such, this is not really an example of a circular product, but rather a delayed disposal of plastic packaging waste (Buchel et al., 2018).

Currently, little textile-to-textile recycling takes place due to technical challenges in fibre separation and fibre quality (Elander et al., 2017; Palm et al., 2014). In mechanical recycling processes, all substances, hazardous and non-hazardous, remain in the material and are carried over to the new product. Furthermore, as the mechanical recycling of most textile materials leads to inferior-quality fibre of reduced fibre lengths and strength, mechanical recycling can be regarded as downcycling (Morley et al., 2006). Currently, mechanical fibre-to-fibre ([12]) cotton recycling is only applicable to 100 per cent cotton textiles. As a result, recycled fibres need to be mixed with virgin fibre when producing new textiles. The maximum share of recycled cotton fibres in new cotton clothing is currently about 30 per cent, while recycled denim in jeans products amounts to 50 per cent (Wolkat, 2020; HNST, 2020). Up to 50 per cent recycled cotton is also used in some blended yarns, in which cotton is mixed with synthetic fibres such as recycled PET or nylon (Recover, 2019). Some applications of recycled polyester fibres, such as duvet filling, contain about 50 per cent recycled content (Watson et al., 2017). Other recycled fibres are widely used in insulation materials for automotive upholstery etc. (Pitkänen, 2019). Overall, at present options for recycling end-of-life technical textiles are quite limited, and significant volumes of them are directed to energy recovery.

The major barrier to high-quality textile recycling is their diverse mix of materials, coatings, dyes and non-textile objects (Elander et al., 2017). Mechanical recycling of mixed fibres does not return a product of the same quality as the original. When recycling polycotton for example, a separate fractionation step is required to separate the cotton from the PET. This can be done chemically by depolymerising or dissolving one of the components while maintaining the other (Palme et al., 2017). Such chemical recycling, however, needs more development and its environmental impacts further investigated (Sandin and Peters, 2018; Schmidt et al., 2016).

Table 2.1 Recycling processes for major fibres/textiles

Material	**Mechanical recycling**	**Chemical recycling**
Polyester	Sorting by type and colour, washing and chopping. Extrusion into yarn	Depolymerisation, repolymerisation and extrusion into chips
Nylon /polyamide	Cleaning and pelletisation (for homogenous flows only)	Depolymerisation and repolymerisation to make new yarn
Cotton	Separation by colour, shredding and re-spinning	Promising innovative development
Wool	Separation by colour, pulling the garment back into a fibrous state	Not available
Polycotton	Small scale processes for producing insulation materials and other lower grade applications	Requires pre-separation into cotton and polyester. Still in pilot phase

Source: Rengel (2017)

Textiles that are not collected separately generally end up in mixed municipal solid waste. Following national municipal solid waste treatment strategies, 34 per cent of this textile waste is incinerated, 25 per

[12] cotton from used/worn textiles converted into cotton to make new textiles

cent is landfilled and 41 per cent is sent to mechanical-biological treatment plants to reduce the organic fraction prior to its incineration or landfilling ([13]).

There are substantial differences among European countries about when used textiles are and are not defined as waste. In some countries all textiles collected through containers are considered waste, while in others the actual reusability or the intention of the person delivering the textiles (discarding or donating) is taken into account. This issue is of key importance for collection, transport, processing and ownership. The handling of waste is regulated by the WFD and requires companies to have collection and processing permits, waste shipping documents and to report in national waste registers (Watson et al., 2018).

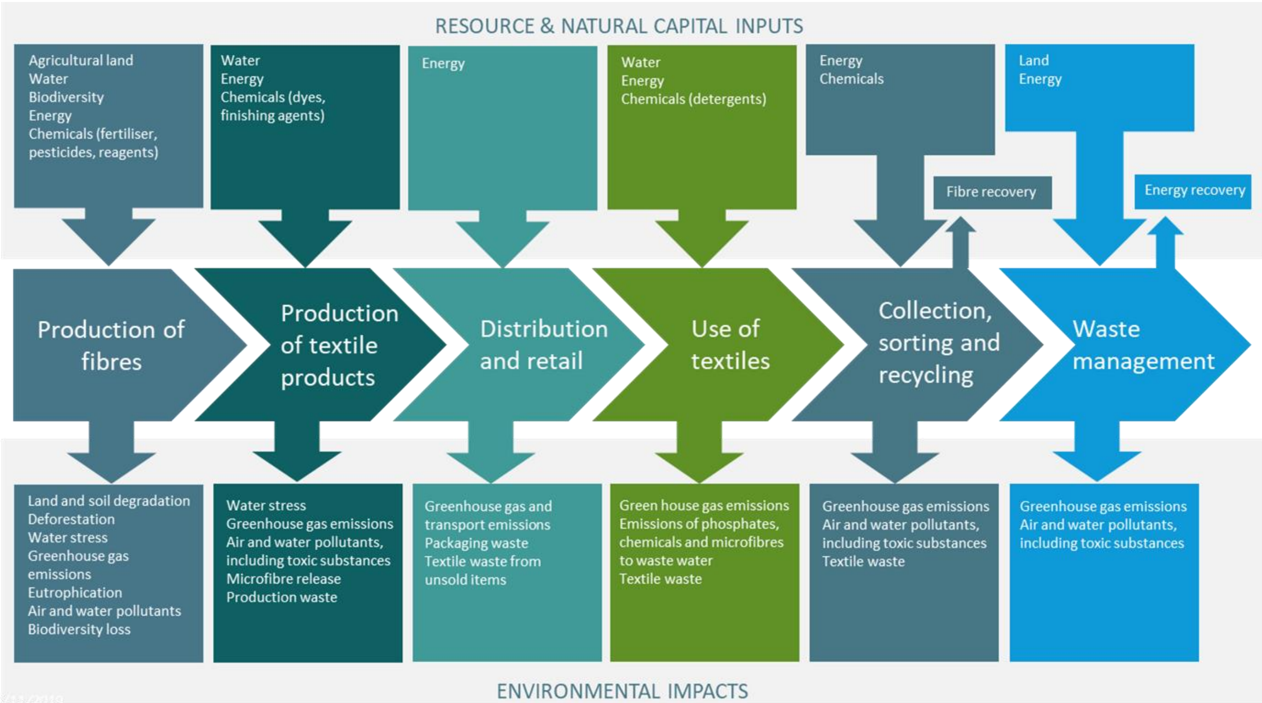
[13] European Reference Model on Municipal Waste Generation and Management, 2018 version, 2015 data for EU, Norway, Switzerland, Turkey and the UK

3 Environmental and social impacts of textiles

3.1 Environmental impacts

The environmental impact of the production and consumption of textiles reflects the high complexity and linearity of their value chain. The range of impacts varies depending on the different textiles and fibres considered, as well as the environmental and socio-economic contexts underlying the production, distribution, use, and end-of-life phase (Figure 3.1). Amongst others, environmental impacts to which the textile sector is a major contributor include the depletion of material resources and water, land use, climate change and chemicals' toxicity (JRC, 2014).

Figure 3.1 Environmental impacts across the textiles life-cycle



Source: EEA and ETC/WMGE, based on EEA (2014)

Environmental impacts in the production phase include the impacts of the cultivation of natural fibres, due to such factors as changes in land use, extraction of water, and the use of fertilisers and pesticides, and the energy required for production of synthetic fibres. The spinning and sizing of the fabrics, as well as the finishing and printing/dyeing of the final products also contribute significantly (JRC, 2014). The shipping of textiles around the globe adds to transport emissions and packaging waste.

Most impacts generated during the use-phase are due to the maintenance of textiles. The way that people use and clean their clothing and household textiles – washing, drying and ironing – has a significant impact on the environment. Washing frequency is high across the EU, with an estimated average of 6.2 washes per week per household, with 12 per cent washing most frequently at 60° C, 43 per cent at 40° C and 24 per cent at 30° C (Gray, 2017). The collection and management of end-of-life textiles also have impacts through their transport and processing, not to mention the significant volume of textiles that are finally incinerated and landfilled.

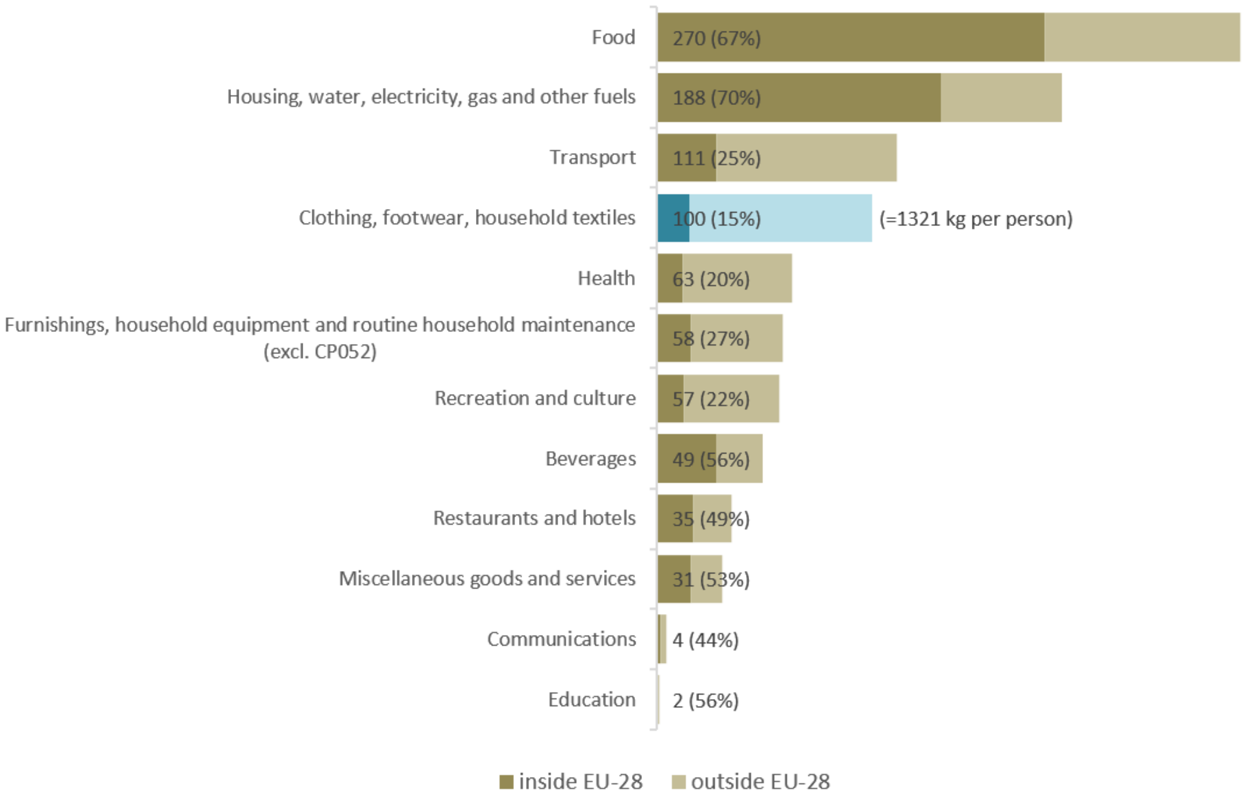
The following sections focus on the environmental impact of textiles from the perspective of resource and land use, climate change through greenhouse gas emissions, and chemicals, which are among the most significant impacts. The global distribution of environmental impacts related to final consumption of textiles has been calculated using an extended multiregional input model based on Exiobase v.3.4 data (Stadler et al., 2018), using environmentally extended product-by-product tables. In figures 3.2, 3.3, 3.4 and 3.5, 2011 Exiobase data were combined with 2017 household consumption data from Eurostat (methodology in annex).

3.1.1 Resource use

The textiles industry relies heavily on resources, both renewable, such as natural fibres, and non-renewable ones, such as oil, to produce synthetic fibres, chemicals for dyeing and processing, and pesticides and fertilisers for growing cotton (Ellen MacArthur Foundation, 2017).

To produce all clothing, footwear and household textiles purchased by EU households in 2017, an estimated 675 million tonnes, 1,321 kg per person, of primary raw materials were used (Figure 3.2). This includes all types of materials, such as fossil fuels as used as feedstock for synthetic fibres and to generate energy; fertilisers, minerals and metals used for production facilities; and biomass, excluding water. Most, 85 per cent, of the primary material consumption, the highest share of all household consumption domains, takes place outside Europe. This illustrates that material and energy intensive parts of the textile supply chain, mostly occur outside Europe, like agriculture and fibre production.

Figure 3.2 The use of primary raw materials in the upstream supply chain ([2]) of EU household consumption domains, indexed values with textile consumption equalling 100, 2017

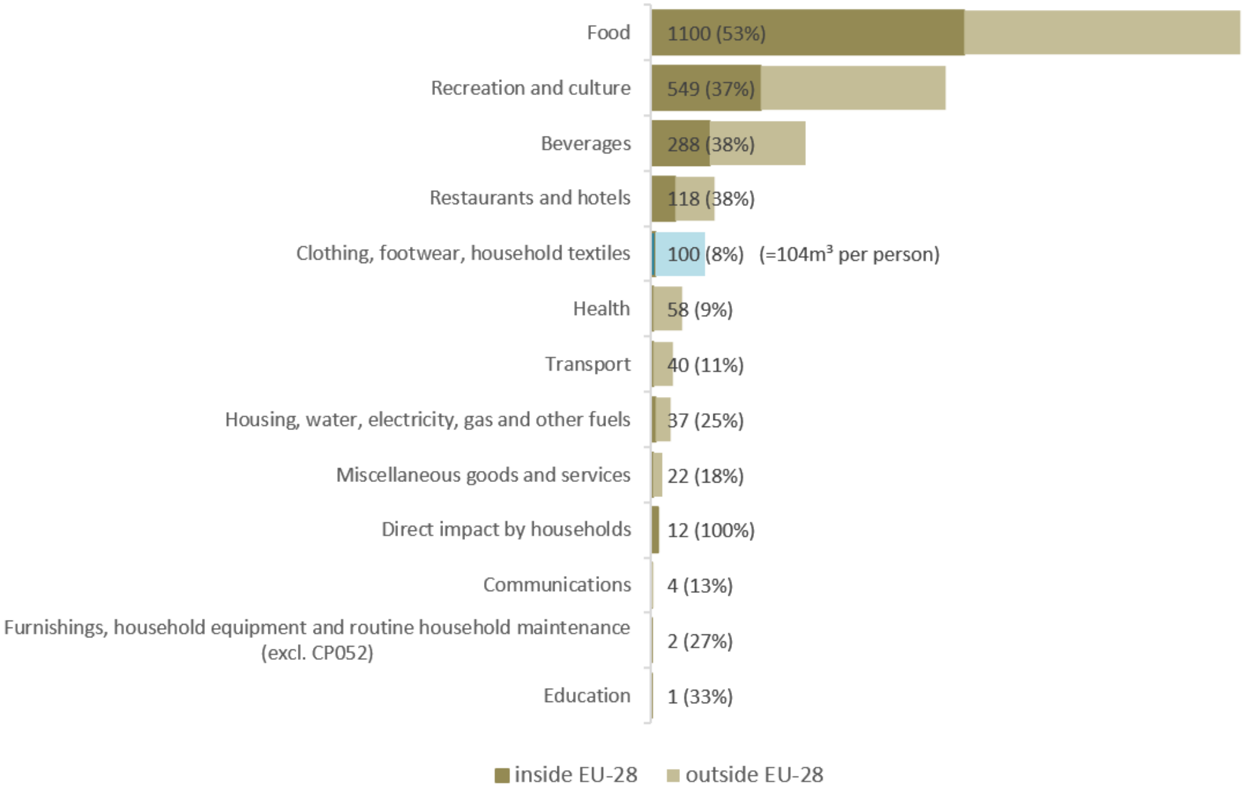


Source: Exiobase v.3.4 (Stadler et al., 2018)
Note: CP052: household textiles

[2] This includes all activities in industrial and service sectors in the production and supply chain of textile products up to purchase by households. It excludes the use of t textile products and end-of-life.

In addition, textile production requires large amounts of water. In 2017, the production of textiles purchased by EU households required an estimated 53,000 million cubic metres (m^3) of water. The major part, more than 90 per cent of this is used outside Europe (Figure 3.3). This is due to the fact that water use is mainly related to the growing of fibre crops, such as cotton, which is mostly takes place elsewhere in the world. This impact is further exacerbated when cotton production occurs in locations with water scarcity, and its use for agriculture competes with demands for drinking and sanitation as well as the production of other crops. Depending on these and other factors, such as the quality of irrigation systems, the global average water footprint of 1 kg of cotton is slightly over 10,000 litres (Chapagain et al., 2006).

Figure 3.3 The water use in the upstream supply chain *([3])* of EU household consumption domains, indexed values with textile consumption equalling 100, 2017



Source: Exiobase v.3.4 (Stadler et al., 2018)
Note: CP052: household textiles

3.1.2 Land use

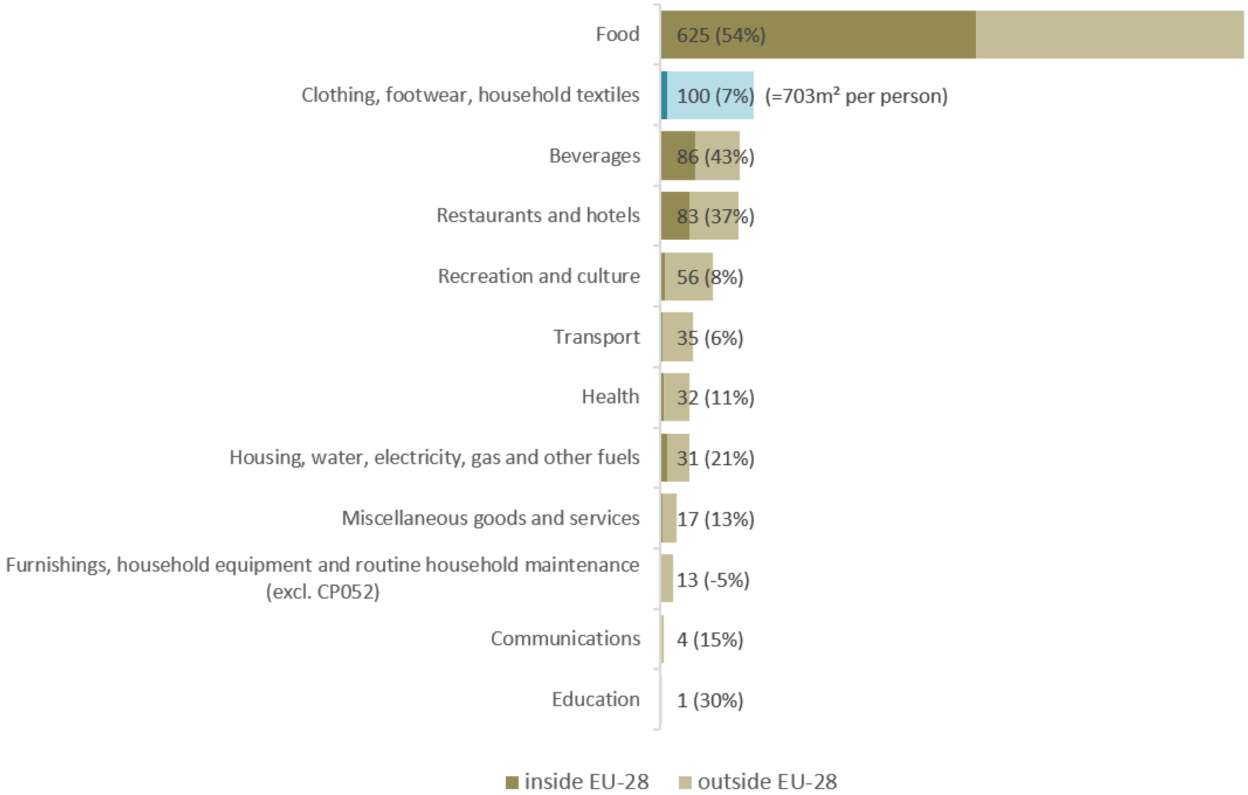
The production phase of textiles dominates the contribution of textiles to land use, in terms of agricultural land and natural land transformation. Particularly for natural fibres like cotton, the cultivation phase has an important impact on land use (JRC, 2014).

The land use in the supply chain of textiles purchased by European households in 2017 is comparable to that of beverages and restaurants and hotels, which are both food related and thus land intensive product

[3] This includes all activities in industrial and service sectors in the production and supply chain of textile products up to purchase by households. It excludes the use of t textile products and end-of-life.

domains (Figure 3.3). It is 6 times lower than the land use for food consumed by European households, but 2–3 times higher than land use related to recreation and culture, and transport.

Figure 3.3 Land use in the upstream supply chain ([4]) of EU household consumption domains, indexed values with textile consumption equalling 100, 2017



Source: Exiobase v.3.4 (Stadler et al., 2018)
Note: CP052: household textiles

For the production of textile products consumed by European households, only 7 per cent of the land use takes place in Europe. Again, this relates to the fact that the agricultural part of the textile supply chain is mainly located elsewhere in the world.

Today, the impact on land use of textiles is to a large extent a consequence of the cultivation of one single fibre crop, cotton. Globally, cotton cultivation covers over 31 million hectares, or 2.4 per cent of the global arable land area (Kooistra and Termorshuizen, 2006), the largest producers being China and India.

Land use for the cultivation of textile fibre crops has the potential to contribute to food deficits, as it may interfere with the growing of food crops. The use of productive land for growing fibre crops contributes to a scarcity of land available for food production, potentially reducing local food availability which can, in turn, lead to malnutrition. It has been calculated that in India, for example, 9 per cent of national malnutrition is attributable to cotton cultivation, which occupies 8 per cent of the country's arable land (Ridoutt et al., 2019).

[4] This includes all activities in industrial and service sectors in the production and supply chain of textile products up to purchase by households. It excludes the use of t textile products and end-of-life.

Despite their durability and lower impacts in the use phase, animal-based fibres and fabrics, such as silk and wool from sheep, but also from cashmere and angora goats, alpaca, etc., generate a significant carbon and land footprint during production due to their extensive use of land and methane emissions (Higg MSI, 2019; Lehmann et al., 2018). For animal fibres, recycling and fair trade initiatives have proved to have a positive impact on land use (TextileExchange, 2018).

3.1.3 Greenhouse gas emissions

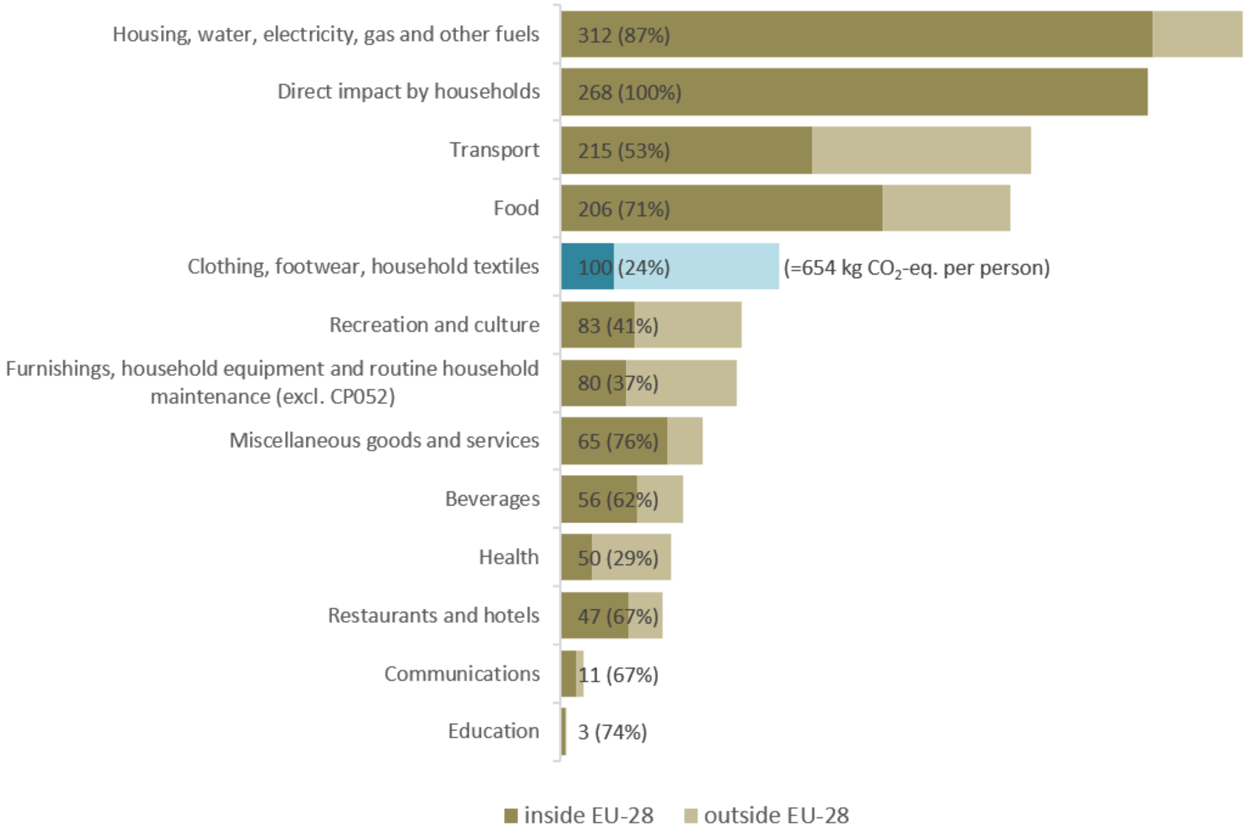
In 2015, greenhouse gas emissions from textiles production amounted to 1.2 billion tonnes CO_2-eq, more than international flights and shipping combined (Ellen MacArthur Foundation, 2017). These greenhouse gas emissions occur all over the world and from many economic sectors, including agriculture, the textile industry and the distribution sector. According to JRC (2014), 51 per cent of the total impact of textiles on climate change occurs in the production phase, 44 per cent in the use phase, and 5 per cent is due to transport. The climate change impact during the use phase is caused by the use of detergents, washing drying and ironing, each contributing an equal share of around 25 per cent of the total impact from the use phase.

The production of textiles is characterised by high greenhouse gas intensity of, depending on the fibre, 15–35 tonnes CO_2-eq. per tonne of textile produced. This is much more than the 3.5 tonnes of CO_2-eq. needed for the production of 1 tonne of plastic, or 1 tonne of CO_2-eq. for 1 tonne of paper (Eunomia, 2015).

Energy use in the production of raw materials and in the finishing of textiles are the main contributors to climate change, with dye is the next most significant factor. The largest contributing fibre type to climate change in the production phase is acrylic, followed by nylon and polyester, while silk has the least impact (JRC, 2014). This reflects the higher impact of synthetic fibres compared to natural and recycled ones. For example, it is estimated that substituting polyester with its recyclable counterpart, rPET, would reduce CO_2 eq. emissions by up to 40 per cent (TextileExchange, 2018).

The production of clothing, footwear and household textiles consumed in the EU generated total emissions of approximately 334 million tonnes CO_2-eq worldwide in 2017, equivalent to 654 kg CO_2-eq. per European citizen, making it the fifth largest, in terms of its climate change impact, amongst EU household product groups. The textile supply chain generates around 30–50 per cent of the greenhouse gas emissions of the housing, mobility and food supply chains (Figure 3.4). The global nature of the textile value chain is highlighted by the fact that more 75 per cent of emissions related to the production of textiles consumed by EU-households are released elsewhere in the world – the highest share of all household consumption domains.

Figure 3.4 Estimated greenhouse gas emissions in the upstream supply chain ([5]) of EU household consumption domains, indexed values with textile consumption equalling 100, 2017



Source: Exiobase v.3.4
Note: CP052: household textiles

3.1.4 Chemicals

Textile production processes make use of a large amount and variety of chemicals. The production of 1 kg of cotton t-shirts, for example, requires about 3 kg of chemicals (KEMI, 2014). The use of dyes, both natural and synthetic, are an important source of chemicals in textile production (Kant, 2012). In addition, many chemicals are applied in the finishing steps to add certain properties, such as water and dirt repellents in outdoor clothing, anti-wrinkle or stiffening additives and biocides to reduce bacteria-induced odours or mould growth during transport and storage (ECHA, 2019).

While most substances used in textile production and found in finished products are safe, some are substances of concern, which are restricted or banned under existing such EU legislation as the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (COM/2013/0656 final). About 3,500 substances used in textile production have been identified, of which 750 are classified as hazardous to human health and 440 to the environment. Two hundred and forty of these substances are considered to be of high potential concern to human health and 120 to the environment (KEMI, 2014).

It is estimated that about 20 per cent of global water pollution is caused by textile dyeing and finishing (Kant, 2012). The discharge of polluted waste water may affect the health of workers and local

[5] This includes all activities in industrial and service sectors in the production and supply chain of textile products up to purchase by households. It excludes the use of t textile products and end-of-life.

communities that use affected water bodies for drinking, fishing and bathing (Ellen MacArthur Foundation, 2017).

Many chemical substances used in textile production have a detrimental effect on the health of workers. Additionally, some of the chemicals used during manufacturing may remain, intentionally or unintentionally, in the final textile products and impact the health of consumers. Allergic contact dermatitis (ACD) can be induced by disperse dyes, finishing agents and some other textile auxiliaries such as softeners, water repellents, flame retardants, formaldehyde, biocides and textile perfumes. Still, it is difficult to draw clear conclusions on the prevalence of contact dermatitis from textiles, due to the limited number of recent studies and a lack of data on concentrations (van der Putte et al., 2013). The European Commission is currently looking into new labelling requirements that could inform consumers of materials and chemicals used in textile products, demonstrate compliance with REACH and facilitate monitoring and enforcement (COM/2013/0656 final).

Due to the long, complex and global nature of textile supply chains, it is difficult to keep track of all the chemicals that have been used along the way (Swedish Chemical Agency, 2013). Polyvinyl chloride (PVC) plastics used in T-shirt prints, shoes and handbags contain softeners, such as phthalates, which have hormone-mimicking properties and can interfere with the human reproductive system.

The EU has restricted or banned many hazardous chemicals that have been used in the textile industry for years, such as certain phthalates, azo colours and dyes, perfluorooctanoic acid (PFOA), chromium VI in the tanning of leather for shoes and handbags, and dimethyl fumarate (DMF), a biocide used to prevent mould (EC, 2009). In recent years, special attention has been given to fluorinated compounds, such as perfluoroalkyl and polyfluoroalkyl substances (PFAS), which are extremely persistent and toxic. These substances have oil and dirt repelling properties and are used as a surface treatment in many consumer products, including such textiles as outdoor clothing, carpets and leather articles (Kotthoff et al., 2015). An EU strategy aiming at reducing the use of PFAS is under development (Norström, 2018). There is also a restriction on the use of substances classified as carcinogenic, mutagenic or toxic for reproduction (CRMs) in textiles, clothing and footwear (Regulation 2018/1513). France and Sweden have submitted a proposal to restrict the placing on the market of textile, leather, hide and fur articles containing skin sensitising substances (ECHA, 2019).

In recent years, plastic fibres from textiles have been shown to be a major source of microplastics entering the environment through wastewater and diverse non-point sources. Despite uncertainty and a lack of data, it is estimated that about half a million tonnes of plastic microfibres are released annually into the ocean through the washing of plastic-based textiles, such as polyester, acrylic and nylon. As a result, it has been estimated that the volume of plastic microfibres in the ocean could rise to more than 22 million tonnes between 2015 and 2050 (Ellen MacArthur Foundation, 2017). A Swedish study on emissions from various textile types indicated that polyester fleece, loosely constructed and worn fabrics shed the greatest amounts of microfibres. Specific solutions to reduce microplastics release from washing of synthetic fibres are still at an early stage of development. To tackle microplastic release into the aquatic environment, a voluntary cross industry agreement was formed by several industry players – the International Association for Soaps, Detergents and Maintenance Products (AISE), the Comité International de la Rayonne et des Fibres Synthétiques (CIRFS), European Outdoor Group (EOG), Euratex and the Federation of the European Sporting Goods Industry (FESI). The partnership has agreed to contribute to the development of international standardised test methods to quantify the microplastics problem, to participate in industrial research aimed at findings solutions and to share information and knowledge (Euratex, 2019a).

Washing clothes also causes emissions of chemicals into household wastewater, and from there into rivers and water bodies, where they contribute to the pollution of water and sludge. Not only can the chemicals themselves have hazardous effects, but also the degradation products that are formed over time or during wastewater treatment can have adverse effects (de Campos Ventura-Camargo and Aparecida Marin-Morales, 2013). Research shows that the concentrations of processing chemicals remaining in clothes slowly decrease through washing, suggesting a slow chemical release along the use phase (Luongo et al., 2015). Secondly, the use of detergents is an important source of release of chemicals into household wastewater. Since 2013, the EU has restricted the use of phosphates in laundry detergents to reduce water eutrophication (EU Regulation No 259/2012). However, as consumers often experience difficulties in fully understanding dose instructions, the overuse of detergents still contributes to water pollution (Gwozdz et al., 2017).

While chemicals not tightly bound to the fibres – residuals, impurities and additives – tend to be washed out over time, persistent hazardous chemicals used during production can stay in the textiles throughout their useful, even if they have been washed several times. In some cases, persistent chemicals are even designed to remain, such as, for example, flame retardants in bedclothes or curtains. This can have implications for possible recovery of the material content of the textiles for use in new products, potentially leading to persistent chemicals remaining in products made from recycled materials (Schmidt et al., 2016).

3.2 Social impacts

The textile value chain generates millions of jobs (paragraph 2.1), but the current dominant linear business model industry also has a variety of detrimental social impacts, both globally and in Europe. The export of large volumes of second-hand clothes from Europe to Africa is often accused of negatively impacting the local textile industry (Katende - Magezi, 2017). However, it has also been argued that the demise of local textile industries primarily resulted from gradual changes in WTO agreements from the late 1990s onwards that opened African markets to cheap imports of new clothing from Asia against which local producers, using old technology, were unable to compete (Brooks, 2015). For example, South Africa's import ban on second-hand clothing does not appear to have had a positive effect on the local textile industry. The gap has rather been filled by increasing imports of cheap new clothing from Asia (Watson et al., 2016). The push to keep up with the speed and competitiveness of the market has been translated into poor employment conditions throughout different parts of the supply chain, both in Europe and Asia.

The textiles sector often employs whole families that depend on their jobs as their sole source of income, making them very vulnerable to exploitation. Workers often have little other choice than to accept precarious working conditions, unfair payments and informal arrangements with minimal or no social security. A study by the Clean Clothes Campaign estimated that in Central and Eastern European countries, out of 1 million garment workers, approximately 350,000 work informally (Luginbühl and Musiolek, 2014). In several European countries, garment workers are paid less than the legal minimum wage and have no decent contracts (House of Commons, 2019; Luginbühl and Musiolek, 2014). In order to increase their daily/monthly earnings, these workers often have to work over-long hours, a common practice in both Asian and European countries. Furthermore, this economic dependency has led to the utilisation of child labour, most prominently in Asia. The International Labour Organization (ILO) (2018) estimates that globally around 152 million children are engaged in child labour across sectors – 71 per cent of this global child labour force is attributed to the agricultural sector, which includes cotton production.

A special characteristic of the textiles and clothing industry is the high share of female employees throughout the garment supply chain. Due to the high share of informal labour, estimates of the percentage of female employees globally vary between 40 per cent (Exiobase 3.4, 2011 data) and 75 per cent (EC, 2017), with the latter being probably closer to reality. The majority of these women occupy positions at the lowest levels of the supply chain, without much opportunity for development, as opposed to the high-skilled, often managerial, and formal positions usually occupied by men. The poor performance on gender equality and economic empowerment of women has been documented in textiles supply chains both in Asia and Europe.

The unsafe physical and infrastructural working conditions to which workers in the garment industry are exposed were tragically exemplified by the Rana Plaza textiles factory's collapse in Bangladesh. This catastrophic event, which resulted in the death of 1,134 employees, shocked the global community and turned widespread attention on to the operation of the textile industry in Asia and worldwide (The Guardian, 2015). Sadly, work accidents, stemming from unsafe physical infrastructure, are not uncommon in the EEA geographical region ([6]) either (Luginbühl and Musiolek, 2014).

The complex supply chains within the textile industry make it particularly challenging to ensure transparency and traceability in the sector. This adds to the challenge of controlling and addressing the social issues. Auditing by monitoring agencies is often limited to the operations of first tier actors, while actors further down the supply chain remain relatively invisible and are much more difficult to identify and monitor (European Commission, 2017; Aets, 2016).

EU initiatives, such as the Blueprint for Sectoral Cooperation on Skills, aim to develop strategic cooperation between key stakeholders within the textile, clothing, leather and footwear sectors. Additionally, it aims to improve and upgrade skills in those sectors, create new training curricula and job opportunities, and consequently improve of social conditions (Skills4Smart, 2019).

[6] The EU, Norway, Switzerland, Turkey and the UK

4 From a linear to a circular production and consumption system for textiles

4.1 Initiatives towards a sustainable textiles system

The fashion industry's current take-make-dispose model is the root cause of the industry's environmental problems and economic value loss. Every second, the equivalent of one garbage truck of textiles is landfilled or burned. If nothing changes, by 2050 the fashion industry will use a quarter of the world's carbon budget. Washing clothes releases half a million tonnes of plastic microfibres into the ocean every year, equivalent to more than 50 billion plastic bottles (Ellen MacArthur Foundation, 2017).

Following the increasing awareness of environmental and social impacts of textiles, initiatives are being taken at different levels to make the their production and consumption system more circular and sustainable. The European Commission has identified textiles, clothes and fabrics, as a priority product category that has significant potential for circularity (EC, 2019b). The new Commission President Ursula von der Leyen made clear she "*will propose a New Circular Economy Action Plan focusing on sustainable resource use, especially in resource intensive and high-impact sectors such as textiles and construction*" (von der Leyen, 2019). Additionally, the 2018 Circular Economy Package and WFD contain a requirement for all Member State to implement the separate collection of textiles by 2025 and to ensure adequate end-of-life treatment. The fashion industry is also showing its potential in facing environmental and social issues by starting to address specific challenges in their supply chains and processes (Box 4.1).

BOX 4.1 The Global Fashion Agenda

The Global Fashion Agenda (GFA), made up of a large number of partners including some of the world's leading textiles and fashion brands, is a leadership forum for industry collaboration on sustainability. Its mission is guiding industry leaders in changing the way fashion is produced, marketed and consumed. Among its activities are the annual Copenhagen Fashion Summit, the Youth Fashion Summit and the publication of the *CEO Agenda* and the *Pulse of the Fashion Industry* report (Global Fashion Agenda, 2019; Lehmann et al., 2019).

The *CEO Agenda 2019*, spells out eight priorities intended to make the industry more sustainable. In the short term, focus is primarily on implementing measures to improve the efficiency of chemical, energy and water use and reduce greenhouse gas emissions, while improving supply chain traceability and working conditions. In the longer term, more fundamental changes will be needed to transform the fashion industry to a circular system, including embracing the opportunities of digitisation that use innovative, sustainable fibres, and fair wages (Global Fashion Agenda, 2019). The 2019 update of the *Pulse of the Fashion Industry* report shows, however, that progress slowed between 2018 and 2019, and that many parts of the industry are yet to address sustainability concerns (Lehmann et al., 2018a).

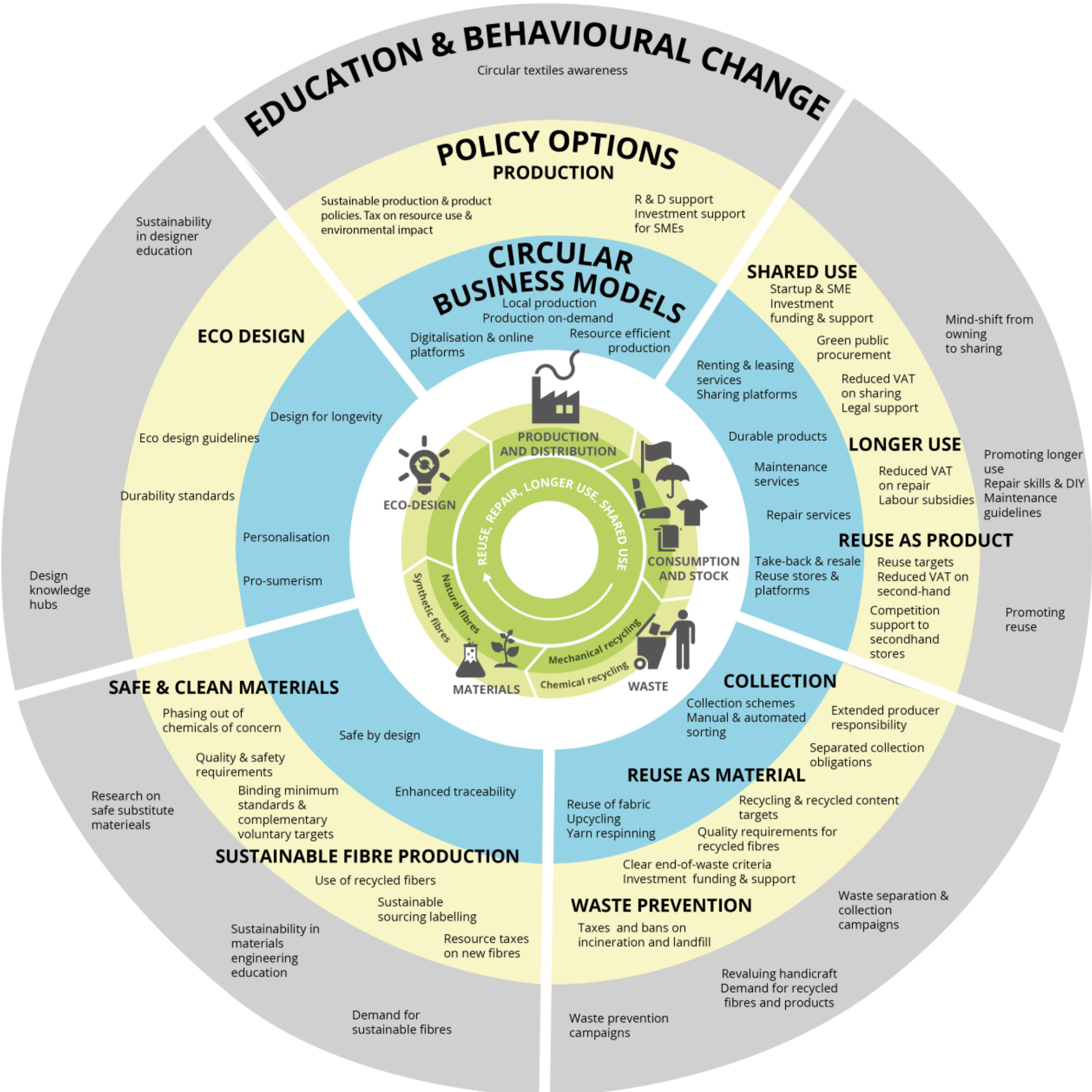
4.2 Envisioning a circular system for textiles

A circular system for textiles should provide access to high-performing textiles, fit for a wide variety of applications, and to high-quality, affordable clothing, in line with people's individual preferences.

In their publication *A new textiles economy*, the Ellen MacArthur Foundation describes a sustainable, circular textiles system as a system *"… that is restorative and regenerative by design and provides benefits for business, society and the environment. A system in which clothes, fabric and fibres are kept at their highest value during use, and re-enter the economy after use, never ending up as waste*" (Ellen MacArthur Foundation, 2017). To achieve a sustainable and circular system, fundamental, systemic changes are needed across the textile value chain. Pollution and waste should be designed out, while focusing on the use of safe, renewable resources and energy and the regeneration of ecosystems by creating net positive impacts, such as producing clean water from production processes. In addition, a circular system should be socially just and distributive by design, so the added value generated is shared among all actors in the textile ecosystem. Workers at all parts of the value chain should benefit from safe and just working conditions, fair wages, gender equality and inclusivity. And finally, the environmental and societal costs of materials and production processes should be reflected in the price of textile products (Ecopreneur.eu, 2019).

A shift towards a sustainable and circular textiles' system requires a profound systemic change rather than just small-scale initiatives and isolated success stories. A circular system requires innovative production methods, new business models, more sustainable behaviour and supporting policy measures at all stages of the value chain (Figure 4.1).

Figure 4.1 Vision of a circular textiles system



Source: EEA and ETC/WMGE, adapted from EEA (2016)

Business model innovation is crucial to making a circular system for textiles viable. A business model broadly describes the way business is done (Magretta, 2002) by illustrating how a business proposes,

creates, delivers and captures value (Richardson, 2008) for the business, customer and wider group of stakeholders (Osterwalder et al., 2005). Circular business models aim to create viable business offerings, while reducing the input of primary resources and the production of waste by, for example, focusing on reusing products and materials (OECD, 2018). In doing so, they can reduce the environmental impact associated with resource extraction, production and disposal. Circular business models for the textiles include the sustainable production of natural and synthetic fibres, and safe additives and process chemicals. It is also essential that textile value chains are transparent and traceable to guarantee clean and safe material cycles.
The design stage is crucial in developing durable textiles made for longer use and reuse, repair or recycling, while sustainable production processes should be resource and energy efficient and free of harmful chemicals. Overproduction should be avoided.

In the use phase, the active lifetime of products should be prolonged by encouraging longer use and the provision of adequate maintenance and repair services, while use intensity can be increased by collaborative consumption – product reuse and shared use.

At the end of life, textile products can be reused as materials for the production of new yarn and textiles. Efficient collection and recycling processes should be put in place, allowing high-quality, clean and safe product and material cycles. Incineration and landfill of textiles should be eliminated.

In a circular business model, much closer collaboration is needed among companies, both downstream and upstream in the value chain, and with customers than is typically the case in a linear system. To support collaboration, circular value has to be created at all stages of a product's value chain and lifecycle. In addition, there must be ways to distribute value fairly among actors along the value chain, creating win-win situations for all involved.

Although there have been many experiments within the textile production and consumption system, most initiatives lack the transformative capacity to create significant disruption of the existing system (Buchel et al., 2018). To achieve real impact beyond mere optimisation of the *status-quo*, circular business models need to scale and achieve significant market penetration. Policy measures and regulations can be powerful tools in enabling this, spurring the transition by promoting sustainable choices and models over unsustainable ones. The European Sustainable Business Federation, Ecopreneur, has listed five pillars that define policy instruments to accelerate the transition to a circular fashion and, by extension, textile system: innovation policies such as subsidies and investment support; economic incentives including value added tax (VAT) and other tax shifts; regulation, quality requirements and bans, for example; trade policies such as import/export requirements; and voluntary actions including commitments and labels (Ecopreneur.eu, 2019).

The implementation of the EU Circular Economy Action Plan – and the expected new action plan – which includes product policies and other priorities at EU and national levels, provides opportunities to regulate the production and consumption of textiles, foster innovation and enable more sustainable business models. To move towards a more circular and sustainable system, regulation of textiles production and consumption should go hand in hand with the industry developing more sustainable production processes, encouraging more sustainable consumption and increasing the reuse and recycling of textiles. These ambitions are, however, very challenging since if consumers lower their textile consumption by repairing and reusing, this could potentially lower sales thereby decrease profits for certain actors along the value chain. Shifting to sustainable production processes and fair working conditions may increase production costs, while the internalisation of the costs of environmental impacts such as emissions and resource use could increase prices for consumers. At the same time, a more circular way of working may allow cost savings and better shared value among stakeholders in the value chain. Additional jobs and revenue opportunities could also emerge through services such as renting, maintenance, repair and redesign, and in collection, sorting and reuse activities.

4.3 Circular business models and policy options for textiles

Without aspiring to be exhaustive, the following sections give an overview of some initiatives that are starting up, under development, or are options for business model and policy innovation. To ensure that production and consumption of textiles are moving towards circularity in a coordinated and synergetic manner, all actors in the textiles value chain need to change their behavioural patterns and ways of thinking and working. Next to business and policy incentives, education and awareness building play a key role in this process.

4.3.1 Choice of materials

The first choice to be made when developing textile products concerns the materials that are used in yarns and fabrics. Different fibres are produced from different resources and thus have different environmental and climate impacts. A cross-cutting issue concerning virgin as well as recycled fibre and fabric production processes is the presence of substances of concern.

Sustainable fibre production

Strategies for moving towards more circularity and sustainability will vary between different fibre types. In the case of natural fibres, such as cotton, attention should be given to the improvement of agricultural practices to reduce the pressures on land and water resources. Apart from a large water footprint (Quantis, 2018), cotton farming also is a large user of fertilisers and pesticides, potentially polluting the surface and groundwater through runoff. Sustainable cotton production would imply a more efficient use of water and agrochemicals, a shift to the use of less toxic chemicals and the implementation of farming techniques that conserve soils, such as composting, crop rotation and reduced tillage. Organic cotton is offered by many clothing brands in response to the demand for more sustainable clothing. However, organic only means that the cotton fibres have been produced according to organic farming practices; it does not exclude the use of hazardous chemicals added during manufacturing or dyeing. Many consumers may not realise that the organic label also does not concern other impacts, such as land use or greenhouse gas emissions, which may be as high or higher than those of non-organic products. A downside of organic cultivation is that it may reduce yields, leading to more land being used (Water Footprint Network, 2017).

In the case of synthetic fibres, such as polyester, environmental impacts are mostly related to energy-use and the use of fossil resources as feedstock for production. Acrylic and nylon fibres have the highest energy demand (Turley et al., 2009). By using recycled fibres, energy use and resource use can be significantly lowered, providing both environmental and economic benefits. Recycling processes generally use less energy than production processes for new materials. A study in Flanders calculated that fibre recycling of clothing and household textiles could reduce greenhouse gas emissions by 8 per cent (OVAM, 2019). Textile traceability and the absence of chemicals of concern are important preconditions to enable high-quality and safe recycling. On the downside, recycling processes cause a deterioration of fibres over time, limiting their reuse potential. Fibre blending, mixing different fibre types in order to obtain specific properties, also makes fibre recycling difficult. To overcome this, fabric design could explore single fibre options for products that are easier to recycle. At the same time, technological innovation, through the development of durable, safe and recyclable materials or using a combination of reused and repaired materials (Johnson and McCarthy, 2014), have the potential to reduce waste and resource use while lowering costs.

Ecolabelling is a way to enable customers to differentiate between products on the basis of their environmental and social impacts. It can provide reliable and transparent information to those consumers who are interested in buying products made of sustainably sourced materials, even though they may be more expensive. There is a wide array of labels used for textiles, initiated by public authorities, private companies and trade associations. A key challenge, however. is that there is no common agreement on criteria or metrics for circularity and sustainability but rather a proliferation of certification schemes and labels using different approaches. An overview by Sinha and Hussey (2009) listed 42 labels used on textile related products, which vary widely in their claims covering agricultural practices, labour conditions, use of chemicals, greenhouse gas emissions, recycled content, etc., and this may confuse and even sometimes mislead consumers. From a company perspective, the challenge is that eco-labels are often tedious and expensive to obtain, which poses a barrier to many small and medium-sized enterprises (SMEs).

The EU eco-label, a flower, is a voluntary label covering criteria on durability – colour resistance and shrink resistance; water use; limited use of hazardous substances; and reduced emissions to water and air during production. The EU eco-label can play an important role in reducing the environmental impact and increase circularity of textiles purchased in the EU.

In Northern European countries, the Nordic Swan eco-label for textiles is known for its stringency – the criteria are especially strict on the use of chemicals (Suikkanen and Nissinen, 2017). Its latest revision focusses on how textiles can contribute to the circular economy. This translates into a further focus on prolonging the product lifetimes, take back systems, re-design and fibre composition. However, the share of eco-labelled textiles compared to the total turnover of textiles is still very low, even in Nordic countries (Eriksson, 2019).

To enable consumers to make conscious choices and raise demand for sustainable fibres, there is a need for easy access to simple and standardised information on social, environmental and climate product performance that is used across brands and products and controlled by an independent and trusted source.

The textile industry itself has taken several voluntary initiatives to promote sustainability across its value chain (Box 4.2).

BOX 4.2: The Higg Index

The Sustainable Apparel Coalition (SAC), representing clothing, footwear, and textile industry members, has developed the Higg Index, which is used by more than 10,000 factories around the world. The index is a suite of assessment tools that empowers brands, retailers and facilities of all sizes to measure their impact on environmental and social dimensions and to identify areas for improvement at every stage of their sustainability journey. The index has three modules: brand, facilities, and product. The brand module measures, amongst other elements, the degree of transparency, environmental/social impact and collaboration with manufacturers. The facilities module focuses on environmental and social measures implemented by manufacturers. The product module provides general frameworks, to be utilised especially by brands, to optimise the sustainability of design and material choices (SAC, 2014).

The SAC and its efforts have inspired many other industry initiatives. The Pulse Score was developed by the Global Fashion Agenda, using the SAC's Higg Index Brand and Retail Module as its underlying data source, to detect patterns of key environmental and social impacts. The score is measured on a scale from 1 to 100, with values higher than 70 signalling a high level of sustainability (Lehmann et al., 2018). The Pulse Score of the fashion industry was 32 in 2017, increased by 6 points in 2018, and by further 4 points in 2019, to a value of 42. This shows increasing sustainability but slowing progress (Lehmann et al., 2019).

To stimulate producers to use recycled fibres, refunded virgin payments (RVP) schemes that resemble a tax on virgin fibres could be effective to counterbalance the low market prices of virgin textile fibres. The revenues could be refunded to the producers proportionally to the share of recycled textile fibres in total production. Best performing producers thus could become net receivers of refunds, while underperforming producers will be net payers. According to Elander et al. (2017) the effectiveness of RVP mostly depend on setting the right charges and on a good level of transparency across the value chain in reporting of use of virgin fibres.

Safe and clean materials

Chemicals used during textile production can stay present in products, but tend to leach out during use and washing, posing potential health risks to users and the environment. The issue of residual chemicals is an argument in favour of prewashing and buying second-hand clothing. As reused clothes have been washed many times, fewer chemicals will be present in the fabric, making their use not only better for the environment, and a consumer's wallet, but also better for people's health. Persistent hazardous chemicals used during production can, however, stay in textiles to the end of their useful lives.

Recently there has also been a lot of attention on the problem of microplastic release to water bodies, caused by the production, washing and waste handling of textiles made from synthetic fibres. Since few viable alternatives are available to replace highly valued synthetic fibres, it is unlikely that synthetic textiles will disappear from the market (Common Objective, 2019). It is therefore crucial that plastic microfibre release from textiles is reduced drastically during production, use and end-of-life stages (Ellen MacArthur Foundation, 2017). It has been shown that polyester fleece, loosely constructed and worn fabrics shed the greatest amounts of plastic microfibres. Smarter textile construction, prewashing and vacuum exhaustion at production sites, and the use of more efficient filters in household washing machines (including adequate filter cleaning procedures) and in wastewater treatment plants could help mitigate this problem (Carney Almroth et al., 2018). Nonetheless, further research and knowledge on microplastics from textiles is needed.

To create safe material cycles, substances of concern should be phased out from the design stage onward. Continuous research is being carried out to reduce chemical use in the textile industry and substitute hazardous ones with environmentally less hazardous options (Zhang et al., 2018). Printing textiles with pigments rather than using dyes uses less water (Bomgardner, 2018). Many sustainable alternatives have been developed to bond to fibre more easily, enabling savings in water and energy. Biological alternatives to chemical dyes are being developed, though the cost of more sustainable dyes is a challenge for the industry, due to its very low margins. Enzymes are also commercially used as chemical replacements as they are highly specific and work under mild conditions (Madhu and Chakraborty, 2017).

A mind shift among product designers is needed to make the transition to the principle of safe by design (Wood Environment & Infrastructure Solutions UK Limited, 2018; EEA, 2017). Including sustainability awareness in education and training is key. Additionally, cooperation between industry and public authorities on quality and safety requirements is important to phase out chemicals of concern in production processes and products.

An option to combining concerns about sustainably sourced, safe and high-quality materials is to develop legally binding standards for textile products that are based on measurable criteria around, for example, durability, agricultural practices, labour conditions, recycled content, use of chemicals, microfibre leaching, durability and recyclability. Such standards could be set based on an analysis of existing voluntary standards and certification schemes, including the EU's ecolabel. In addition, complementary voluntary targets could be set, so frontrunners could have the opportunity to move ahead.

Additionally, better traceability in textile supply chains could allow companies to follow material and production flows from the stage of fibre production up to the final product reaching the customer (UNECE, 2017). Traceability assures quality and compliance, mitigates fraud and engages each actor in the product value chain to bear direct responsibility for their processes and activities. Setting up a traceability system requires the collaboration of all stakeholders, as well as technical solutions, for example through blockchain technology. Blockchain platforms can support verified and secure transactions, while recording and storing information on raw materials used, production processes, sustainability certification and product use, and can thus facilitate sustainable, safe and clean material loops for textile products (Rusinek et al., 2018). This could not only allow producers to make better and more sustainable procurement decisions but can also empower consumers to make more sustainable choices, while increasing trust in recycled materials and second-hand products.

4.3.2 Design

The design stage is crucial in the development of a circular value chain for textiles. It is at this stage that the choices are made significantly determine the environmental and climate impact of textile products, as well as the potential for circularity in later stages of the product's lifecycle. Not only is the choice of materials important, so too is the way in which a product is conceived and assembled to encourage a long life. In general, product design should aim to facilitate long use, reparability and reuse, as well as efficient production processes with little waste and few emissions (Bauer et al., 2018).

Ecodesign

To enable consumers to use textile products for longer, it is important that products are *designed for longevity*. This overall concept consists of three designs principles: *design for durability*, *design for long-lasting style* and *design for disassembly* (Circular Fashion, 2019). The first aims to creating textile products that are resilient to wear and tear and can withstand abrasion and washing. The choice of durable high-quality fabrics and other components is key here, as well as the way seams are constructed in order to withstand tearing out. The second principle considers users' sensitivity to style and changing fashion. By carefully selecting colours and styles that are regarded as timeless and appealing to a broad audience, designers avoid items being disposed of because they are perceived to be out-of-fashion. Moreover, timeless items retain a higher value on the second-hand market, encouraging longer use and reuse. Finally, the way a textile product is assembled determines whether and how easily it can be taken apart to facilitate maintenance, repair, component reuse and/or recycling. In this regard, design-for-disassembly strategies choose stitching over gluing, avoid fusible interfacing by using blind hemming and use low density stitching (Gam et al., 2011), so different parts can easily be taken apart in order to allow repair, component reuse or recycling.

Adding a personal touch to clothes or household textiles could also be an option to encourage longer use. Personalised designs have been found to increase a user's emotional attachment to items, which can stimulate consumers to maintain and repair, rather than discard (Mugge et al., 2005). Within this context, new business models need to be developed and scaled that increase the role consumers can play in production. The concept of a prosumer is emerging as a consumer involved in different phases of production, such a design or reuse/recycling. Prosumer, a term introduced by Alvin Toffler in his book *The Third Wave* (Toffler, 1980), combines *pro*ducer and con*sumer* to express the active role that consumers could play in the design and manufacture of products. In the case of textiles, this relates to increased interest in traditional handicrafts and personalized items.

Public authorities can play an important role in steering industry towards sustainable design and production processes, aimed at long-lasting textiles that are free of chemicals of concern. The EU Ecodesign Directive focusses on energy efficiency in energy-consuming products but little attention has been given so far to material choices and circularity aspects. Based on ecolabelling and green public procurement criteria, Bauer et al. (2018b) propose a set of ecodesign requirements for textiles and furniture that do take reparability and recyclability into account. The objective of these criteria is to increase the active lifespan of textile products through, for example, durable fasteners, availability of spare parts, colour fastness and fabric resilience; promote the use of recycled materials to offset virgin production through recycled content thresholds; and reduce water and energy use during maintenance by, for example, providing care and maintenance labelling. In July 2019, the Ellen MacArthur Foundation's Make Fashion Circular Initiative published a set of Jeans Redesign Guidelines (Box 4.3).

BOX 4.3 Jeans Redesign Guidelines

The Jeans Redesign Guidelines (Ellen MacArthur Foundation, 2019) set out minimum requirements to ensure jeans last longer, can easily be recycled and are made in a way that is better for the environment and the health of garment workers. Health, safety and improvement of working conditions in global textile manufacturing are prerequisites. Beyond this, the Guidelines provide minimum requirements for jeans on durability, material health, recyclability and traceability.

Durability
- jeans should withstand a minimum of 30 home laundries, while still meeting the minimum quality requirements of the brands;
- garments should include labels with clear information on product maintenance.

Material health
- jeans should be produced using cellulose fibres from regenerative, organic or transitional farming methods;
- jeans should be free of hazardous chemicals and conventional electroplating. Stone finishing, potassium permanganate (PP) and sandblasting are prohibited.

Recyclability
- jeans should be made with a minimum of 98% cellulose fibres by weight;
- metal rivets should be designed out, or reduced to a minimum;
- any additional material added to the jeans should be easy to disassemble.

Traceability
- information that confirms each element of the Guidelines' requirements has been met should be made easily available;
- organisations that meet the requirements will be granted permission to use the Jeans Redesign logo on jeans produced in line with the Guidelines;
- Jeans Redesign logo use will be reassessed annually based on compliance with reporting requirements.

Ecodesign requires interdisciplinarity between designers, chemists, material developers, etc. and education, both during professional education and in life-long-learning programmes for industry professionals. A strong sustainability focus in designer education curricula could be a powerful lever to spur a change in design culture. Educating designers in sustainable material choices and designs that are timeless, durable and easy to repair could have a considerable impact. On the other hand, designers may not have incentives or a mandate within a company to design for circularity (Bauer et al., 2018). To assure effective implementation, it is important that the same mind shift takes place at the top management level, at which financial and strategic decisions are taken.

The establishment of accessible knowledge hubs can support companies, entrepreneurs and start-ups that want to implement sustainable and circular design principles in their products and business models (Watson et al., 2017). By providing knowledge, technical expertise, tools, training and information on existing circular business models, policy measures and funding schemes, these hubs can guide companies in the development of their own circular product design and business strategies and reduce the risk of failure. Moreover, such hubs can be instrumental in communicating and reinforcing the effect of other policy measures, such as funding support and awareness raising campaigns.

4.3.3 Production and distribution stages

As it has been shown throughout this report, one of the biggest issues with mainstream business models is that they rely on cheap mass production, mainly in Asia, and worldwide distribution channels. A sustainable and circular production process should be resource efficient, avoid waste and overproduction, while offering healthy products and fair working conditions. A shift to more local production, using digital technology, could reduce worldwide shipping, while creating jobs within Europe.

Sustainable production

A large portion of the textiles consumed in Europe are produced elsewhere in the world, mostly in Asia, to take advantage of low labour costs, but this also leads to significant environmental and social impacts. Moving to more EU-based production would not only strengthen European manufacturing industry but also reduce dependency on long-distance supply chains and the associated costs and impacts. Modernisation and automation of the industry are needed to develop cleaner production processes, which are less labour and resource intensive.

In a sustainable textiles system, resource-efficient production is a key element. Reducing production waste and the energy, material and needs water of the sector, while switching to healthy and renewable materials and energy at the same time, would reduce the environmental impact of the textile industry. Additionally, to tackle the negative social impacts of the textiles industry, the wages and working conditions of the workers need to be improved. This may increase the price of textile products, which in turn may reduce consumption.

Automation of the sector holds opportunities for improving labour efficiency by providing innovative technologies that can change labour-intensive steps such as those for sewing, patching and finishing of products (Andersson et al., 2018). For instance, 3D knitting machines and/or techniques can produce clothes without seams or sewing (Bain, 2018). Local production also offers the opportunity to make the industry more circular. On the other hand, automation may also lead to shorter production cycles and even faster fashion, while causing major job losses in producing countries – mainly in Asia. It is estimated that increased automation could reduce labour needs by 26–46 per cent (Andersson et al., 2018). Manual and labour-intensive production processes, however, have a role to play in a sustainable and circular textile system. Since hand-made is valued in this industry, unique and artisanal products can encourage customers to keep products in use for longer, and repair and reuse them. Many customers are willing to pay higher prices for high-quality, handmade items, supporting job creation for artisans and such handcrafters as repairing services both in Europe and abroad.

Overproduction is a significant issue in the fashion industry, generating enormous amounts of unused clothing articles ending up as waste. Estimates on the percentage of clothing that is sold at discounted prices, or is not sold at all vary widely (Wijnia, 2016). In general the industry states that a third of products are sold at full price, a third sold in sales and the remaining third generate almost no revenue, takes up space as dead stock and is eventually incinerated or landfilled (SITRA and Circle Economy, 2015). Part of the solution to avoid overproduction could be to move from push to pull sales models and support companies to deploy demand-driven production models.

The rapid rise of online retail has already caused a major change in the landscape of fashion brands and retailers. Online platforms do not only enable the large retailers to reach their customers, but also offer small manufacturers and even amateur artisans direct access to potential customers (Buchel et al., 2018).

Within the online shopping environment, the emergence of new digital technologies that aim to virtualising the human-textile interactions – visualisation, touch, feel and fit – could change consumer habits considerably in the future (Zimniewska et al., 2016), either enabling or inhibiting sustainable textile and fashion consumption. In combination with further automatisation, reducing production time and the emergence of new production technologies that allow greater flexibility and local, decentralised production facilities, such as 3D printing and laser-cutting, digital technologies offer enormous possibilities to ensure a closer connection with customer needs and preferences. The revaluing of manual craftmanship can also play a role here, for example, in the creation of personalised items, enabling customer-led design and upcycling (Section 4.3.2). Successful implementation of such models requires close communication with the market, using big data and artificial intelligence to better predict consumer wants, needs and tastes (BOF and McKinsey, 2017). These evolutions could drastically change fashion retail, and the wider textiles sector as well. A close relationship between producer and end-user gives the garments a much higher added value than that of mass-produced fashion, while avoiding overstocking as garments will only be made after they are sold (Post-couture Collective, 2019). Such a strategy ensures that a higher percentage of a collection would be sold full price, offering an opportunity for brands to improve profit margins. Producing on demand, in local facilities close to the customer also reduces transport.

A better understanding of technological developments, as well as of current and future consumer preferences and behaviours, is needed to improve policies and interventions that aim to make production processes more sustainable and change consumer behaviour and lifestyles to more circular and sustainable models.

The EU, with the Action Plan on Circular Economy (COM, 2015, 614), is committed to improving the environmental performance of products, excluding dangerous products for the environment from the European single market, while increasing visibility of environmental friendly products. In the field of textiles production, an extensive body of EU policy instruments is already in place to stimulate and enforce sustainable production: requirements, for example, have been set for textile fibre names and related labelling, as well as for marking fibre composition in textile products (Regulation 1007/2011). The REACH regulation sets chemical restrictions on textile products and production, while pollution and industrial emissions are regulated through compliance with the reference document on best available techniques (BREF) for the textile industry (currently under review) under the Industrial Emissions Directive (IED). More specifically, the EU Emission Trading System sets limits for greenhouse emissions. EU ecolabel criteria exist for textiles and a number of producers have adopted the label. EU green public procurement (GPP) criteria include requirements on sustainability for textiles. All these measures have the potential to influence producers outside the EU, as they have to adapt to strict environmental performance rules to access the EU market.

Through the Horizon2020 and LIFE programmes and the Executive Agency for Small and Medium-sized Enterprises (EASME), the EU is funding R&D and pilot experiments for textiles. The aim of these programmes is to support sector-wide partnerships to develop technological innovation in production and recycling, design new circular business models and foster collaboration among actors across the value chain. To assure sufficient budget to facilitate these programmes, and especially the upscaling of innovation to enable large-scale system transformation, advocacy is needed (Ecopreneur.eu, 2019).

As for many industrial sectors, the uptake of innovative technological solutions for production processes, products and services by the textile and clothing industry is very challenging, since it consists of many SMEs that lack investment power. Investment support for SMEs is needed to spur the adoption of new technologies. At the European level, several innovation projects for textiles are in development within the Smart Specialisation Platform on Industrial Modernisation. The aim of these is to build regional innovation capacity across Europe, facilitate investment by SME's and establish effective collaboration between regional actors (EC, 2019a). Subsidies may also be useful to encourage potential losers in the transition to a circular economy, such as companies that are highly dependent on linear business models, to turn their business activities around (Ecopreneur.eu, 2019).

Economic instruments, in the form of, for example, tax shifts from labour to resource use and environmental impacts, offer interesting opportunities to influence market dynamics in favour of sustainable textiles by internalising external costs. An important reason why most textile production still works in an unsustainable way is the fact that the negative environmental and social impacts caused by their production – transportation, use and waste management – are not reflected in prices. Cheap clothing made of textiles which have high environmental impacts, for example, are sold for just a few Euros and as a result they are sometimes only worn once or, at most, a few times. Producers are not required to pay for the damage done to the environment and climate, for example from energy and chemicals use or water pollution.

4.3.4 Use stage

Reducing the volume of textiles purchased can be part of lowering the environmental and climate impacts of the textile system. By encouraging shared use, longer use and reuse, the need for textile products could be fulfilled, while reducing the number of products that are purchased. As a consequence, the need for resources, production and distribution would be reduced as well, avoiding the associated environmental and climate impacts and the generation of waste. At the same time, the intensity of textile utilisation would increase, as items would be used for longer, more often or by more people. This sets requirements for material quality and product design, as textile products need to be more durable as well as easy to maintain and repair. Additionally, the logistics services needed to support collaborative consumption patterns and product redistribution pose new challenges to the textile distribution system that is currently organised in a linear way.

Although some initiatives promoting circularity in textiles are starting to be successful, many others are struggling to become profitable. Policy measures could support business viability by enabling profit making and raising consumer awareness on the importance of increasing the active lifespan of textile products through reuse and extending lifetimes. Moving to consumption patterns based on shared use, longer use and reuse will require substantial behavioural change. Educating consumers on the environmental and social impacts of textiles can effectively reduce environmental and climate impacts, as consumers are unlikely to be aware of the full environmental and social impacts of the textiles they buy, due to the complexity of global supply chains (EEA, 2014). Better knowledge about lifecycle pressures can encourage behavioural change towards the more responsible consumption of textiles, such as buying less and from more sustainable sources, choosing durable items, using items for longer, repairing, considering reuse and selective disposal.

Shared use

Service-based offerings, such as the renting or leasing of clothing, furniture and carpets, can significantly lengthen the active lifetime of textiles and in that way improve sustainability during the use phase. Through these services, the same product is shared among multiple users, either for a short periods (renting) or for longer ones (leasing). The ownership of the products stays with the company offering the service – in business-to-business (B2B) or business-to-consumer (B2C) models – or with the individuals who participate in sharing or swapping communities – consumer-to-consumer (C2C) models (Elander et al., 2017).

Companies are increasingly looking into service-based business models to complement direct product sales. The customer only pays for the use of the product, which can be cheaper than buying. But even if the long-term cost of the service is higher, product-service systems can still be appealing since they offer a high level of convenience: performance is guaranteed while maintenance, replacements and waste disposal are often included in the service. In this way, leasing of carpet tiles, for example, provides a convenient and waste-free solution for the user, as the responsibility of installing, replacing, take back and responsible waste disposal is held by the carpet company or brand. Additionally, producers have an intrinsic incentive to select materials and product designs that are maintenance-friendly, resistant to wear and tear, easy to repair and durable. Also recyclability or the potential for subsequent reuse in different applications can be an important asset to conserve value and avoid waste treatment costs (Lindström, 2019). In the case of carpet tiles, multiple companies offer leasing systems on the B2B market combined with take-back programmes. These offer the customers affordable floor covering that can easily be replaced, while the producers stay in control of their carpets and their end of life (Desso, 2019; Interface, 2019).

For clothing, many different sharing platforms are emerging to support shared use. A well-known example are clothing libraries, which first appeared at the beginning of 2010s. A monthly membership/subscription fee allows members to borrow a specific number of clothing items for a limited amount of time, typically a few weeks. A handful of platforms exist in Germany, Netherlands, the Nordic countries and the UK. The main clientele are mostly young women, living in an urban environment (Elander et al., 2017). Libraries are especially attractive for renting designer clothing and garments for special occasions such as gala dresses and fancy dress as well as for garments that serve for a short period of time, such as children's and pregnancy clothes.

Maintaining such a library with fashionable garments is a big investment and pay-back times are long as consumers are often only prepared to pay small fees. A lifecycle assessment of a clothing library system has shown that there are potential benefits per garment use of implementing clothing libraries so long as the garments' service life is prolonged, but it is important to achieve a substantial increase of service life for environmental gains to occur as, for example, emissions caused by long transport distances can outweigh the benefits of reduced consumption (Zamani et al., 2017). A main challenge for sharing systems is acquiring new members or subscribers and in most cases the membership base is slow to develop. Investment costs at start-up can be an important financial barrier, while operating costs – labour costs for maintenance, repairs and logistics – are also significant. Often, sharing services are only profitable in parallel with traditional retail models based on sales, or due to various support measures, such as voluntary work (in the case of charities) or the provision of free materials (Elander et al., 2017).

Currently, the lack of market demand for circular products and services is a major barrier to the implementation of circular business models (Ecopreneur.eu, 2019). The public sector can play an important role in their development, breakthrough and scaling by purchasing and using such services or implementing economic incentives such as reduced VAT or other taxes for renting, leasing and sharing systems.

Green public procurement in the purchasing of textiles could pave the way for the scaling up of service-based business models and increased awareness within society as a whole. The public sector in Europe – including hospitals, schools and administrations – is a huge consumer of textiles. Examples include uniforms and bed linen in hospitals, carpets and curtains in schools and public buildings, to name a just few. Green public procurement is a voluntary instrument in the EU, used to varying degree in Member States. In some countries, GPP has been used to increase demand for sustainable textiles, resulting in demands for uniforms, bed linen, curtains and carpets produced in a way that lives up to green and sustainability standards (EC, 2011). Circular product-service offerings could also be encouraged in procurement procedures, for example, by taking the life-cycle cost of products, including maintenance, repair, replacement and waste disposal costs, into account in tendering procedures.

Investment support to start-ups and SMEs setting up sharing systems and innovative business models would also help overcome the financial barriers that many initiatives face. Smaller business often cannot afford substantial investment to transform their own business models, while investors are reluctant to take the risk of embarking in lesser known business concepts (Watson et al., 2017). Some EU initiatives and pilot-projects are focused on supporting SMEs in the textile sector to adopt innovative technologies, improve productivity and resource efficiency, and create high added-value niche-market products and services, such as the recently launched ELIIT project (EASME/COSME/2018/013).

Apart from economic incentives and subsidies, legal adjustments are important for the development new business models. Many current laws and regulations are based on traditional linear producer/consumer relationships and do not take into account the possibility of collaborative consumption and new relationships between producers and customers. For example, new regulations and agreements may be needed to facilitate exchanging, sharing and co-owning products. Additionally, issues related to risk-management in the case of shared use, such as warranties and liabilities, need to be solved (Kassan and Orsi, 2012).

A shift to collaborative consumption patterns would require a mind shift from owning to sharing among customers. Often, these models require customers to do make extra effort, such as making a reservation, collecting and returning products or embarking in a leasing model, which might seem less convenient than simply buying a product. Distribution costs may be involved if products are sent to the customer's home, which may also act as a deterrent (Watson et al., 2017).

Longer use

Longer active use of textile products reduces the need for new textiles and avoiding waste generation. A study performed by the Ellen MacArthur Foundation pointed out that if the number of times a garment is worn were doubled, and garment purchases and production were reduced by half as a consequence, the greenhouse gas emissions of the textiles industry would be reduced by 44 per cent (Ellen MacArthur Foundation, 2017).

In order to last longer, textile products should be made more durable. Using designs based on durable materials is an opportunity for companies to save in raw materials and reach new market opportunities while improving environmental performance (Vezzoli et al., 2018; Ellen MacArthur Foundation, 2017). Adding durability claims to textile labels would provide users with useful information on fabric resilience to washing, wear and tear and expected product lifetimes.

The trend and campaigns for slow fashion try to convince consumers to buy fewer clothes and to keep them for longer. The idea embraces transparent supply chains, small-scale local production, high-quality materials and trans-seasonal and durable garments. While reduced sales volumes are a desired consequence of this approach, it raises some questions concerning affordability and profitability. A shift to high-quality products is expected to result in higher prices for the consumer, at least at the point of purchase. Business models based on leasing or sharing of high-quality and durable products could assure more people with access to affordable, high-quality clothing. At the same time, the longer lifespan of products might also lower the long-term cost of clothing by reducing the need for frequent replacements. From a producer's point of view, fewer sales might lead to reduced profitability, threatening the economic survival of traditional business models that are based on fast fashion cycles and frequent sales. A shift towards durability, however, opens up alternative opportunities for companies to build circular, environmentally beneficial business models that rely on design for durability and design for repair, offering maintenance and repair services to customers.

Product maintenance and repair are crucial to prolonging product life, but maintenance practices for textile products, such as vacuum cleaning, washing and drying, and the use of detergents, all have an environmental impact. Washing and drying of textiles result in significant water and energy use, and release chemicals and micro-plastics into wastewater. Smarter textile construction, prewashing and vacuum exhaustion at production sites, and use of more efficient filters in household washing machines, including adequate filter cleaning procedures, and wastewater treatment plants could help mitigate this problem (Carney Almroth et al., 2018). Additionally, environment-friendly maintenance guidelines should be communicated to users, such as washing at full load and reducing temperatures, minimizing detergent use and avoiding tumble-drying (EEA, 2014). Clear labelling and communication of maintenance instructions should inform consumers that certain items, such as wool and jeans, do not have to be washed very often, that drying can be done in the open air and that ironing is not always necessary (Clevercare, 2019). Maintenance services, such as laundry and cleaning services, can relieve users of maintenance efforts – and owning the needed maintenance appliances – while offering business opportunities for service providers and efficiency gains in the maintenance process.

Consumers are often reluctant to repair textile products, especially clothes, because of lack of time and skills, and because of low replacement costs in comparison with the costs of repair. Taking an item to a repair shop and collecting it afterwards can also be seen as inconvenient. Repair activities are generally more attractive to older consumers (Armstrong et al., 2015). Some high-end fashion brands make reparability one of their key selling propositions. These garments are designed to be easy to repair and come with repair kits containing spare buttons, thread, patches and even a manual on how to carry out repairs. Repair services are also sometimes offered by the brand itself or a third party together with the possibility of returning worn out items so that they can be recycled (Goworek et al., 2013; Rissanen, 2011). For repair services to become viable, it is important that repair costs decrease, for example through favourable labour schemes or reduced VAT on repair services – Sweden has recently reduced VAT rates for repair services, including textiles (Finansdepartementet Skatte- och tullavdelningen, 2015). This is a way of contributing to making repair worthwhile and can significantly extend the number of times textiles are used.

Strong awareness campaigns promoting longer use are also key, linked to convenient systems for identifying and accessing repair shops, spare parts and repair instructions, so that people can easily choose to repair. At the same time, do-it-yourself (DIY) skills, such as sewing, mending and darning, can be revalued and practical courses made accessible. The Sustainable Apparel Coalition's global consumer research proved that consumers want to be part of a sustainable fashion revolution, have access to information about their favourite brands and products to enable informed decision making, and also want a better understanding of their own impacts in the use phase (SAC, 2019).

Reuse as a product

The reuse of textiles has considerable environmental benefits, as the impacts of the transport and processing of used textiles are small in comparison to the savings caused by offsetting new textiles production (Schmidt et al., 2016; EEA, 2014). A study in Flanders illustrated that reuse of clothing and footwear can reduce primary raw material consumption by 24 per cent and the greenhouse gas emissions of the textile value chain by 16 per cent, compared to 8 per cent for fibre recycling (OVAM, 2019).

Textiles can be re-used as a product through, for example, second-hand stores and informal giving, or as material for up-cycling and recycling. Transactions mostly take place informally among friends and relatives, formally in second-hand stores, or over online platforms. Reuse stores and platforms are most common for clothing, often linking to the trend for vintage fashion. The terms swishing and swapping both refer to a peer-to-peer exchange of clothing, facilitated by online platforms or events. Thrift shops typically offer a significant amount of second-hand clothing, taking about 30–40 per cent of total revenues (De Kringwinkel, 2019).

Sometimes a second-hand market is facilitated and enabled by companies or brands themselves. Some clothing brands encourage consumers to return used garments to their stores, sometimes in return for a discount on their next purchase. A distinction can be made between business models focusing on own brand take back only, generally by high-quality or exclusive brands, or on general collection. In the case of own-brand take backs, garments are often in good condition and are re-sold in dedicated second-hand stores, while garments in poor condition are donated to charity organisations. In general collection schemes, clothes are collected regardless of condition and donated to charity or sold on global markets for reuse and recycling (Elander et al., 2017). Often charity organisations take part in the collection logistics. Another common sales model, often used by independent second-hand shops, is sales on commission. In this model, consumers bring used garments to the second-hand shop, which displays and resells them. If the garment is sold, the owner receives typically 30-50 per cent of the sales price; items that do not sell within a specified period, typically 1–3 months, are returned to the owner.

Despite being sold at lower prices, the overall transaction cost of second-hand garments increases considerably when the time and effort consumers make to find a piece of clothing that suits and fits is included, as second-hand retailers are typically located outside main shopping areas (Watson et al., 2015; Svengren Holm and Holm, 2010). One promising option to improve the competitiveness of second-hand stores is enabling them to locate in central shopping malls by renting space at reduced rates. This could also stimulate regular clothing stores to allocate some of their space to second-hand sales (Watson et al., 2017).

In the EU, the Seventh VAT Directive was enforced for avoiding double taxation of second-hand goods, as they have already borne VAT when they were originally sold. As a consequence, second-hand sales are taxed on the basis of the difference between the price at which the vendor bought the goods and the price at which the vendor resells it, instead of on the full value. More far-reaching schemes could be set up for implementing reduced VAT on second-hand sales, stimulating business based on reuse and supporting the achievement of EU targets on reuse.

The EU WFD sets up one combined target for reuse and recycling, and some Member States are establishing more specific reuse targets (RREUSE, 2016). By 2020, Spain, for example, aims to achieve 50 per cent preparation for re-use and recycling of all municipal waste, including 2 per cent preparation for reuse of textiles, waste electrical and electronic equipment (WEEE) and furniture. France, within its Extended Producer Responsibility Schemes for furniture and clothing, aims to increase the share of used furniture and clothing put back on the market by social enterprises, with important impacts in providing jobs and training opportunities.

4.3.5 Collection, recycling and waste treatment stages

Better collection, sorting and management of textile waste is fundamental to ensuring more reuse and recycling and preventing waste from being incinerated or landfilled.

Collection

As touched upon in the previous section, different types of take back and collection systems have been put in place by brands, charities or public authorities, with different objectives. While brand-specific take backs are mostly aimed at high-quality product resales, general collection schemes aim at a combination of reuse, recycling and waste treatment. Both private and public actors are active in textile waste collection, and an important role is played by charities. Sorting the collected waste streams can be done by the charity itself, or by third parties specialised in the manual and automatic sorting of textiles.

The development of large-scale separate collection systems, combined with manual and automatic sorting processes, is a crucial step for improving textile recycling. New separation techniques and purification processes on a molecular level would enable better handling of increasingly mixed fabrics. Moreover, Europe could develop and deploy technologies that enable the traceability of the content of textiles in respect of chemical additives, such as surface finishes, that remain in textiles at the end of the use phase (Wood Environment & Infrastructure Solutions UK Limited, 2018; Watson et al., 2016). This links to the above-mentioned need for safe and clean material cycles and requires thoughtful planning at the design stage. Used materials should not be polluted by the addition of other materials and chemicals that cannot be separated at end of life. Reducing complexity and avoiding persistent chemicals, even in small quantities, is key.

From the EU policy side, there is an obligation on EU Member States for the separate collection of textile waste by 2025 (Directive (EU) 2018/851). But better collection is only one side of the coin. Once used and waste textiles have been collected it is important to respect the waste hierarchy and ensure that as much as possible is reused or recycled into other products. Article 10.4 of the WFD contains an obligation for Member States to ensure that separately collected waste is neither incinerated nor landfilled. Additionally, Art 9.d of WFD encourages the setting up of systems for repairing and reusing textiles.

Waste collection awareness campaigns could educate consumers about the importance of separate waste textile collection. Brands often try to motivate customers to return old clothes by offering reduction vouchers for new purchases, while charities communicate such aims as the provision of opportunities for disadvantaged workers or support for families in need.

Extended producer responsibility (EPR) is an instrument that has been introduced with a set of minimum requirements (Directive (EU) 2018/851) to enable more circularity for different product types such as plastics, WEEE, packaging, batteries, and end-of-life vehicles. The concept of EPR is that the cost of managing a product's end of life in an environmentally responsible way is born by the producer. Schemes can take different forms, such as take or buy backs, or a recycling programmes, and producers are allowed to delegate their responsibility to third parties. The result is that the responsibility for product end-of-life management is put upon the industry, instead of the government.

France is the only country to date to implement an EPR policy for end-of-use clothing, linen and shoes. This EPR policy has contributed to a 150 per cent increase in the collection rate of post-consumer textiles since 2007, which is estimated to be about 35 per cent of all textile waste generated in France. About 60 per cent of the collected waste is reused, although only 4 per cent is considered for high-value reuse on Western markets; about 30 per cent is recycled, mainly in south-east Asia; and 8 per cent is incinerated. The French system has, however, also had a number of challenges. The target of 50 per cent textile waste collection has not yet been reached, showing that awareness building is still needed among consumers and retailers. On the financial side, economic support is needed to sustain the system as the revenues alone are not sufficient to cover the costs of collection and sorting. At the same time, the efficiency and viability of different sorting installations is not transparent due to confidentiality issues and seems to vary significantly between installations. Additionally, a lack of recycling outlets is expected to form an obstacle to the treatment of increasing volumes, especially if exports of low-grade reusable textiles decrease (Aujollet et al., 2018).

The argument for EPR is that it facilitates collaboration between different actors and, if designed well, encourages upstream effects, such as conscious material choices and design-for-recycling efforts (EEA, 2014). If companies are given the responsibility for their textiles after their use, then they will have to make sure that they are collected and can be managed in a responsible way. In practice, this could be managed either by the companies themselves, or through others designated to set up appropriate schemes. Well-designed EPRs for textiles could both lead to better management of textile waste and to changes in the design and production of textiles in a way that improves their recyclability and the reuse of fabrics. The impact of EPR schemes under consideration, however, needs to be assessed to evaluate and ensure their effectiveness. A key challenge is that the system can face economic difficulties that can only be partly covered by a tariff collected from retailers (Bukhari et al., 2018).

Reuse as material

If clothes, household or other textile products cannot be reused, an option is to prepare the fabric for re-use. A typical application for waste clothes is to cut them up into industrial rags and cleaning cloths. Fabric reuse can also be used to upcycle products for certain niche markets. The practice of upcycling is that pre- and post-consumer waste materials are reused to create a totally new and better product, often with an artistic and original twist. Some waste textiles. For example, are combined in original combinations to redecorate old furniture. Upcycling is often done as a handicraft activity by creative individuals, but some professional designers are also embracing upcycling activities as a key approach to design of contemporary furniture and other objects. For example, in the production of children's clothing, reused fabrics, such as hotel linen and terry cloth, can offer the special advantage that they have been washed countless times, making them soft and low in residual chemicals (Stormie Poodle, 2019). Some workshops and social initiatives also create new products and accessories from reclaimed fabrics – publicity textiles, such as flags and banners for events, are readily available from event agencies and city councils and can be easily transformed into toilet bags, pencil cases and bicycle bags (Flagbag, 2019), while worn-out tarpaulins can be transformed into travel bags and backpacks (Freitag, 2019). In Europe, these initiatives often focus on local production and social employment to minimise transport and labour costs and make them viable business models. As the market price of these products is often a major barrier, the best deal is when a company buys upcycled products made from their own discarded materials.

If textile fabric reuse is not possible, then high-quality fibre recycling can be an option through yarn respinning. In order to facilitate fibre recycling, the development of smart sorting solutions for material identification is needed, as well as systems that can detect the presence of potentially hazardous chemicals. Processing mixed post-consumer textiles into homogenous fibre fractions would enable higher value recycling of the mixed material flow. Automated sorting technology, able to sort large volumes of mixed post-consumer textiles based on material composition, is being piloted and demonstrated in Europe, for example, through the EU Fibresort project. Such sorting solutions include spectrometric sensors that could be developed further for colour separation.

Another solution is to combine recycled fibres with high-quality virgin materials into a sandwich structure, consisting of two layers: one layer of 100 per cent virgin material and second layer of up to 80 per cent textile waste. Such innovative materials can replace traditional textiles in several industrial products (Toom Tekstiil, 2019). Additionally, processes are in development for the chemical recycling of cotton and polyester mixes (polycotton), in which the components are dissolved and fractionated; the cotton is turned into new viscose filaments and the polyester into new monomers (de la Motte and Palme, 2018). The global non-profit organisation Textile Exchange forecasts that 20 per cent of all polyester will be recycled by 2030 (TextileExchange, 2018).

Despite these developments, the high cost associated with fibre sorting and the limitations of mechanical and chemical recycling technologies are regarded as an obstacle to scaling up (Euratex, 2019c). The challenge for textile recycling is to turn it into a commercially viable business. Investment funding and support, backed up by legislative measures to stimulate the market demand for recycled fibres, could help to overcome this, but to generate good quality outputs even advanced sorting technologies will ultimately depend on the recyclability of products.

Some brands are marketing the use of recycled fibres as a value proposition to customers that are motivated by environmental concerns. Examples are numerous in the clothing industry, with the reuse and recycling of waste materials into new products, such as jeans or felt, closing the circle from pre-production design to end of life (BNP, 2019; HNST, 2019; Wolkat, 2019). Nonetheless both economic instruments such as GPP and such legal ones as targets for recycling and recycled content and quality requirements for recycled fibres could be used to stimulate demand and help develop a market for products made from recycled fibres (Euratex, 2019c). Markets for low-quality downcycled materials such as insulation materials will, of course, continue to exist.

Waste prevention

All the above strategies ultimately have the goal of reducing the amount of textile waste that is produced by reducing the use of resources and reusing textile products. Waste prevention involves re-thinking product design and development, waste collection, sorting and recycling (Koszewska, 2018). Awareness raising aimed at waste prevention should be combined with regulatory instruments, such as taxes or bans on incineration and landfill of reusable textile waste. Although textiles are not mentioned explicitly, a ban on landfill of separately collected waste materials is included in the revised EU Landfill Directive, implying that separately collected textile waste is not allowed to be landfilled. Also, by 2030, Member States must endeavour to ensure that all waste suitable for recycling or other recovery is not sent to landfill (EU, 2018).

Clear end-of-waste criteria for textiles would improve the management of textile waste and open up possibilities for the production of valuable recycled materials for further use. Since textiles are often complex and made up of different fibre types, clear definitions are needed to define when a textile waste ceases to be waste (Euratex, 2019c).

5 Conclusions

Textiles play an important role in European manufacturing industry, trade and retail, contributing considerably to economic growth and job creation within Europe and abroad. On the other hand, European textile production and consumption patterns generate significant and growing negative environmental and social impacts in Europe and other regions of the world. These include wasteful resource use, ecosystem pollution through eutrophication and the dispersal of hazardous chemicals, contributions to climate change and competition for land and water. Since a large share of textile production occurs outside Europe, with little transparency on where and how products are produced, most environmental and social pressures remain invisible to the European consumer.

Textiles production, labelling and marketing in Europe is regulated through EU and national legislation (EC, 2019b). An elaborate body of EU policy instruments is already in place to encourage and enforce sustainable textile production in Europe, such as the REACH regulation, the Industrial Emissions Directive (IED), the Ecodesign Directive, EU ecolabelling, etc. Furthermore, the 2018 revision of the EU WFD includes an obligation to separately collect textiles by 2025 (EC, 2019a). Nevertheless, the challenge we face today is that the system of production and consumption of textiles is still a largely linear one. Fibres are almost completely made from virgin feedstock, from both natural and fossil resources. Production trends have evolved towards fast-moving fashion products with an increasing share of synthetic and mixed fabrics. Consumption trends show a tendency towards more and cheaper products with shorter lifetimes. Reuse of textile products is limited, especially within Europe. Most used textiles are exported for reuse outside Europe or for recycling into lower-value applications. High-quality recycling is virtually non-existent. A large share of used textiles is still incinerated or landfilled.
Its linear value chain makes the textiles value chain one of the most polluting and resource-intensive production and consumption systems, especially in the production and use phase.

Materials and water depletion, land use, climate change and chemicals' toxicity are only some of the environmental impacts to which the textiles sector contributes significantly. Among all consumption domains in the EU, consumption of clothing, footwear and household textiles is the fourth highest pressure category for primary raw materials use and for water use, after food, housing and transport, and the fifth highest for greenhouse gas emissions. The land area used to produce the textiles consumed in Europe, mainly cotton, is exceeded only by that for food production. The vast majority of the pressures and impacts related to the consumption of clothing, footwear and household textiles in Europe are generated in other regions of the world, where most of the production takes place. This is the case for 85 per cent of primary raw materials used, 92 per cent of the water used, 93 per cent of the land used and 76 per cent of greenhouse gas emissions.

From these figures it is clear that fibre cultivation for textiles potentially competes with food production or other industrial crops for arable land, leading to increasing deforestation, food scarcity and malnutrition. Apart from greenhouse gas emissions and climate change, pollution caused by fertiliser use during cultivation and the use of hazardous chemicals during processing is an important threat to ecosystem health and biodiversity. Additionally, it is estimated that more than half a million tonnes of microplastics are annually discharged into the world's oceans as a result of washing of plastic-based textile products (Ellen MacArthur Foundation, 2017).

Currently, many efforts are still being made to further optimise of the current linear system. A shift to a circular system for textiles requires a fundamental systemic change throughout the whole value chain of textiles supported by adequate policies. Not only is technological innovation needed to improve efficiency and reduce environmental impacts, but profound social innovation and advancement in terms of working conditions, equality and social justice are also needed, as well as a change to new business models and policies and the provision of better information that enables and encourages consumers to make sustainable choices.

Everything starts with the material and design choices made. These choices greatly affect product lifetimes and reparability and the potential for creating safe product and material cycles at the end-of-life phase. The phasing out of substances of concern is a key precondition, requiring adequate regulation and control.

A change in the attitude of both consumers and producers towards durability, repair, reuse and recycling is key for generating the environmental and economic benefits that circularity entails. New circular business models can play an important role in making sustainable choices more attractive. Service-based models, such as the leasing of clothing or carpets, can encourage more durable and repairable designs or the use of recyclable materials. Transparent labelling can also enable consumers to make more sustainable choices and gives recyclers vital information. It is essential to organise the effective collection of used textiles, together with high-performing sorting procedures and processing technologies to support product reuse and fibre recycling. The development of well-functioning markets for used textile products and recycled fibres is a key challenge.

The EU’s prioritisation of textiles in developing a circular economy would be instrumental in capturing the economic, social, environment and climate benefits of a circular system for textiles. Circular solutions can be supported by regulation and policy options addressing materials and design, production and distribution, use and reuse, collection and recycling. By implementing suitable policy instruments, authorities and the public sector can play an important role in supporting innovation, upscaling circular initiatives and designing new business models, while phasing out current unsustainable practices. This can be done by introducing economic and other incentives, such as, for example, EPR schemes, circular public procurement procedures and tax or VAT reductions to promote sustainable choices. In addition, the transition to a circular system for textiles could be accelerated by deploying policies aimed at technological and business model innovation, such as R&D subsidies, training programmes and investment support for SMEs. Voluntary action by the textile industry itself should also be promoted, as these encourage stakeholders to collaborate across the entire value chain.

Apart from incentives, regulatory action is also needed to enforce quality, safety and durability standards, circular design requirements, and to establish value chain transparency and traceability. At the end-of-life stage, separate textile waste collection targets, policies on the waste trade and bans on incineration and landfill would support the development of reuse and recycling.

Annex

The global distribution of pressures and effects related to final the consumption of textile products have been calculated using an extended multiregional input model based on EXIOBASE v.3.4 data (Stadler et al., 2018). For this purpose, environmentally extended product-by-product tables were used. The calculation started from the following identities:

$$x = A \cdot x + y \qquad (1)$$

where *x* is the total output vector, *A* the matrix of direct input coefficients (or matrix of technological coefficients), and *y* is the final demand vector. Solving the model for output gives (Miller and Blair, 2009):

$$x = (I - A)^{-1} \cdot y = L \cdot y \qquad (2)$$

where *I* is the identity matrix, and *L* the Leontief inverse also known as the multiplier matrix or matrix of direct and indirect output requirements per unit produced for final demand. The Leontief model implies the following assumptions: prices are fixed in the short term, input coefficients are constant regardless of output or final demand level changes, structure of the economy is taken to be constant, at least in the reported period.

The direct environmental effects of national production are the result of the sum of the direct effects associated with each unit produced in each industry:

$$e^T = \sum_1^n e_i = \sum_1^n e_i^{int} \cdot x_n = < e^{int} > \cdot \, x \qquad (3)$$

By multiplying the environmental pressure per output unit (measured in physical units per Euro worth of output) by the total output of each industry (measured in Euro), defined by equation (2), an environmentally extended input-output model is created:

$$e^T = < e^{int} > \cdot \, x = < e^{int} > \cdot \, (I - A)^{-1} \cdot y \qquad (3)$$

where e^T is the vector of total environmental pressures associated with the corresponding amounts of the products groups finally used (vector *y*) and e^{int} the environmental pressure intensity vector. Each element of e^{int} represents the amount of the environmental pressure directly caused by the production of a product group. Each element of e^{int} in Exiobase is allocated to a region, which allows to derive the EU-28 share of generated gross value added, employment, raw material use, water use, land use and greenhouse gas emissions in the total footprint.

In Figures 2.5, 2.6, 3.2, 3.3, 3-4 and 3.5 we combined the 2011 Exiobase data with 2017 household consumption data from Eurostat.

References

Aets, 2016, *Study on the responsible management of the supply chain in the garment sector* (https://ec.europa.eu/europeaid/study-responsible-management-supply-chain-garment-sector_en) accessed 21 February 2019.

Andersson, J., et al., 2018, *Is apparel manufacturing coming home?*, McKinsey & Company (https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/is%20apparel%20manufacturing%20coming%20home/is-apparel-manufacturing-coming-home_vf.ashx) accessed 4 March 2019.

Armstrong, C. M., et al., 2015, 'Sustainable product-service systems for clothing: exploring consumer perceptions of consumption alternatives in Finland', *Journal of Cleaner Production* 97, pp. 30-39 (DOI: 10.1016/j.jclepro.2014.01.046).

Aujollet, Y., et al., 2018, *Avenir de la filière REP de gestion des déchets de textiles, linge de maison et chaussures (TLC)* (https://www.economie.gouv.fr/files/files/directions_services/cge/Rapports/Rap2017/CGE_R2017-25_FiliereREPdechetsTLC.pdf) accessed 10 April 2019.

Bain, M., 2018, 'The high-tech future of fashion manufacturing', Quartz (https://qz.com/1356087/the-high-tech-future-of-fashion-manufacturing/) accessed 2 April 2019.

Bauer, B., et al., 2018a, *Ecodesign Requirements for Textiles and Furniture.*, Nordic Council of MInisters, Copenhagen (https://norden.diva-portal.org/smash/get/diva2:1210007/FULLTEXT01.pdf) accessed 10 April 2019.

Bauer, B., et al., 2018b, *Potential Ecodesign Requirement for Textiles and Furniture* (http://norden.diva-portal.org/smash/get/diva2:1221509/FULLTEXT01.pdf).

Beasley, J. and Georgeson, R., 2014, *Advancing resource efficiency in Europe. Indicators and waste policy scenarios to deliver a resource efficient and sustainable Europe*, European Environmental Bureau, Brussels (https://makeresourcescount.eu/wp-content/uploads/2014/11/FINAL_Advancing-Resource-Efficiency-in-Europe_PUBL.pdf) accessed 13 February 2019.

BNP, 2020, 'BNP Brinkmann' (http://www.bnp-brinkmann.de/) accessed 15 June 2020.

BOF and McKinsey, 2017, '10 Trends That Will Define the Fashion Agenda in 2018 | Intelligence | BoF', Business of Fashion (BOF) (https://www.businessoffashion.com/articles/intelligence/10-trends-that-will-define-the-fashion-agenda-in-2018) accessed 13 February 2019.

Bomgardner, M., 2018, 'These new textile dyeing methods could make fashion more sustainable.', *Chemical & Engineering News* 96(29).

Brooks, A., 2015, *Clothing Poverty. The hidden world of fast fashion and second-hand clothes.*, Zed Books, London.

Buchel, S., et al., 2018, *The transition to good fashion*, DRIFT (https://drift.eur.nl/wp-content/uploads/2018/11/FINAL_report.pdf) accessed 26 September 2019.

Bukhari, M. A., et al., 2018, 'Developing a national programme for textiles and clothing recovery', *Waste Management & Research* 36(4), pp. 321-331 (DOI: 10.1177/0734242X18759190).

Business Beyond Borders, 2017, 'Road to Texworld: 10 facts about the EU textile industry' (http://www.businessbeyondborders.info/road-to-paris-10-facts-about-the-eu-textile-industry/) accessed 6 May 2019.

Carney Almroth, B., et al., 2018, 'Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment', 25(2), pp. 1191-1199.

CBI, 2018, 'Which trends present opportunities and threats on the European apparel market? | CBI - Centre for the Promotion of Imports from developing countries' (https://www.cbi.eu/market-information/apparel/trends) accessed 13 February 2019.

CBRE, 2013, *How we shop - inside the minds of Europe's consumers*, CBRE (http://nrw.nl/wp-content/uploads/2015/02/CBRE-How-we-shop-inside-the-minds-of-europes-consumers-2013.pdf) accessed 13 February 2019.

Chapagain, A. K., et al., 2006, 'The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries', *Ecological Economics* 60(1), pp. 186-203 (DOI: 10.1016/j.ecolecon.2005.11.027).

Circular Fashion, 2019, 'Design for longevity' (https://www.greenstrategy.se/circular-fashion/key-principles-of-circular-fashion/) accessed 27 September 2019.

Clevercare, 2019, 'How to reduce climate impact, effort and money caring for fashion the clever way.', How to reduce climate impact, effort and money caring for fashion the clever way. (http://www.clevercare.info/en) accessed 9 March 2019.

Common Objective, 2019, Fibre Briefing: Polyester, (https://www.commonobjective.co/article/fibre-briefing-polyester) accessed 24 September 2019.

de Campos Ventura-Camargo, B. and Aparecida Marin-Morales, M., 2013, 'Azo Dyes: Characterization and Toxicity– A Review', *Textiles and Light Industrial Science and Technology (TLIST)* 2(2).

De Kringwinkel, 2017, *De Kringwinkelsector in 2017* (https://www.dekringwinkel.be/imgv2/documenten_9999/2017SectorrapportKringwinkels.pdf) accessed 6 May 2019.

De Kringwinkel, 2019, Thrift shop sales.

de la Motte, H. and Palme, A., 2018, *The development of the Blend Re:wind process* (http://mistrafuturefashion.com/wp-content/uploads/2018/06/Mistra-Future-Fashion-2018-5-H.-dl.-Motte.-Blend-Re-wind.pdf) accessed 22 April 2019.

Desso, 2019, 'Carpet Leasing' (http://www.desso-businesscarpets.com/services/carpet-leasing/) accessed 17 June 2019.

EC, 2009, 'Consumers: EU to ban dimethylfumarate (DMF) in consumer products, such as sofas and shoes (press release)', European Commission (http://europa.eu/rapid/press-release_IP-09-190_en.htm) accessed 5 June 2019.

EC, 2011, *Green public procurement — textiles — technical background report*, European Commission Directorate-General for Environment, Brussels (https://ec.europa.eu/environment/gpp/pdf/tbr/textiles_tbr.pdf).

EC, 2017, Commission Staff Working Document — sustainable garment value chains through EU development action, (https://ec.europa.eu/europeaid/staff-working-document-sustainable-garment-value-chains-through-eu-development-action_en) accessed 21 February 2019.

EC, 2019a, 'Smart regional investments in textile innovation', European Commission (https://s3platform.jrc.ec.europa.eu/textile-innovation) accessed 10 January 2019.

EC, 2019b, Sustainable products in a circular economy — towards an EU product policy framework contributing to the circular economy (SWD(2019) 92 final).

EC, 2019c, 'Textiles and clothing industries', European Commission (https://ec.europa.eu/growth/sectors/fashion/textiles-clothing/).

ECHA, 2019, 'Clothes and textiles' (https://chemicalsinourlife.echa.europa.eu/clothes-and-textiles) accessed 5 June 2019.

Ecopreneur.eu, 2019, *Circular Fashion Advocacy. A strategy towards a circular fashion industry in Europe.* (https://ecopreneur.eu/wp-content/uploads/2019/03/EcoP-Circular-Fashion-Advocacy-Report-28-3-19.pdf) accessed 6 May 2019.

EEA, 2014, *Environmental indicator report 2014*, European Environment Agency (http://www.eea.europa.eu/publications/environmental-indicator-report-2014).

EEA, 2016, *Circular economy in Europe — Developing the knowledge base*, EEA Report No 2/2016, European Environment Agency (https://www.eea.europa.eu/publications/circular-economy-in-europe).

EEA, 2017, *Circular by design — products in the circular economy*, EEA Report No 6/2017, European Environment Agency (https://www.eea.europa.eu/publications/circular-by-design) accessed 25 September 2018.

EEA, 2018, *Waste prevention in Europe — policies, status and trends in reuse in 2017*, EEA Report No 4/2018, European Environment Agency (https://www.eea.europa.eu/publications/waste-prevention-in-europe-2017) accessed 5 June 2019.

Elander, M., et al., 2017a, *Evaluation of business models for increased reuse, collective use and prolonged life time of textiles.* (http://mistrafuturefashion.com/wp-content/uploads/2017/11/Mistra-report-D3.3.3.1.-Evaluation-of-business-models.pdf).

Elander, M., et al., 2017b, *Impact assessment of policies promoting fiber-to-fiber recycling of textiles*.

Ellen MacArthur Foundation, 2017, Circular Fashion - A New Textiles Economy: Redesigning fashion's future, (https://www.ellenmacarthurfoundation.org/publications/a-new-textiles-economy-redesigning-fashions-future) accessed 5 February 2019.

Ellen MacArthur Foundation, 2019, 'Make Fashion Circular launches the Jeans Redesign', 16 July 2019 (https://www.ellenmacarthurfoundation.org/news/make-fashion-circular-launches-the-jeans-redesign) accessed 27 September 2019.

Eriksson, U., 2019, Ecolabel Svanen.

EU, 2018, Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste (OJ L 150, 14.6.2018, p. 100-108).

Eunomia, 2015, *The Potential contribution of waste management to a low carbon economy* (https://zerowasteeurope.eu/downloads/the-potential-contribution-of-waste-management-to-a-low-carbon-economy/).

Euratex, 2019a, 'Cross Industry Agreement' (https://euratex.eu/cia/) accessed 10 April 2019.

Euratex, 2019b, Key Figures 2018 - The EU-28 Textile and Clothing Industry in the year 2018, (https://euratex.eu/wp-content/uploads/2019/05/EURATEX-KEY-FIGURES-2018.pdf) accessed 14 June 2019.

Euratex, 2019c, *Prospering in the circular economy* (https://euratex.eu/wp-content/uploads/2019/01/EURATEX_CE_policy_brief_LR.pdf) accessed 30 September 2019.

Eurostat, 2019a, 'EU trade since 1988 by HS2-HS4' (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=DS-016894&lang=en) accessed 28 October 2019.

Eurostat, 2019b, 'HICP (2015 = 100) - annual data (average index and rate of change)' (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=prc_hicp_aind) accessed 28 January 2019.

Eurostat, 2019c, 'Total production by PRODCOM list (NACE Rev. 2) - annual data [DS-066342]' (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=DS-066342&lang=en) accessed 10 April 2019.

Eurostat, 2020, 'Final consumption expenditure of households by consumption purpose (COICOP 3 digit)', Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_co3_p3&lang=en) accessed 27 October 2020.

Farrant, L., et al., 2010, 'Environmental benefits from reusing clothes', *The International Journal of Life Cycle Assessment* 15(7), pp. 726-736 (DOI: 10.1007/s11367-010-0197-y).

Fashion Revolution, 2018, *Consumer Survey Report*, Fashion Revolution (https://www.fashionrevolution.org/wp-content/uploads/2018/11/201118_FashRev_ConsumerSurvey_2018.pdf) accessed 13 February 2019.

Finansdepartementet Skatte- och tullavdelningen, 2015, *Skattefrihet för ideell second hand-försäljning* (https://www.regeringen.se/rattsliga-dokument/departementsserien-och-promemorior/2015/05/skattefrihet-for-ideell-second-hand-forsaljning/).

Flagbag, 2019, 'Bags from flags' (http://flagbag.be/) accessed 17 June 2019.

Freitag, 2019, 'Freitag' (https://www.freitag.ch/en) accessed 17 June 2019.

Gam, H. J., et al., 2011, 'Application of design for disassembly in men's jacket: A study on sustainable apparel design', *International Journal of Clothing Science and Technology* 23(2-3), pp. 83-94 (DOI: DOI 10.1108/09556221111107289).

Gittleson, K., 2018, 'Used clothes: Why is worldwide demand declining?', 31 January 2018 (https://www.bbc.com/news/business-42777804) accessed 10 April 2019.

Global Fashion Agenda, 2019, *CEO Agenda 2019* (https://www.globalfashionagenda.com/ceo-agenda-2019/#) accessed 6 May 2019.

Global Fashion Agenda and Boston Consulting Group, 2017, *Pulse of the fashion industry 2017* (https://www.globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf) accessed 4 November 2019.

Goworek, H., et al., 2013, 'Consumers' attitudes towards sustainable fashion — clothing usage and disposal', in: *Sustainability in fashion and textiles: Values, design, production and consumption*, Greenleaf, Sheffield, UK.

Gray, S., 2017, *Mapping clothing impacts in Europe: the environmental cost*, WRAP, Banbury (http://www.ecap.eu.com/wp-content/uploads/2018/07/Mapping-clothing-impacts-in-Europe.pdf).

Gunther, M., 2016, 'Fast Fashion Fills Our Landfills', JSTOR Daily (https://daily.jstor.org/fast-fashion-fills-our-landfills/) accessed 13 February 2019.

Gwozdz, W., et al., 2017, 'An Environmental Perspective on Clothing Consumption: Consumer Segments and Their Behavioral Patterns', *Sustainability* 9(762) (DOI: 10.3390/su9050762).

HNST, 2020, 'Premium jeans, radicaal anders.' (https://www.letsbehonest.eu/) accessed 15 June 2020.

House of Commons, 2019, *Fixing fashion: clothing consumption and sustainability* (https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/1952/1952.pdf) accessed 10 April 2019.

Hvass, K. K. and Pedersen, E. E. G., 2019, 'Toward circular economy of fashion', *Journal of Fashion Marketing and Management* 23(3), pp. 345-365 (DOI: https://doi.org/10.1108/JFMM-04-2018-0059).

ICAC, 2019, Facts on global fiber consumption trend 1960-2016.

ILO, 2018, Clear Cotton. Eliminating Child Labour and Forced Labour in the Cotton, Textile and Garment Value Chains: An Integrated Approach, (https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---ipec/documents/publication/wcms_650172.pdf) accessed 21 February 2019, International Labour Organization.

Interface, 2019, 'Interface website' (https://www.interface.com/) accessed 17 June 2019.

Johnson, M. R. and McCarthy, I. P., 2014, 'Product recovery decisions within the context of Extended Producer Responsibility - ScienceDirect', *Journal of Engineering and Technology Management* 34, pp. 9-28.

JRC, 2014, *Environmental improvement potential of textiles (IMPRO-Textiles)*, JRC Scientific and Technical Reports, Joint Research Centre, Ispra, Italy.

Kant, R., 2012, 'Textile dyeing industry an environmental hazard', *Natural Science* 4(1), pp. 22-26 (DOI: 10.4236/ns.2012.41004).

Kassan, J. and Orsi, J., 2012, 'The Legal Landscape of the Sharing Economy', *Journal of Environmental Law & Litigation* 27(1).

Katende - Magezi, E., 2017, *The Impact of Second Hand Clothes and Shoes in East Africa*, CUTS International, Geneva (http://www.cuts-geneva.org/pdf/PACT2-STUDY-The_Impact_of_Second_Hand_Clothes_and_Shoes_in_East_Africa.pdf) accessed 24 March 2020.

KEMI, 2014, *Chemicals in textiles – Risks to human health and the environment*, No 6/14, Swedish Chemicals Agency, Stockholm (https://www.kemi.se/files/8040fb7a4f2547b7bad522c399c0b649/report6-14-chemicals-in-textiles.pdf) accessed 10 April 2019.

Kooistra, K. and Termorshuizen, A., 2006, 'The sustainability of cotton: consequences for man and environment.', *Report 223, Wageningen University*.

Koszewska, M., 2018, 'Circular economy - challenges for the textile and clothing industry', *Autex Research Journal* 18(4), pp. 337-347 (DOI: 10.1515/aut-2018-0023).

Kotthoff, M., et al., 2015, 'Perfluoroalkyl and polyfluoroalkyl substances in consumer products', *Environmental Science and Pollution Research* 22(19), pp. 14546-14559 (DOI: 10.1007/s11356-015-4202-7).

Lehmann, M., et al., 2018a, *Pulse of the fashion industry 2018*, Global Fashion Agenda and Boston Consulting Group (https://www.peta.org.uk/wp-content/uploads/2019/03/Pulse_of_the_fashion_industry_report_2018-1.pdf) accessed 29 September 2021.

Lehmann, M., et al., 2018b, *Pulse of the Fashion Industry*, Global Fashion Agenda (https://www.globalfashionagenda.com/initiatives/pulse/#).

Lindström, 2019, 'New ways to recycle' (https://lindstromgroup.com/article/new-ways-to-recyclee/) accessed 17 June 2019.

Ljungkvist, H., et al., 2018, *Developments in global markets for used textiles and implications for reuse and recycling* (http://mistrafuturefashion.com/wp-content/uploads/2018/09/Mistra-Future-Fashion-2018.04-M-Elander-D.3.3.4.1.pdf) accessed 10 April 2019.

Luginbühl, C. and Musiolek, B., 2014, *Stitched up: poverty wages for garment workers in Eastern Europe and Turkey*, Clean Clothes Campaign (https://cleanclothes.org/resources/publications/stitched-up-1) accessed 21 February 2019.

Luongo, G., et al., 2015, 'The washout effect during laundry on benzothiazole, benzotriazole, quinoline, and their derivatives in clothing textiles', *Environmental Science and Pollution Research* 23(3) (DOI: DOI: 10.1007/s11356-015-5405-7).

Madhu, A. and Chakraborty, J. N., 2017, 'Developments in application of enzymes for textile processing', *Journal of Cleaner Production* 145, pp. 114-133 (DOI: 10.1016/j.jclepro.2017.01.013).

Magretta, J., 2002, 'Why Business Models Matter', *Harvard Business Review*, 1 May 2002 (https://hbr.org/2002/05/why-business-models-matter) accessed 1 October 2019.

Mastercard, 2017, *Masterindex 2017: Pan-European e-commerce and new payment trends*, Mastercard (https://newsroom.mastercard.com/wp-content/uploads/2017/03/Masterindex-2017.pdf) accessed 13 February 2019.

Miller, R. E. and Blair, P. D., 2009, *Input output analysis foundations and extensions*, Cambridge University Press, Cambridge, UK.

Morley, N., et al., 2006, *Recycling of Low Grade Clothing Waste* (https://www.oakdenehollins.com/reports/2006/11/1/recycling-of-low-grade-clothing-waste) accessed 6 May 2019.

Mugge, R., et al., 2005, 'Product Attachment and Product Lifetime: the Role of Personality Congruity and Fashion', *European Advances in Consumer Research* 7, pp. 460-467 (DOI: 10.2752/146069205789331637).

News24, 2018, 'Locals lose out in Rwanda's second-hand clothes war', 7 January 2018 (https://www.news24.com/Africa/News/locals-lose-out-in-rwandas-second-hand-clothes-war-20180701) accessed 10 April 2019.

Norström, K., 2018, 'Highly fluorinated substances (PFAS) in the Baltic Sea environment', 9 May 2018.

Nova Institut, 2021, *Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2020-2025* (http://bio-based.eu/downloads/bio-based-building-blocks-and-polymers-global-capacities-production-and-trends-2020-2025/).

OECD, 2018, *Business Models for the Circular Economy: Opportunities and Challenges from a Policy Perspective* (https://www.oecd.org/environment/waste/policy-highlights-business-models-for-the-circular-economy.pdf).

Osterwalder, A., et al., 2005, 'Clarifying Business Models: Origins, Present, and Future of the Concept', *Communications of the Association for Information Systems* 16 (DOI: 10.17705/1CAIS.01601).

OVAM, 2019, *Circulaire economie en de Vlaamse klimaatdoelstellingen. Voedings- en textielsysteem.*

Palm, D., et al., 2013, *Livscykelanalys av svensk textilkonsumtion. Underlagsrapport till Naturvårdsverkets regeringsuppdrag om nya etappmål (in Swedish).*, No IVL Rapport B2133. NV-00336-13. Bilaga 1. (http://www.ivl.se/sidor/publikationer/publikation.html?id=3114 .) accessed 2 May 2016.

Palm, D., et al., 2014, *Towards a Nordic textile strategy: collection, sorting, reuse and recycling of textiles*, Nordic Council of Ministers, Copenhagen, Denmark.

Palme, A., et al., 2017, 'Development of an efficient route for combined recycling of PET and cotton from mixed fabrics', *Textiles and Clothing Sustainability* 3(4), p. 9 (DOI: 10.1186/s40689-017-0026-9).

Paras, M. K., et al., 2018, 'An Exploratory Study of Swedish Charities to Develop a Model for the Reuse-Based Clothing Value Chain', *Sustainability* 10(4), p. 1176 (DOI: 10.3390/su10041176).

Pitkänen, T., 2019, Industrial recycling of blends.

Post-couture Collective, 2019, 'Post-couture Collective' (www.postcouture.cc) accessed 15 April 2019.

Quantis, 2018, Measuring Fashion: Insights from the Environmental Impact of the Global Apparel and Footwear Industries study., (https://quantis-intl.com/measuring-fashion-report-2018/).

Recover, 2019, 'Recover' (https://www.recovertex.com/products/) accessed 10 March 2019.

Remy, N., et al., 2016, 'Style that's sustainable: A new fast-fashion formula | McKinsey' (https://www.mckinsey.com/business-functions/sustainability/our-insights/style-thats-sustainable-a-new-fast-fashion-formula) accessed 13 February 2019.

Rengel, A., 2017, *Recycled Textile Fibres and Textile Recycling*, Federal Office for the Environment (FOEN) (https://www.bafu.admin.ch/).

Richardson, J., 2008, 'The business model: an integrative framework for strategy execution', *Strategic Change* 17(5-6), pp. 133-144 (DOI: 10.1002/jsc.821).

Ridoutt, B., et al., 2019, 'An LCA impact assessment model linking land occupation and malnutrition-related DALYs', *The International Journal of Life Cycle Assessment* (DOI: 10.1007/s11367-019-01590-1).

Rissanen, T., 2011, 'How can fashion designers make clothes less disposable?', Ecouterre (http://www.ecouterre.com/how-can-fashion-designers-make-clothes-less-disposable/) accessed 8 July 2014.

RREUSE, 2016, *RREUSE response to the European Commission's Circular Economy Package Proposals* (http://www.rreuse.org/wp-content/uploads/RREUSE-response-to-CEP-FINAL-28.4.2016.pdf).

Rusinek, M. J., et al., 2018, 'Blockchain for a Traceable, Circular Textile Supply Chain: A Requirements Approach', *Software Quality Professional*, 2018.

SAC, 2014, 'The Higg index' (http://www.apparelcoalition.org/higgindex/) accessed 6 January 2014.

SAC, 2019, *Empowering consumers through transparency* (http://apparelcoalition.org/wp-content/uploads/2019/07/Research-Report-Empowering-Consumers-through-Transparency.pdf) accessed 10 April 2019.

Šajn, N., 2019, *Environmental impact of the textile and clothing industry. What consumers need to know*, European Parliamentary Research Service (http://www.europarl.europa.eu/RegData/etudes/BRIE/2019/633143/EPRS_BRI(2019)633143_EN.pdf) accessed 13 February 2019.

Sandin, G. and Peters, G., 2018, 'Environmental impact of textile reuse and recycling - A review', *Journal of Cleaner Production* 184, pp. 353-365.

Schmidt, A., et al., 2016, *Gaining benefits from discarded textiles LCA of different treatment pathways*, TeemaNord No 537 (https://norden.diva-portal.org/smash/get/diva2:957517/FULLTEXT02.pdf).

Sinha, P. and Hussey, C., 2009, *Product labelling for improved end-of-life management*, Centre for Remanufacturing and Reuse, Aylesbury, UK.

SITRA and Circle Economy, 2015, *Service-based business models & circular strategies for textiles* (https://s3-eu-west-1.amazonaws.com/stjm/20160330092502/Service-based-business-models-and-circular-strategies-for-textiles-2015-SITRA-STJM.pdf) accessed 4 September 2019.

Skills4Smart, 2019, 'Skills 4 Smart TCLF 2030' (www.s4tclfblueprint.eu/) accessed 10 April 2019.

Stadler, K., et al., 2018, 'Exiobase 3: developing a time series of detailed environmentally extended multi-regional input-output tables', *Journal of Industrial Ecology* 22(3), pp. 502-515 (DOI: https://doi.org/10.1111/jiec.12715).

Stormie Poodle, 2019, 'Saving the planet in style' (https://stormiepoodle.com/) accessed 17 June 2019.

Suikkanen, J. and Nissinen, 2017, *Circular Economy and the Nordic Swan Ecolabel*, TemaNord No 2017:553 (http://norden.diva-portal.org/smash/get/diva2:1142769/FULLTEXT01.pdf) accessed 6 May 2019.

Svengren Holm, L. and Holm, O., 2010, 'Sustainable fashion - a driver for new business models.', *The Nordic Textile Journal* 1, pp. 30-39.

Swedish Chemical Agency, 2013, *Hazardous chemicals in textiles — report of a government assignment*, No 3/13, Swedish Chemical Agency, Stockholm (https://www.kemi.se/global/rapporter/2013/rapport-3-13-textiles.pdf).

TextileExchange, 2018, *Preferred fiber & materials Market Report 2017* (https://textileexchange.org/downloads/2017-preferred-fiber-materials-market-report/).

TextileToday, 2018, 'Consumer behaviour, fast fashion, and sustainability', TextileToday (https://www.textiletoday.com.bd/consumer-behaviour-fast-fashion-sustainability/) accessed 13 February 2019.

TextileToday, M., 2016, 'World technical textile consumption to reach 42.2 million metric tons by 2020' (https://www.textiletoday.com.bd/world-technical-textile-consumption-reach-42-2-million-metric-tons-2020/) accessed 4 October 2019.

The Guardian, 2015, 'Reliving the Rana Plaza factory collapse: a history of cities in 50 buildings, day 22', *The Guardian*, 23 April 2015 (https://www.theguardian.com/cities/2015/apr/23/rana-plaza-factory-collapse-history-cities-50-buildings) accessed 10 April 2019.

Toffler, A., 1980, *The third wave*, Morrow, New York.

Toom Tekstiil, 2019, 'Recycling' (http://www.toomtekstiil.ee/en/collections/recycling/) accessed 4 November 2019.

Turley, D. B., et al., 2009, *The role and business case for existing and emerging fibres in sustainable clothing: final report to the Department for Environment, Food and Rural Affairs (Defra)*, London, UK.

UNECE, 2017, *Transparency in textile value chains in relation to the environmental, social and human health impacts of parts, components and production processes.*, The United Nations Economic Commission for Europe. (https://www.unece.org/fileadmin/DAM/uncefact/UNECE_Research_Paper_Traceability_for_Sustainable_Clothing_Nov_2017_FINAL.pdf) accessed 10 April 2019.

van der Putte, I., et al., 2013, *Study on the Link Between Allergic Reactions and Chemicals in Textile Products* (https://ec.europa.eu/docsroom/documents/10481/attachments/1/translations/en/renditions/pdf) accessed 10 April 2019.

Vehmas, K., et al., 2018, 'Consumer attitudes and communication in circular fashion', *Journal of Fashion Marketing and Management:An International Journal* 22(3), pp. 286-300 (DOI: https://doi.org/10.1108/JFMM-08-2017-0079).

Vezzoli, C., et al., 2018, *Designing Sustainable Energy for All*, Springer International Publishing, Cham.

Von der Leyen, U., 2019, *A Union that strives for more — my agenda for Europe — political guidelines for the next European Commission 2019-2024.*, European Commission, Brussels (https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf) accessed 10 April 2019.

Water Footprint Network, 2017, 'Guiding farmers toward sustainable cotton production. Managing the water footprint on cotton farms.', 2017.

Watson, D., et al., 2015, *EPR-systems and new business models. Part II: Policy packages to increase reuse and recycling of textiles in the Nordic region.*

Watson, D., et al., 2016, *Exports of Nordic Used Textiles. Fate, benefits and impacts*, Tema Nord No 558, Nordic Council of Ministers (http://norden.diva-portal.org/smash/get/diva2:1057017/FULLTEXT03.pdf).

Watson, D., et al., 2017a, *Business Models Extending Active Lifetime of Garments Supporting Policy instruments.* (http://mistrafuturefashion.com/wp-content/uploads/2018/04/Mistra-report-3.2.4-Policies-for-Supporting-New-Business-Models.pdf).

Watson, D., et al., 2017b, *Textile-to-textile production*, Nordic Council of Ministers (http://www.diva-portal.org/smash/get/diva2:1147645/FULLTEXT01.pdf) accessed 10 March 2019.

Watson, D., et al., 2018, *Used textile collection in European cities. Study commissioned by Rijkswaterstaat under the European Clothing Action Plan (ECAP)* (http://www.ecap.eu.com/wp-content/uploads/2018/07/ECAP-Textile-collection-in-European-cities_full-report_with-summary.pdf).

Wijnia, G., 2016, *Mapping obsolete inventory in the Dutch apparel industry. A qualitative and quantitative analysis of discounted and unsold volumes in apparel. MSc Thesis.*, Wageningen University (https://www.circulairondernemen.nl/uploads/533f4c3f41690f93c32556361f9f30c4.pdf) accessed 9 December 2019.

Wolkat, 2020, 'Circulaire Textiel Recycling' (http://wolkat.com/) accessed 15 June 2020.

Wood Environment & Infrastructure Solutions UK Limited, 2018, *Safe Chemicals Innovation Agenda* (https://www.chemischestoffengoedgeregeld.nl/sites/default/files/39982%20-%20Safe%20Chemicals%20Innovation%20Agenda%20-%2020180613i6%20final%20copy.pdf).

WRAP, 2012, *Valuing our clothes: the true cost of how we design, use, and dispose of clothing in the UK*, Waste and Resources and Action Programme, Banbury, UK.

WRAP, 2019, *Fibre to fibre recycling: An economic & financial sustainability assessment* (http://www.wrap.org.uk/sites/files/wrap/Fibre_to_Fibre_report.pdf).

Zamani, B., et al., 2017, 'Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion?', *Journal of Cleaner Production* 162, pp. 1368-1375 (DOI: 10.1016/j.jclepro.2017.06.128).

Zhang, Y., et al., 2018, 'Improved design for textile production process based on life cycle assessment', *Clean Technologies and Environmental Policy* 20(6), pp. 1355-1365 (DOI: 10.1007/s10098-018-1572-9).

Zimniewska, M., et al., 2016, *Towards a 4th Industrial Revolution of Textiles and Clothing. A Strategic Innovation and Research Agenda for the European Textile and Clothing Industry*, Textile ETP, Brussels, Belgium (http://www.textile-platform.eu/home/2016/10/17/new-strategic-innovation-and-research-agenda-released.html) accessed 13 February 2019.

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