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Plastic in textiles: potentials for circularity and reduced environmental and climate impacts

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1 Introduction

It is hard to imagine a world without plastics, yet the large-scale production and use of plastics only started in the 1950's. But despite the fact that they are fairly new raw materials, their versatile and unique properties and multitude of applications, including in textiles, have led to the production of more than 8 billion tonnes of plastics worldwide over the past 70 years (Geyer et al., 2017).

Over the last 20 years, there has been a great increase in the use of synthetic, plastic-based fibres in textile production, and expectations are that both shares and absolute volumes will increase further (Textile Exchange, 2019). Today these synthetic textiles are part of everyday life; they literally surround us. in the clothes we wear and the bed sheets we sleep in; we use them to decorate our homes as furniture and cushion covers, as curtains and carpets. And often they are present without us knowing, less visible as reinforcements in car tyres and sports gear. The 2019 EEA Briefing and European Topic Centre (ETC) report *Textiles and the environment in a circular economy* found that globally about 60 % of textiles are made of fibers based on synthetic polymers (EEA, 2019; ETC/WMGE, 2019b). While the majority of these is produced and processed in Asia, Europe stands out as the world's largest importer of synthetic fibre by trade value (Birkbeck, 2020).

Textiles play an important role in European manufacturing industry, employing 1.7 million people and generating a turnover of EUR 178 billion in 2018 (Euratex, 2019). After China, Europe is the second largest exporter of textiles and clothing in the world (Euratex, 2019). Alongside the design and production of high-quality clothing, Europe is a leading producer of synthetic fibers, technical and industrial textiles and non-woven textiles, such as industrial filters, medical products and textiles for the automotive sector (ETC/WMGE, 2019b).

Textiles are a policy priority for the European Commission (EC). The shift to a circular economy is regarded as an opportunity to establish new job-intensive activities and bring more manufacturing back to the European Union (EU) in some sectors, while minimising environmental and climate impacts. As part of the European Green Deal, the new Circular Economy Action Plan mentions textiles and plastics as two of the key product value chains that will be addressed as a matter of priority (European Commission, 2020a). Indeed, the textiles' system is characterised by significant greenhouse gas emissions and a high use of resources: water, land and a variety of chemicals (EEA, 2019; ETC/WMGE, 2019b). Moreover, it is estimated that in 2015, 42 million tonnes of plastic textile waste was generated globally, making the textiles sector the third largest contributor to plastic waste generation (Geyer et al., 2017). Unfortunately, since only about one third of post-consumer textile waste is collected separately for reuse or recycling (Watson et al., 2018), the majority of the textile waste ends up in the residual waste and is incinerated, landfilled, or enters the environment as litter. A specific concern is that synthetic textiles do not naturally degrade, but stay in the biosphere as waste unless they are incinerated.

While recycling rates for non-fibre plastics have steadily increased since the 1980s – PlasticsEurope estimated that about one third of European waste plastics was recycled in 2018 (PlasticsEurope, 2019) – no significant recycling is taking place for fibrous plastics, such as synthetic textiles. To date, end-of-life textiles, both natural and synthetic, almost entirely end up in landfill or are incinerated, either in Europe or, after export, in other regions of the world.

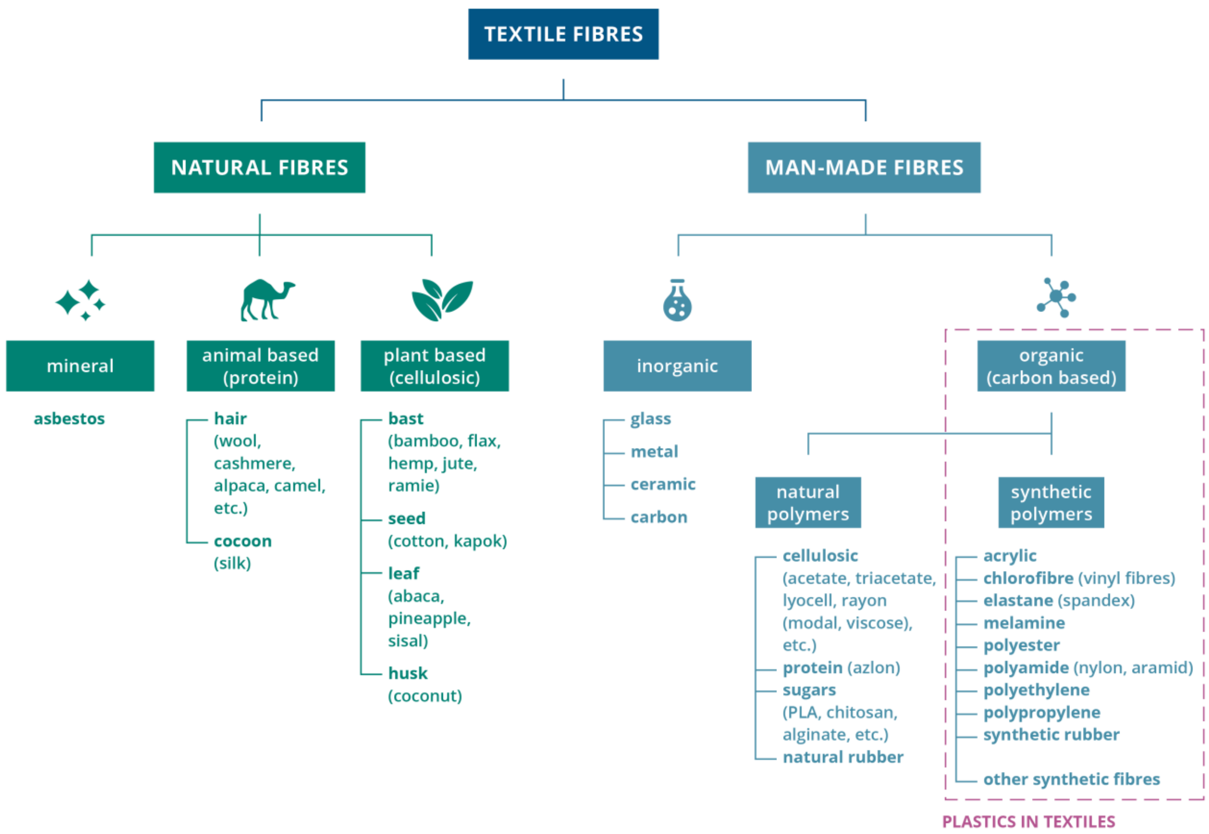
Responding to these challenges, the EC will propose a comprehensive EU Strategy for Textiles with concrete policy measures to strengthen industrial competitiveness and encourage innovation in Europe, boosting the EU market for sustainable and circular products, services and business models. Member States have to ensure that, by 1st January 2025, textile waste is collected to facilitate the sorting, re-use and recycling of textiles.

For plastics, the focus is mainly on tackling plastic pollution, particularly from single use plastics, increasing recycled content and reducing waste. Microplastics are a particular concern. As synthetic plastics are a source of unintentional emissions, efforts will target the increased capture of microplastics, for example by filters; improved and harmonised measuring methods; and building the knowledge base related to the risk and occurrence of microplastics in the environment, drinking water and food (European Commission, 2020a).

The scope of this report is textiles made of synthetic fibres (Figure 1). These textiles are widely used for clothing, household textiles and in industrial applications. Their popularity is due to such properties as strength, elasticity, resistance to shrinking or quick drying. Polyester and nylon are the most common fibres, although many others are used as well. Synthetic fibres are produced using organic (carbon-based) polymers, which are made from fossil fuels. These fibres are spun into pure or blended yarns and woven into fabrics that receive final finishing to yield textiles with specific aesthetics and properties.

Apart from synthetic fibres, a broad variety of other types of fibre is used in textiles. Other man-made ones are made from natural polymers such as viscose from wood cellulose and polylactic acid (PLA) from corn sugar, or from inorganic (non-carbon) materials such as glass and metal. Natural fibres include plant-based ones such as cotton and hemp; protein fibres of animal origin including wool and silk, and mineral fibres such as asbestos (Figure 1). These fibres are not part of the scope of this report, although they are briefly mentioned if relevant.

Figure 1 Scope of this report



Source: EEA and ETC/WMGE, illustration by CSCP

In this report Chapter 2 presents an overview of current knowledge and data on the production and consumption of synthetic polymers in Europe. This includes estimates of the volumes of synthetic fibres produced in, imported to and exported from Europe. The different types of fibre used in the production of textiles are explored, including their properties and applications. Finally, the generation and fate of textile waste generated in Europe is described.

Chapter 3 provides insights into the environmental and climate impacts of synthetic textiles, focusing on resource and water use, greenhouse gas emissions, the use of chemicals and the release of microplastics.

Chapter 4 investigates how synthetic textiles could be made and managed more sustainably, focusing on design choices, circular economy strategies and the mitigation of microplastic pollution.

Finally, Chapter 5 reflects on the report's findings and their potential implementation in EU action plans and strategies on plastics and textiles in a circular economy.

2 Consumption and production of synthetic textiles in Europe

2.1. Consumption of synthetic textiles and fibres in the EU

Synthetic fibres are everywhere in everyday life and are important to our lifestyles. They are in the clothes we wear and the towels we use; they are the stuffing and covers of our sofas, cushions and beds and in the curtains and carpets of our homes. They are in the safety belts of our cars and in protective workwear. They are used as reinforcement materials in plastic sports equipment, such as skis and surfboards, and in vehicle tyres. Many of the products we use every day for comfort, leisure and protection are made from or contain synthetic fibres. Per person textile consumption estimates come with a lot of uncertainty, as various studies provide different estimates ranging from 9 to 27 kilograms per person, depending on the country, data source and product scope (ETC/WMGE, 2019b; Šajn, 2019; Watson et al., 2018; JRC, 2014). In 2017, the total consumption of textile products by EU households was estimated at 13 million tonnes (Stadler et al., 2018).

Around 71 % of synthetic textile fibres are processed into clothing and household textiles, and the remainder used for technical textiles such as safety wear and in industrial applications including in vehicles and machinery (Ryberg et al., 2017). Synthetic fibres are inexpensive and versatile, allowing the production of cheap fast fashion as well as high-performance textiles for durable clothing. Today, it is estimated that about 60 % of fibres used in clothing are synthetic, of which polyester is predominant (FAO/ICAC, 2013). In household textiles, synthetics make up around 70 % of household textiles – mainly polyester, 28 %, and nylon, 23 % (Beton et al., 2014). Acrylic, nylon and polypropylene are important fibres in carpet manufacture.

In Europe, technical textiles account for an increasing share of the production of synthetic fibres (Adinolfi, 2019) and currently make up 25–28 % of EU textiles and clothing turnover. Technical textiles are also, to a large extent, made of synthetic fibres. Technical textiles are used in a variety of products mainly used in industry, such as conveyor belts in machinery, filters in air conditioning and medical applications, construction materials, tyre cord reinforcements for vehicles and industrial safety fabrics used in protective workwear including fire-, heat- or chemical-resistant clothing. Synthetic fibres and fabrics are also used as reinforcements in light-weight composite materials. Such composites are used to replace metals, allowing weight savings in, for example, aircraft and cars (Scheffer, 2012), or as reinforcements in sporting goods such as snowboards or hockey sticks. Technical textiles are engineered to meet the specific requirements of each end use, such as durability, chemical resistance or strength.

Polyester (PET) is the most commonly used synthetic fibre across the world. It has a multitude of uses because of its low price and fabrics made of it are strong, durable, resistant to shrinking, stretching and creasing. Clothing accounts for a large share of the usage of polyester fibres, but it is also used in home furnishings and a variety of industrial applications. Fleece clothing and blankets are a well-known example of the use of recycled PET (rPET) from bottles. It is often used in blends with other fibres, such as cotton, yielding a lightweight polycotton which is often used in blouses and shirts. Due to its versatility and low price, the use of PET has fuelled the fast fashion trend, which relies on cheap manufacturing, fast-changing trends and shorter lifetimes of textile products (Niinimäki et al., 2020; Greenpeace, 2017).

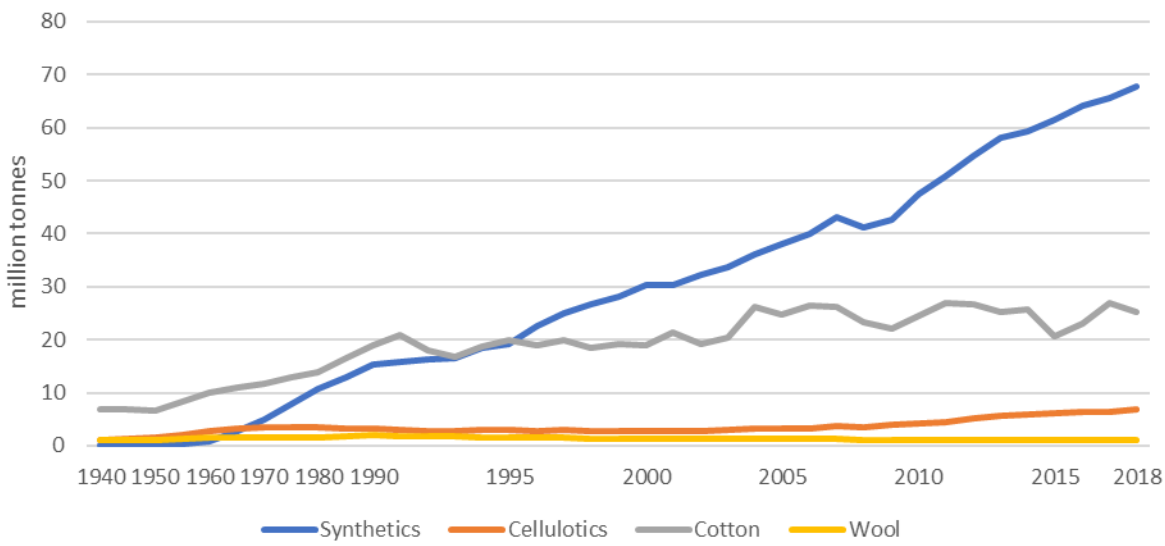
After PET, polyamide (nylon) is the most common synthetic fibre. Nylon is mainly used for knitted apparel, such as hosiery and underwear, and for technical woven fabrics including airbags, ropes and carpets. It has excellent mechanical properties including high tensile strength, high flexibility, good resilience and high impact strength (toughness). Carpet manufacturing accounts for about 17 % of global nylon usage (Carmichael, 2015).
A broad variety of other synthetic fibres are used in lower quantities, for specific uses. Polyolefin fibres (polypropylene and polyethylene) are used in upholstery, carpets and geotextiles, because they are ticker

than other fibres. Acrylic fibres are soft, flexible, thick and fluffy, and some types have flame-retardant properties. They are widely used in blankets, home furnishings and in knitted clothing, such as artificial wool for sweaters. Elastane (spandex) fibres are elastic and often used in garments where comfort and/or fit are important. Typical examples are sports and leisure wear, elastic corset fabrics and stockings. Aramid fibres, such as kevlar, are very strong, five times stronger than steel, which makes them very suitable as reinforcements in sports gear including snowboards, and bullet-proof vests. They are also used to replace asbestos in automotive parts such as brake and clutch linings. Some aramids have excellent heat resistance and are used in protective clothing, hot gas filtration and as electrical insulation. Aramid fibres are also used in car tyres as they reduce rolling resistance (CIRFS, 2020a). Chlorofibres are a group of fibres made from polyvinyl chloride (PVC). They are soft, comfortable, quick-drying, waterproof and insulating, and are used in a variety of applications depending on the specific fibre type, such as hosiery and underwear (Fibre2fashion, 2020a). Melamine fibres are flame and heat resistant and used in mattresses and firefighting apparel (Maity and Singha, 2012).

In many cases, different fibres types are combined in blends with other synthetic or natural fibres to reduce costs or to build fabrics that combine properties that cannot be achieved with a single fibre. Polycotton is the most common blend used in clothing.

The global consumption of synthetic fibres increased from a few thousand tonnes in 1940 to more than 60 million tonnes in 2018, and continues to rise. Since the late 90's polyester has surpassed cotton as the most used fibre (Figure 2).

Figure 2 Global fibre demand, 1940–2018, million tonnes per year



Source: CIRFS (2020b)

2.2. Production of synthetic textiles

The value chain of synthetic textiles is shown in Figure 3. Synthetic fibres are produced from fossil resources, such as oil and natural gas. At a global level, synthetic fibres consume 48 million tonnes of crude oil per year, around 1 % of total production (EIA, 2020; Ellen MacArthur Foundation, 2017). Production and use of bio-based synthetic fibres are very limited in general, although the use of some fibre types in textiles amounts to several thousand tonnes per year, for example polylactic acid (PLA) and polytrimethylene terephthalate (PTT) (Section 4.1 and Figure 20) (European Bioplastics, 2020).

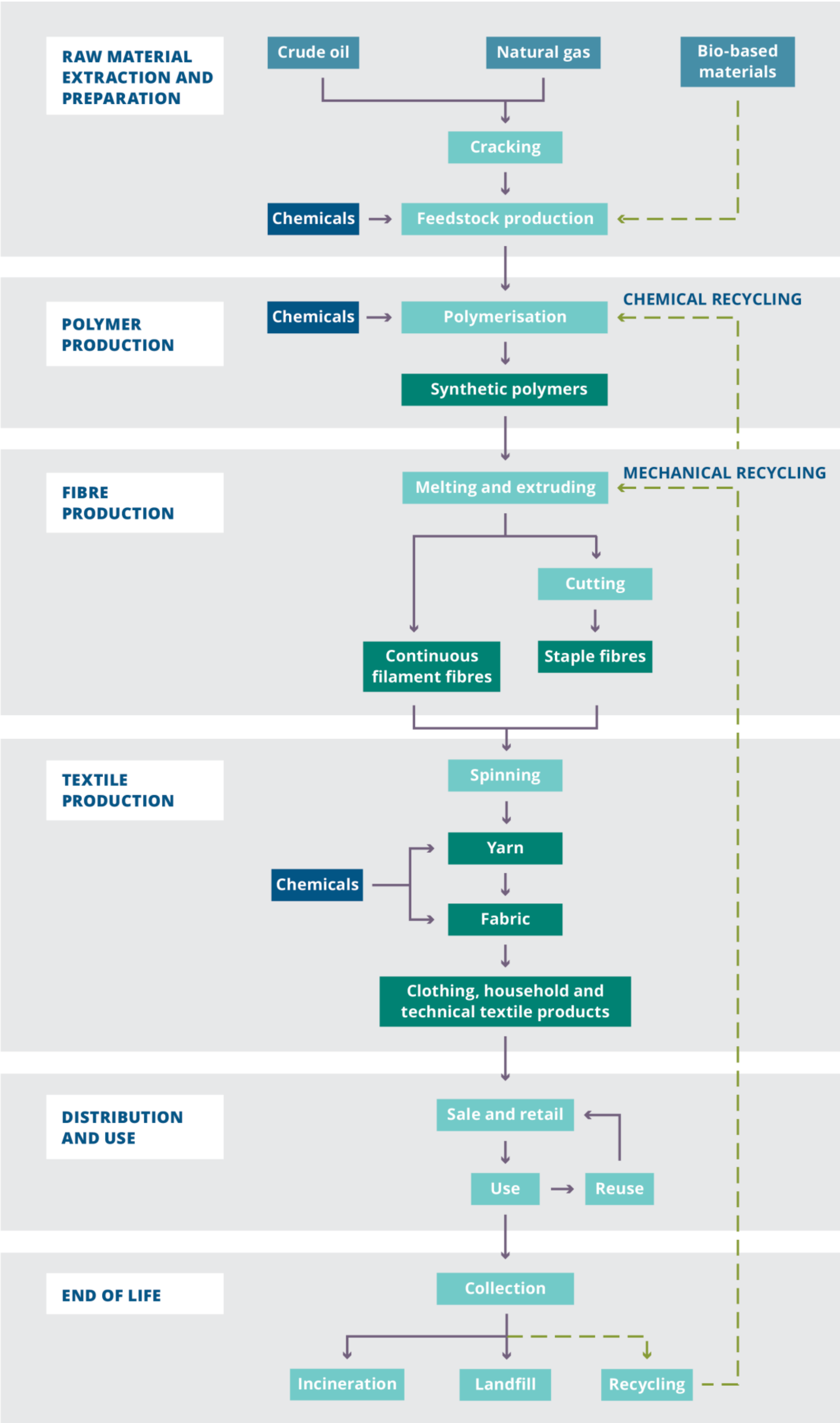
From this feedstock, different synthetic polymers are produced, such as polyester or nylon, that can be processed further into fibres. To produce textile fibres, some manufacturers start from polymer chips, while others produce the polymer themselves and turn it directly into fibres without producing chips (CIRFS, 2020a).

To produce textile fibres, the polymer is melted and then the melt is extruded into long, continuous filaments. Depending on the intended use, these filaments can be used as such (*continuous filament fibres*), or they can be cut into shorter fibres a few centimetres long (*staple fibres*). In order to produce fabrics, fibres need to be processed or spun into yarn. Continuous filaments yarns are generally thin and smooth. As the fibres are longer, the resulting yarns are very strong. Nylon is often used in the form of continuous filament yarn, for example, in fishing nets, swim wear or sewing thread. Because they are short, staple fibres require spinning to produce yarn, but they have the advantage that they can be blended with other fibre types, both natural and synthetic, into a variety of yarn compositions and formations. Staple fibres are widely used in clothing textiles.

Yarns can then be woven into fabrics or knitted directly into final products. Also, staple fibres in their fibrous form can be incorporated directly in fillings or compressed into non-woven or felted fabrics (CIRFS, 2020a). Across the textile production process many chemicals are added to provide the textiles with colours, prints and additional properties.

About one third of post-consumer textiles is collected separately, the remainder end up in residual waste. Of all collected textiles, up to 50–75 % is reused, in Europe or mostly abroad (Watson et al., 2020; 2018). Most non-reusable textiles are incinerated or landfilled; recycling of textiles is minimal and mainly focused on cotton-rich products. The recycling of synthetic textiles is still in its infancy, at the level of research and pilot scale production. Recycling routes can be split into mechanical recycling processes, based on melting and respinning synthetic polymers, and chemical recycling processes, based on the solution or chemical breakdown of the polymers, followed by repolymerisation (Figure 3).

Figure 3 The value chain of synthetic textiles



Source: EEA and ETC/WMGE, illustration by CSCP

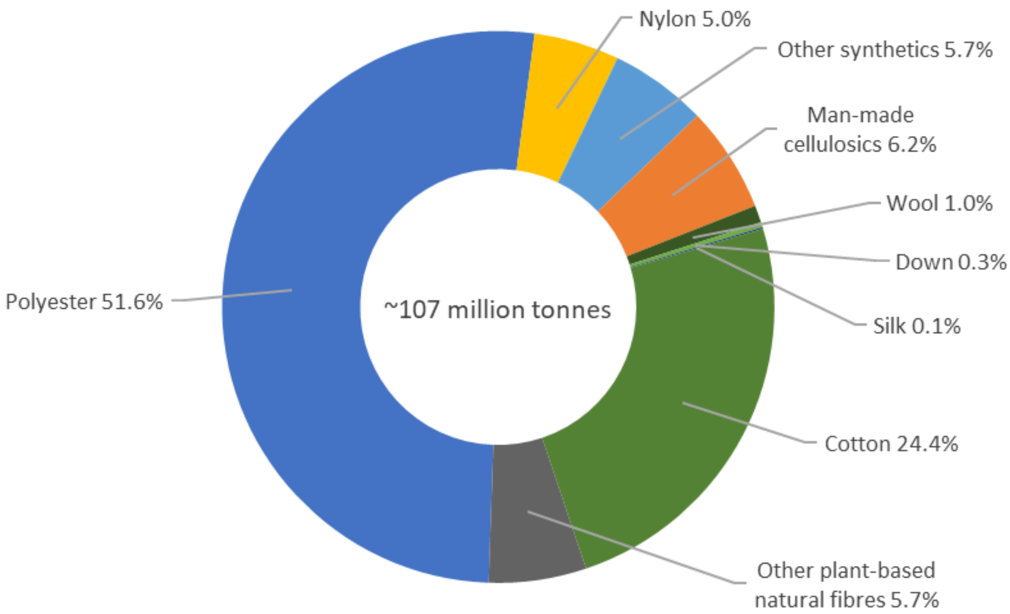
The following sections focus on the global and European production and trade volumes of the most common synthetic fibres used in textiles and the chemicals used in their production.

Production and trade of synthetic fibres

The world of plastics encompasses more than 30 different polymer types, with a broad range of properties, for a multitude of applications. In 2018, global plastics production reached about 425 million tonnes, of which almost 68 million tonnes were synthetic textile fibres, making textiles account for about 16 % of plastic consumption worldwide (CIRFS, 2020b; PlasticsEurope, 2018).

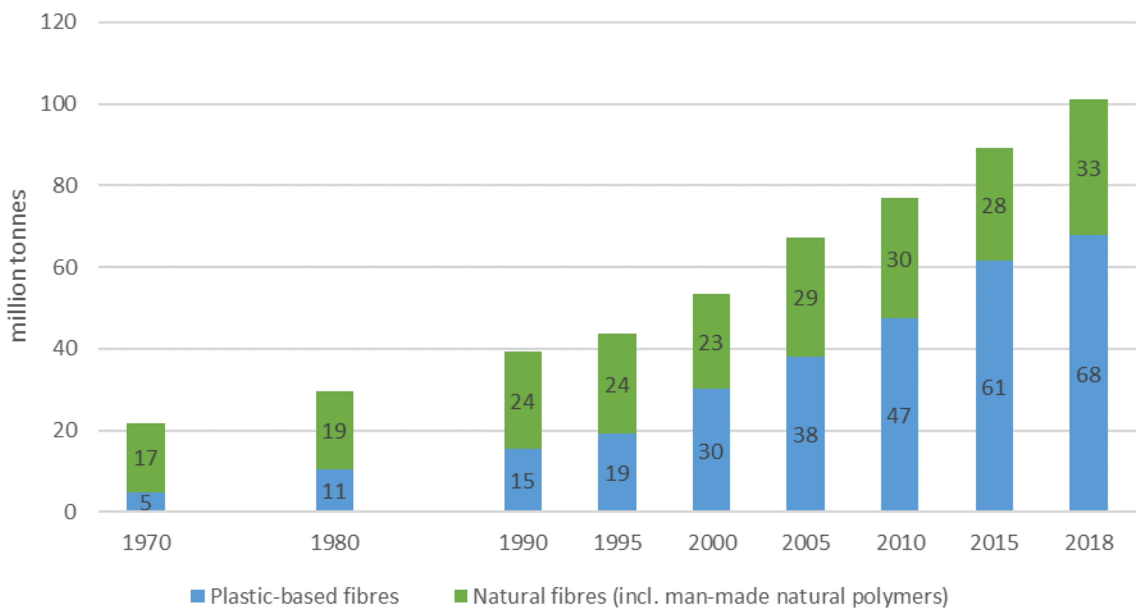
The global production of natural and synthetic textile fibres totalled about 107 million tonnes in 2018, of which synthetic fibres made up almost two thirds (Figure 4) (Textile Exchange, 2019). Over the last 20 years, the production of synthetic textile fibres has more than doubled (Figure 5) and is expected to continue to rise (Textile Exchange, 2019).

Figure 4 Global fibre production, 2018, million tonnes/per cent



Source: Textile Exchange (2019)

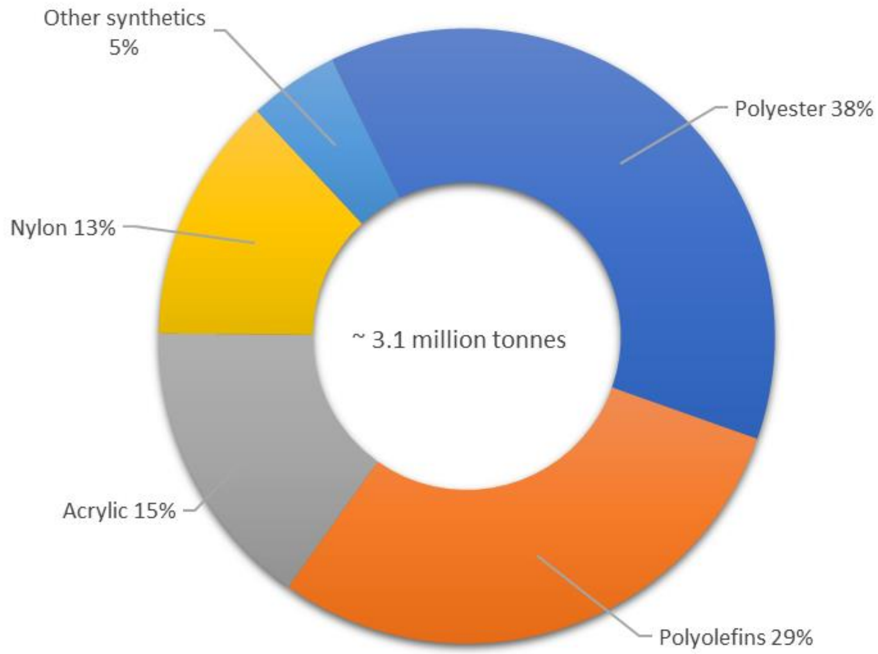
Figure 5 Global production of synthetic fibres, 1970–2018, million tonnes



Source: CIRFS (2020b)

According to the European Man-Made Fibres Association (CIRFS), European production of man-made fibres amounted to 3.5 million tonnes in 2018, of which 85 % was synthetic (CIRFS, 2020b). The main European producers are Germany, Italy and Turkey. A breakdown of fibre types is presented in Figure 6.

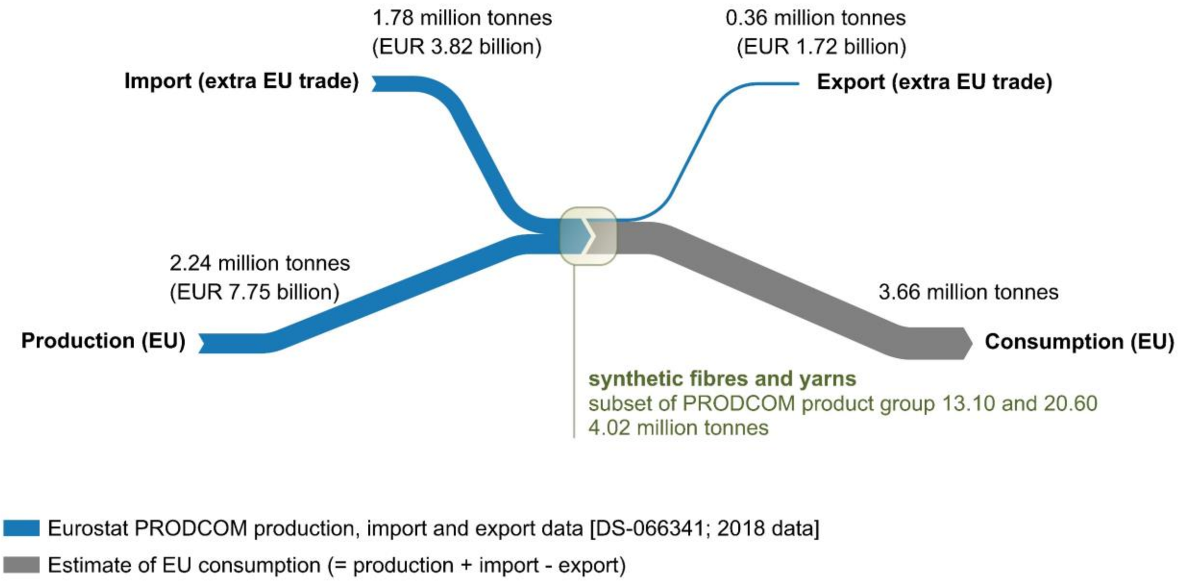
Figure 6 European synthetic fibre production, 2018, million tonnes/per cent



Source: CIRFS (2020b), data including Turkey

According to Eurostat data, 2.24 million tonnes of synthetic fibres and yarns (1) were produced in the EU in 2018 (Figure 7). In the same year, 1.78 million tonnes of synthetic fibres and yarns were imported, and 0.36 million tonnes exported. This implies that the total 2018 consumption of synthetic fibres and yarns in the EU was 3.66 million tonnes (Eurostat, 2018). This consumption volume concerns 'apparent consumption' by EU industry (2), calculated using import, export and production figures. The outputs of this industrial consumption are intermediate and finished products, which are meant for internal EU use as well as for export.

Figure 7 Production, import, export and apparent consumption of synthetic fibres and yarns in the EU (1)



Source: Eurostat (2018)

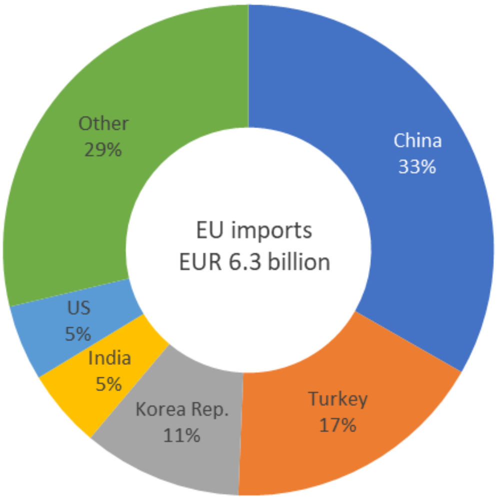
In 2018, the EU imported synthetic fibres, yarns and fabrics (3) valued at more than EUR 6 billion from all over the world. Imports are mostly from China, followed by Turkey, the Republic of Korea and India. In the same year, the EU exported about EUR 4 billion worth of synthetic textiles, mainly to Turkey, the United States of America (US), Morocco and China (Figure 8) (COMEXT, 2018). These trade figures only include extra-EU trade, trade between EU Member States and the rest of the world. The value of intra-EU trade, trade between EU Member States, is much larger, almost EUR 9 billion. Italy and Germany are the largest contributors to both intra- and extra-EU trade in synthetic textiles, both in terms of export and import value.

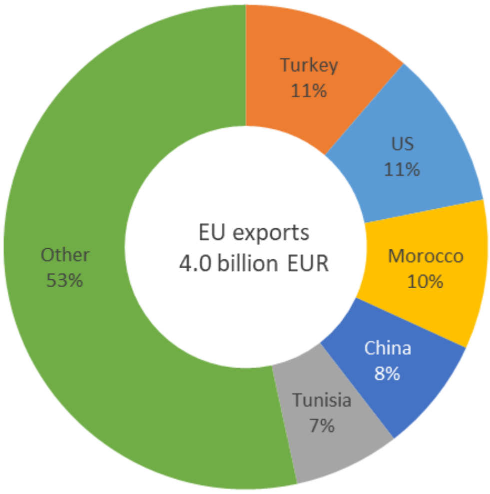
1 Synthetic fibres and yarns are reported in Prodcom under product groups 13.10 and 20.60.In the analysis the following subcategories (last 4 digits in 8-digit code) of product group 13.10 were included: 3100, 8110, 8150, 8210, 8250, 8320, 8333, 8336, 8340, 8380, 8390, 83Z0, 8510, 8550; the following product subcategories of product group 20.60 were included: 1110, 1120, 1130, 1140, 1150, 1190, 1220, 1240, 1260, 1310, 1320, 1330, 1340, 1350, 1390, 1420, 1440 The production volume in Figure 7 is an estimate, and may contain some gaps or double countings. Since Eurostat data report 'sold products', fibres that are sold to yarn producers could be counted twice in the data, while fibres and yarns that are processed immediately after production into fabrics and other intermediate or finished products may not appear in the data for 'fibre and yarn production' since they are traded and thus reported under another product code. Synthetic fabrics were not included to avoid double counting.

2 Since fibres and yarns are base products for textile manufacturing, this consumption can be attributed mainly to industry. Based on this analysis, no conclusions can be drawn on the amount of fibres that eventually end up in finished products for EU household consumption.

3 Only products containing man-made synthetic fibres, yarns and fabrics are included in the graphs (COMEXT HS 4-digit codes 5401, 5402, 5404, 5406, 5407, 5501, 5503, 5505, 5506, 5508, 5509, 5511, 5512, 5513, 5514, 5515). Man-made fibres, yarns and fabrics from artificial fibres – viscose and others – are excluded from the analysis.

Figure 8 Extra-EU trade in synthetic textiles, 2018, EUR billion/per cent ([4])

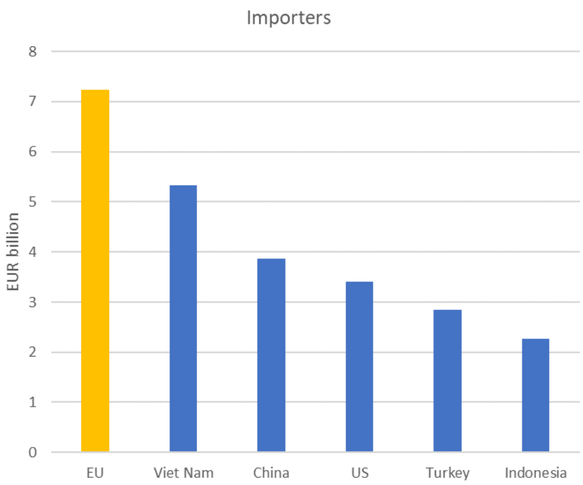


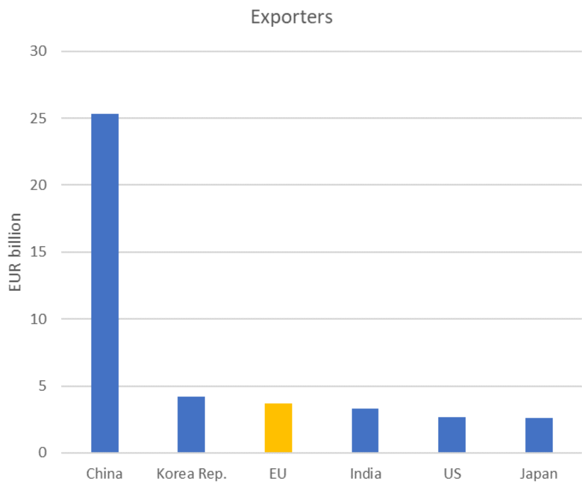


Source: COMEXT (2018)

Set in a world perspective, the EU is the third largest exporting region, after China and the Republic of Korea. China is by far the largest exporter of man-made textiles in the world (~ EUR 25 billion in 2018) (Figure 9). In terms of imports, the EU is the largest importing region, followed by Viet Nam, China, the US, Turkey and Indonesia.

Figure 9 Major importers and exporters of synthetic textiles ([4]), 2018, EUR billions





Source: WITS (2018) based on UN COMTRADE data, exchange rate: USD 1 = EUR 0.89

[4] Only products containing man-made synthetic fibres, yarns and fabrics are included in the graphs (COMEXT HS 4-digit codes 5401, 5402, 5404, 5406, 5407, 5501, 5503, 5505, 5506, 5508, 5509, 5511, 5512, 5513, 5514, 5515). Man-made fibres, yarns and fabrics from artificial fibres (viscose and others) are excluded from the analysis.

Polyester

Polyester (PET), a strong, low-cost fibre is the most widely used synthetic fibre and accounted for more than half of global fibre production fibre in 2018 (55 million tonnes) (Textile Exchange, 2019). It is used in a multitude of applications but clothing accounts for a large share of its use since polyester is a cheaper and thinner alternative to cotton. Figure 2 shows how the demand for PET has outgrown that of cotton. Sportswear is an important use segment, with industrial uses of PET, including in tyre cord, furniture fillings and non-woven textiles, expanding.

Polyester is made from petroleum-derived ethylene glycol and terephthalic acid. It is widely used in plastic packaging (PET bottles), but textile fibres for clothing currently make up more than 60 % of PET production. Despite its current popularity, it only came into use as a textile fibre in the 1970s. To produce textile fibres, some producers start from polyester polymer chips, melt them and then extrude the melt into continuous filaments. These can be used as such or are cut into staple fibres (cut fibres of a specific length).

Others produce the polymer and turn it directly into fibres without producing chips (CIRFS, 2020a). About 60 % of all PET fibres are produced in the form of filament fibres, while the remainder is staple fibres (Plastics Insight, 2020).

China accounts for around two thirds of global polyester fibre production. When India and Southeast Asia are added, these countries are responsible for 86 % of global PET production (Chatterjee, 2018). This shows that the European textile industry is highly dependent on imports of PET. Although European domestic fibre production of high-quality, tailor-made fibres is highly efficient, its competitiveness suffers from higher production costs (CIRFS, 2020c).

In 2018, about 13 %, 7.2 million tonnes, of the global PET fibre production was rPET (Textile Exchange, 2019), mainly made by recycling discarded PET bottles although it can also be made from other sources such as polyester textiles and collected ocean plastic waste. It is increasingly used in the production of polyester textiles, such as fleece garments and blankets. In parallel with technical innovation, sectoral initiatives are emerging to promote the uptake of rPET in the textile and plastics industries (Greenbiz, 2020).

Nylon

In 2018, more than 5 million tonnes of nylon fibre, widely used in tights, carpets and umbrellas, were produced, making it the most common synthetic fibre after PET (Textile Exchange, 2019). Nylon is more difficult to recycle than PET, although recycled nylon fibres made from fishing nets and plastic waste are already available on the market and used in carpet and clothing production (Econyl, 2020). Several fashion brands have made commitments on the replacement of virgin nylon with recycled fibre (Textile Exchange, 2019). The market share of recycled nylon is difficult to estimate, as reliable production numbers are not publicly available. In environmental terms, however, one producer estimates that 70,000 barrels ([5]) of oil and 57,000 tonnes of carbon dioxide (CO_2) emissions are saved per 10,000 tonnes of regenerated nylon (Aquafil, 2018).

The productions volumes of the other synthetic fibres remain below 5 million tonnes per year (Textile Exchange, 2019; Carmichael, 2015).

[5] 11,200 cubic metres (m^3) of oil. 1 barrel = 0,16 m^3

Blended yarns and textiles

In order to create yarns and textiles that have properties that cannot be achieved with a single fibre, whether man-made or natural, while remaining comfortable, different synthetic and natural fibre types are frequently combined into blended yarns and textiles.

The most common blend is of polyester-cotton, or polycotton, usually produced as 35 % polyester/65 % cotton or 50 % polyester/50 % cotton blends. Combining polyester with cotton results in a stronger material, which is more durable and cheaper to produce while its cotton content reduces pilling and static electricity. Furthermore, this fabric keeps it shape and colour for longer and is shrink resistant. As a result, polycotton is a popular fabric for clothing, especially for uniforms and workwear, and for non-clothing applications such as futon, seat and cushion covers (Pearce, 2017).

In blends, the natural fibres, such as cotton or wool, increase moisture absorbency, increase comfort and reduce static electricity. The synthetic fibres, such as polyester, improve durability and abrasion resistance, and reduce shrinking, stretching and wrinkling. Nylon is usually added to natural fibres for increased durability and comfort. Blended with wool, nylon decreases itchiness and coarseness, resulting in a fabric that is more durable and wrinkle/shrinkage resistant. Nylon/cotton blends are used, for example, for military wear, while polypropylene (PP) is typically blended with wool in carpets to reduce the price.

Blends containing elastane (spandex) are increasing on the market. It is typically mixed in with cotton to provide better stretch and recovery properties in fabrics such as denim and rib knit collars of T-shirts, while the cotton fibres provide a comfortable feel (Jabbar et al., 2020).

Box 1: Specialty fibres and smart textiles in sportswear

Today's casual activewear and sportswear make use of a broad variety of highly functional and technical textiles. The most common fibre used in sportswear is PET, but nylon, elastane, polypropylene and acrylic fibres are also used. Fibre blends and functional coatings are ubiquitous, creating sophisticated clothing and footwear that is fashionable, comfortable and resistant to extreme weather and use conditions. Temperature and moisture regulation are key properties to assure sufficient thermal insulation, while releasing body heat and sweat during exercise. Stretchability assures freedom of movement and coatings protect against injuries or reduce wear and tear.

Besides conventional synthetic fibres, many specialty ones and smart textiles are used to meet specific requirements. Smart textiles are those that can respond to changes in their environment, such as temperature, moisture, light, pressure, electric currents or acidity, improving comfort and performance – better fit, thermal regulation or moisture management (Becker, 2020). Others, known as wearables, have integrated electronics and sensors that can be worn on the body (TextileMates, 2020).

Sportswear brands are increasingly using recycled fibres. Most use rPET made from PET bottles (Ambiletics, 2020; Pure, 2020), but some brands also work with recovered ocean plastics or recycled nylon made from discarded fishing nets (Econyl, 2020), or with recycled elastane (Common Objective, 2020). Some brands are also looking for plant-based fibres to replace polyester, such as lyocell, which is a soft, strong, drapable, quick-drying and wrinkle-resistant fibre made from wood pulp or bamboo (Bleed, 2020).

Chemical additives

Chemical additives are used in all stages of fibre and textile production – worldwide more than 10,000 different dyes and pigments are used in the textile and printing industries alone – but the majority are used as finishing treatments such as those to add water or stain repelling properties, fire retardants, easy-care or antistatic coatings, etc. Most are synthetic, in many cases plastic resins, and, as a result, it is important to recognise that almost all textiles, including those made of natural fibres, such as cotton or wool, should in fact be considered synthetic due to the amount of processing and finishing chemicals that have been applied to them. Many of these, such as dyes, anti-wrinkle agents, water repellents, flame retardants or antimicrobial agents, are added to give the textile product additional properties and are intended to remain in the final article even after numerous washing cycles. Coatings can make up 5–20+ % of the final weight of the textile product. Typical materials used for textile coatings are polyvinyl chloride (PVC), acrylates and polyurethanes (Singha, 2012).

About 70 % of dyes used in the textile industry are azo dyes that are cost-effective and easy to use. In order for dyes to be useful, they must possess a high degree of chemical and photolytic stability. As a result, these compounds do not degrade easily in natural environments and their removal from industrial effluents is a major environmental problem (Ciullini et al., 2012). While both cotton and synthetic fibres are normally coloured with synthetic dyes, dyeing cotton is usually a more water- and heat-intensive process – the surface of cotton fibres is negatively charged and does not readily react with negatively charged dye compounds (Bomgardner, 2018).

As textiles are typically highly flammable, flame retardants are commonly applied to them, either blended into the polymer or applied in finishing using inorganic salts, organohalogens or formaldehyde-based flame retardants. Due to their toxic potential, the European Chemicals Agency (ECHA) has banned many halogenated compounds but to maintain safety standards, new halogen-free flame retardants are being developed and substitute products are emerging on the market. One challenge with these, however, has been their low stability with respect to washing and mechanical abrasion, which has somewhat limited their applicability in textile finishing (Mayer-Gall et al., 2019).

Other process chemicals, such as solvents, surfactants and storage preservatives that are necessary in textile production and processing, are not intended to remain in the finished products. Some nonetheless do remain and can cause environmental or health risks during use and recycling.

Overall, the EU is restricting or banning many dangerous chemicals that have been used in textiles, for example, certain azo colours, antimicrobials such as dimethylfumarate (DMF) and certain phthalates used to increase softness and flexibility, are restricted under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation. Another group of compounds requiring substitution is poly/perfluorocarbons (PFCs) used to achieve water and dirt resistance. Many textile manufacturers are also reducing the number of dangerous chemicals in their products on voluntary basis (ECHA, 2020; 2017).

Box 2: Recycling carpets

Carpets are multilayer textile products. They are used in many different environments such as heavy-duty industrial buildings, offices and theatres, as well as in private homes. About 80 % of the fibres used in the carpet industry are synthetic, with the remaining 20 % usually made of wool or cotton. The dominant yarn constructions, making up about 90 % of the market, are combinations of nylon and PP.

The EU is the second-largest market in the world for carpets, with European production meeting 65 % of the demand and the remainder being imported (Hilton, 2018).

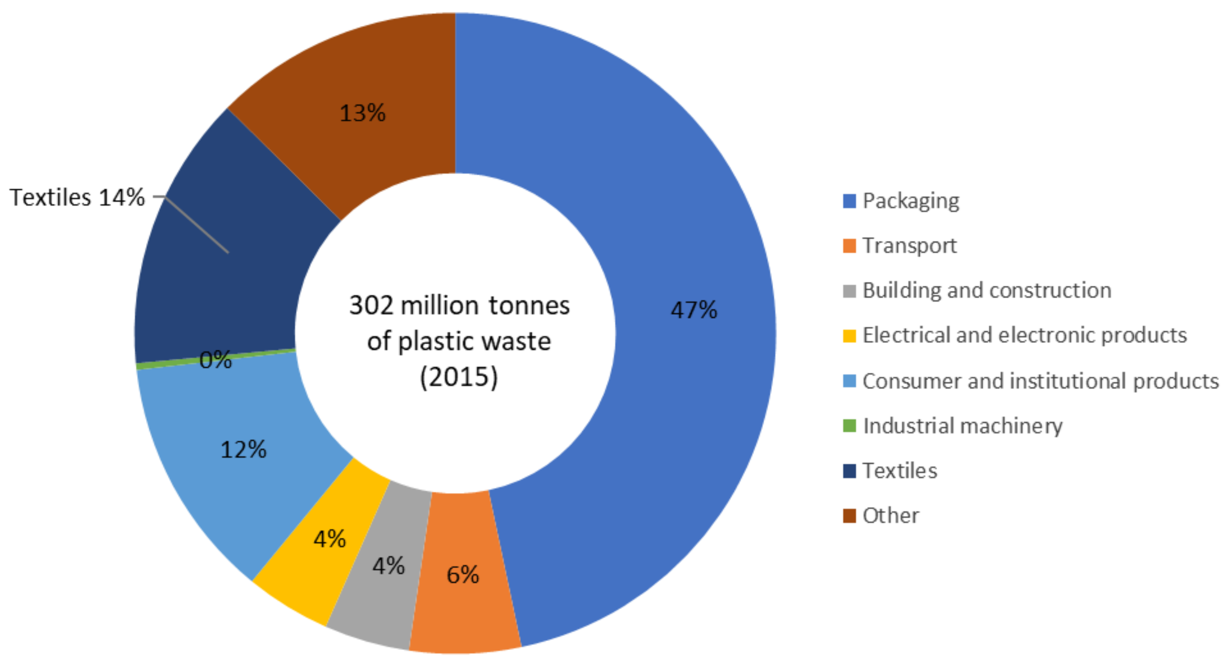
It is estimated that, currently, less than 3 % of carpet placed on the market in the EU is recycled (Hilton, 2018), resulting in an estimated 1.5 million tonnes of carpet being landfilled or incinerated annually. Recycling and/or reuse is challenging due to the complex structure of the products and the chemicals they contain. Previous research (Changing Markets, 2018) has highlighted that over 50 hazardous substances can be present in European carpets. Recyclate from carpets, therefore, is likely to be too contaminated to be used in new products. Currently the major recycling schemes involve energy utilisation in cement kilns (Anon, 2019).

A number of initiatives, such as the Circular Carpet Platform, product passports for carpets and suggestions to introduce an extended producer responsibility (EPR) system for carpets by certain countries, aim to improve the situation. Many municipalities already organise collections of reusable carpets, although a fair amount of the recovered material is downcycled to non-textile applications, such as buckets and flower pots, or incinerated for energy recovery (Anon, 2019).

2.3. Synthetic textile waste

In 2015, an estimated total of 42 million tonnes of plastic textile waste were generated globally, making textiles the third largest contributor to plastic waste generation, accounting for 14 % of all plastic waste (Figure 10) (Geyer et al., 2017).

Figure 10 Global plastic waste generation per industrial sector, 2015, million tonnes/per cent



Source: Geyer et al. (2017)

The total amount of textile waste generated annually in the EU is unknown. It is estimated that EU consumers discard about 5.8 million tonnes of textiles annually, about 11 kilograms per person (Beasley and Georgeson, 2014). As about 60 % of textiles are synthetic (FAO/ICAC, 2013), this suggests that about 3,5 million tonnes of plastic textile waste is discarded in Europe each year.

Even the volume that is selectively collected is high uncertainty as not all Member States keep records, and even if they do, reporting is inconsistent and incomplete. For example, textiles that are collected by third-party collectors, whether charitable or commercial, are often not registered (Watson et al., 2020). In 2016, about 2 million tonnes of textile waste were reported as having been collected separately (Eurostat, 2016). Collection rate estimates (share of quantity put on the market) vary greatly between countries, from 0.2 to 12.5 kilograms per person; on average about one third of the volume put on the market is separately collected (European Commission, 2020b; Watson et al., 2018), suggesting that an even larger volume of textile waste ends up in the residual waste.

Separately collected textile waste is sorted and a large part is exported for reuse or recycling abroad, mostly outside Europe. While percentages vary among countries, about 60–70 % of all collected textiles is reused locally or abroad), 10–30 % is recycled and 10–20 % is incinerated for energy recovery or landfilled (minor) (Watson et al., 2020). Recycling activities mainly entail lower-value downcycling into industrial rags, insulation materials and upholstery fillings.

Globally, it is estimated that only 0.06 % of all textile waste is recycled into fibres for use in new textile products (Textile Exchange, 2020a). Currently, there is no significant recycling of synthetic textiles and the limited fibre-to-fibre recycling that does occurs is mainly mechanical recycling of 100 % cotton products.

Fibre-to-fibre recycling processes for textiles include mechanical and chemical processes. Mechanical recycling processes for synthetic textiles include the shredding of the fabrics, followed by melting the polymers and extruding of new fibres, such as polyester. Nonetheless, most recycled polyester is made from PET bottles and not from polyester textiles. This is because there is already excellent collection systems and recycling infrastructure in place for PET bottles, which are pure PET and relatively clean, making it relatively easy to shred them into flakes, melt these and extrude new PET fibres.

Chemical recycling processes rely on the use of specific solvents that selectively target the dissolution of certain synthetic fibres. So far, for this to work efficiently and without complications, the technique requires textiles to consist only of the same target fibre. Chemical recycling does occur within the textile industry, although not yet at a wider industrial scale. Although much research is being done on the topic, both for plastics and synthetic textiles (CEFIC, 2020; Adelphi, 2019), there are still many problems, knowledge gaps and uncertainties about the environmental impacts associated with these processes (Zero Waste Europe, 2019).

Although synthetic textiles are technically recyclable, there are currently very few commercially viable recycling processes as many economic and technical challenges persist. Firstly, the currently collected amounts of textile waste are not sufficient to support a commercially viable recycling sector. Widespread post-consumer collection systems need to be put in place to provide a significant volume of continuous feedstock supply. Secondly, mixed textiles need to be accurately sorted, which increases the cost of the recycling process. Scaling-up the sorting capacity to meet yarn-mill demand would be a first step. This requires a shift from manual to automated sorting, using, for example, near-infrared systems (NIR), which need to have high quality and quantity sorting capacity to be cost-effective (Watson et al., 2020; WRAP, 2019). Furthermore, a better transparency on fibre content in textile products would also aid better sorting. Nevertheless, because the majority of textiles contain both natural and synthetic fibres or mixtures of synthetic fibers, technical feasibility remains a challenge. Although promising innovative processes are evolving, especially for the common mix of polyester and cotton (WRAP, 2019; Palme et al., 2017), these applications have not yet reached full technological readiness (Section 4.3). Generally, the more homogenous a textile, the greater the chance it has of being returned to the cycle.

Finally, the market for recycled fibres needs to be developed to find outlets for the recycled materials, both within the textile industry and in other applications.

3 Environmental and climate impacts of synthetic fibres and textiles

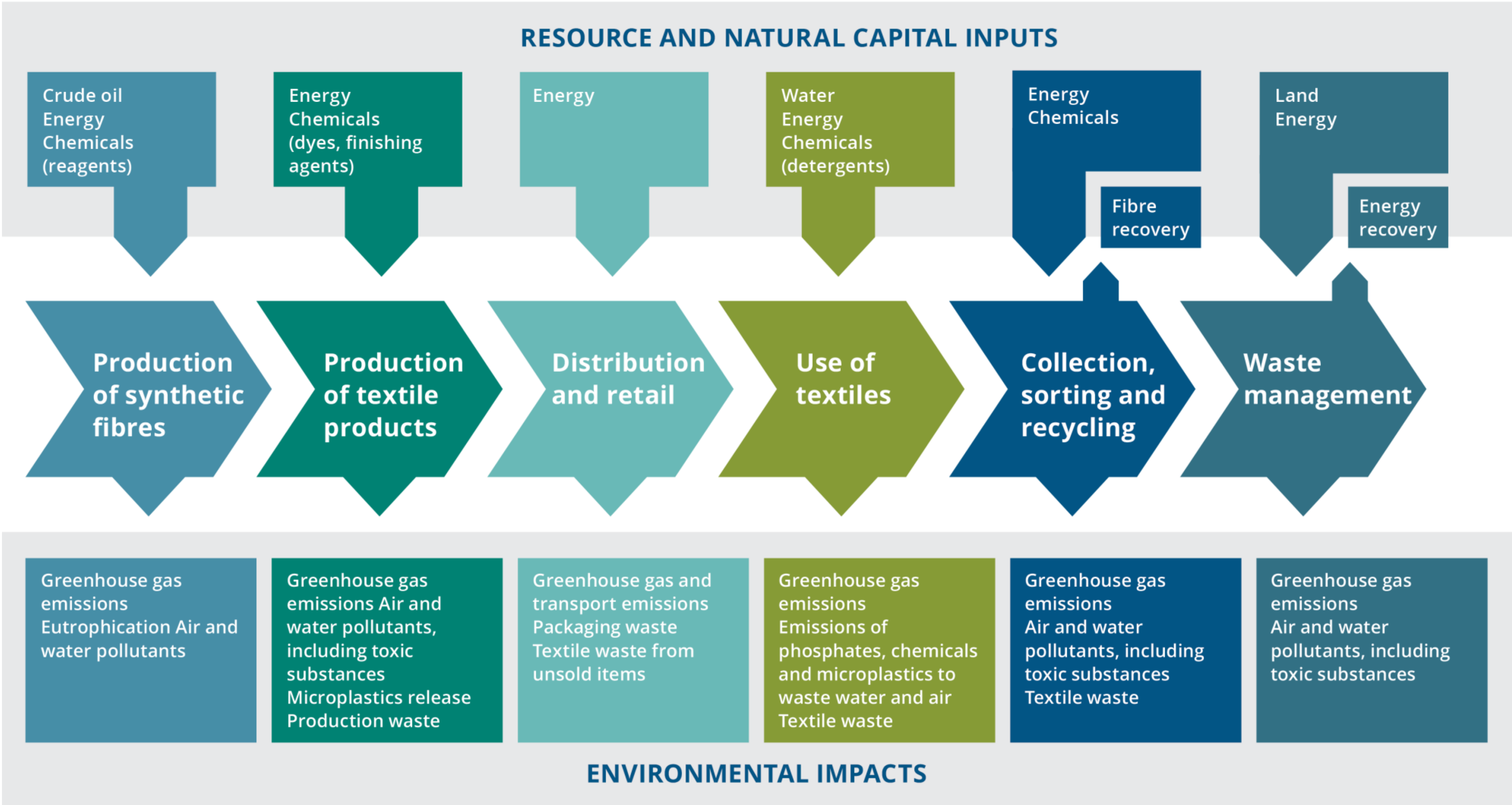
3.1. Impacts across the value chain

The production and consumption of textiles have significant environmental impacts including greenhouse gas emissions, resource and water use, land use and impacts related to the use of chemicals. The ranges of impacts heavily depend on the type of fibre (ETC/WMGE, 2019b) and synthetic fibres and textiles mainly contribute to the depletion of fossil resources, greenhouse gas emissions and the release of microplastics.

Due to negative perceptions of petroleum-based materials, the environmental impacts related to synthetic fibres are often considered more severe than those of natural fibres like cotton. As synthetic fibres are oil based and require large amounts of energy to be produced, they are significant contributors to impacts related to climate change and the depletion of fossil resources. In contrast to cotton, the most common natural fibre, however, the production of synthetic fibres does not require the use of agricultural land, excessive use of water, toxic pesticides or eutrophying fertilisers (Sandin et al., 2019). If the environmental assessments extended beyond resource depletion and climate change to include other traditional impact categories such as land and water use, and ecosystem impacts, identifying superior fibre types in terms of environmental performance is not straight forward (Beton et al., 2014).

When looking beyond fibre production alone and taking the entire textile manufacturing process – yarn spinning, weaving, dyeing and finishing of fabric – into account, there are some environmental advantages to synthetic textiles, especially in the dyeing and finishing steps. Polyester, for example, requires high temperature dyeing but the process is shorter and requires fewer chemicals, resulting in lower impacts than cotton dyeing (Natural Resources Defense Council, 2012). There is no fabric, however, with an overall best-in-class manufacturing process; natural and synthetic fibres simply generate environmental burdens in different impact areas. These impacts also depend on case specific parameters including fibre thickness, dyeing techniques used and whether the fabric is knitted or woven (van der Velden et al., 2014).

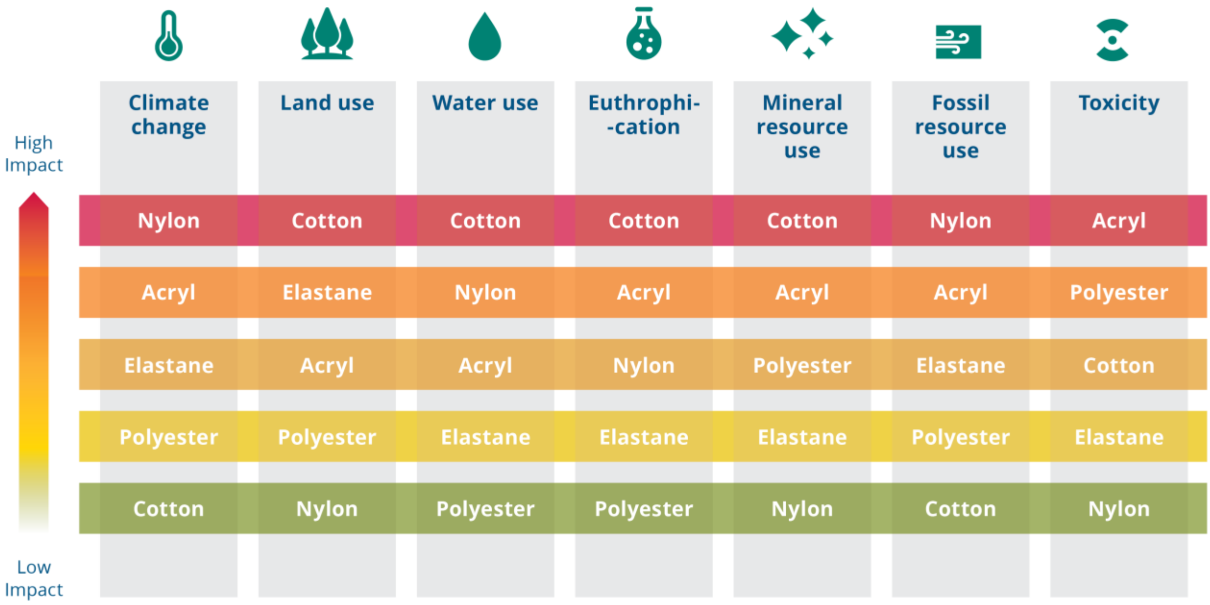
Figure 11 Environmental impacts across the lifecycle of synthetic textiles



Source: ETC/WMGE (2019b), illustration by CSCP

In Figure 12, the environmental impacts of the most common synthetic fibres and cotton are compared, per kilogram of dyed, woven fabric. It is, however, important to keep in mind that overall (annual) impacts also depend on production volumes of the respective fibres and fabrics. For example, while the manufacturing of polyester fabric uses less energy than nylon, the former's yearly production greatly exceeds the latter's; therefore, so will its overall energy requirement.

Figure 12 Comparison of the environmental impacts of the manufacturing of 1 kilogram of dyed, woven fabric (red = worst, green = best)



Source: OVAM (2019) and the Higg Index (Sustainable Apparel Coalition, 2020), illustration by CSCP

Of course, detrimental environmental effects are not only generated during the production of textiles. During use, the main environmental impacts are generated by domestic and/or industrial washing, drying and ironing. While these caretaking activities require a lot of energy and thus contribute significantly to climate change, they enable longer and more intensive product use, adding to product lifetimes.

The generated impacts are heavily case dependent; the number of times a product is washed, the washing temperature and the energy efficiency of the appliances used influence the end result to a large extent. The impacts of drying and ironing depend on the product properties and application. As synthetic fibres tend to be more wrinkle and stain resistant, dry faster and hold their form better than natural fibres, they require relatively less care, water and energy for maintenance compared to cotton (CFDA, 2020).

An environmental challenge related to synthetic fibres is their large contribution to microplastic pollution, of which the long-term consequences on the aquatic environment and species as well as human health are still unclear (Henry et al., 2019). This type of pollution is currently not taken into account in state-the-art environmental impact assessment methodologies, but mainly occurs during the washing of synthetic fabrics.

When reaching the end of their useful lives, some textiles are collected for recycling but most of the textile waste is burned in a municipal waste incinerator, largely without energy recapture, or landfilled – plastic-based fibres, however, do not biodegrade and remain present in landfill sites for at least multiple decades (Common Objective, 2019). In general, the recycling of end-of-life textile products provides environmental gains compared to landfilling or incineration. However, these benefits mainly arise by avoiding the production of new products, but they may remain questionable if the replacement rate is low and the production of new products from virgin resources is only replaced to a minor degree, or if the avoided production processes are relatively clean (Sandin and Peters, 2018a).

From a lifecycle perspective it is impossible to distinguish good and bad fibre types in terms of environmental performance. Burdens differ depending on the impact areas taken into account and results are very case dependent. They are heavily affected by the intended use, design and applied manufacturing processes, as well as caretaking and disposal practices. Obviously (local) regulations with regards to production, use and end-of-life treatment of textiles and the means of enforcement have a role to play here. Also, the lifespan of a textile product heavily influences the overall impacts, the longer it lasts, the lower they are. In this sense it is important to select a fibre type the properties of which suit the intended use. Because synthetic fibres have superior mechanical properties in terms of strength and abrasion resistance, they are usually more durable and have longer expected lifetimes. That is why for products with high demands on technical strength, for example, synthetic fibres might be the superior sustainable choice (Sandin et al., 2019).

The following sections discuss the environmental impact areas that are most relevant for synthetic textiles: resource use, greenhouse gas emissions, use of chemicals and microplastic release. Results are discussed for polyester and nylon, as they are the most common synthetic fibres, and compared to cotton which has the largest share of natural fibres.

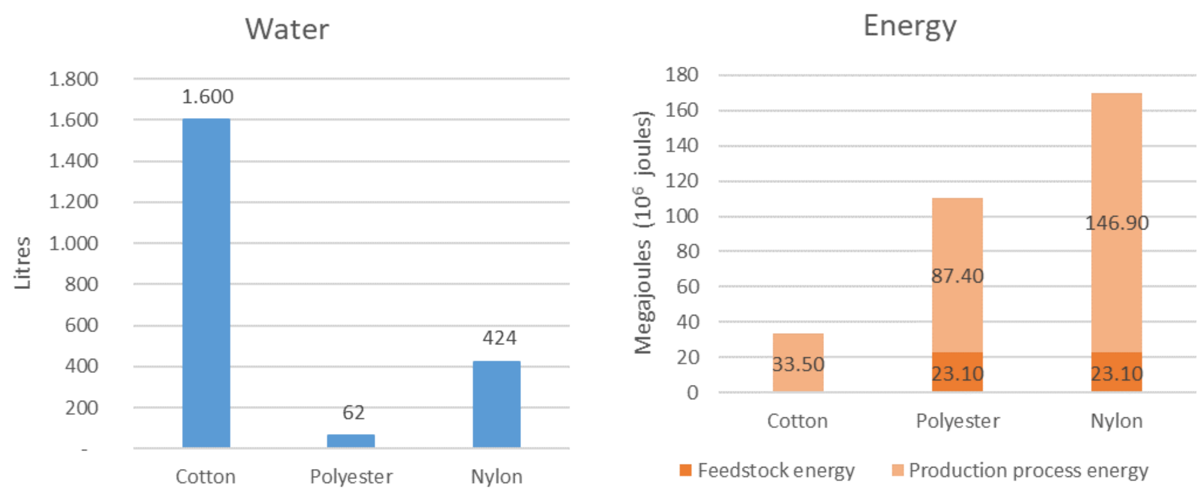
3.2. Resource use

When focusing on resource use, synthetic fibres are typically associated with high impacts as they originate from fossil resources. An estimated 342 million barrels or more than 54 billion litres of oil are required on an annual basis for the production of plastic fibres for textiles (Ellen MacArthur Foundation, 2017). This is the equivalent of more than 21,000 Olympic swimming pools full of oil.

Furthermore, as synthetic fibres are entirely man made, their production requires considerable amounts of energy. The production of polyester fibres requires two to three times as much energy and nylon more than four times as much as is needed to produce the same amount of cotton (Figure 13).

On the other hand, only limited amounts of water, leave alone pesticides and fertilisers, are used in the production of synthetic fibres. Although the water requirement for the production of cotton fibres heavily depends on the aridity of the region and the specific site where the crops are grown, based on the global average around 26 times as much water is need to produce the same amount of cotton as polyester and around four times as much as nylon (Figure 13).

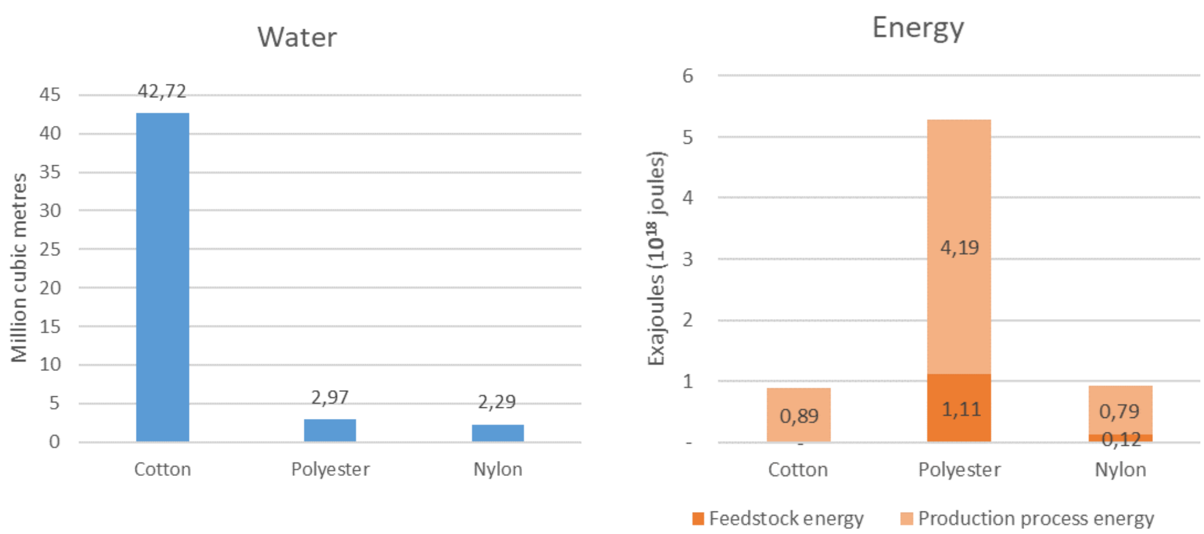
Figure 13 Water and energy, including feedstock energy of synthetics, required for the production of 1 kilogram of fibre



Source: Sandin et al. (2019)

A distinction can be made in the energy use related to the production of synthetic fibres between the feedstock energy of the fossil resource (23.1 megajoules per kilogram) and the energy required in the production process itself. Figure 14 illustrates overall resource requirements when annual production volumes for the different fibre types are taken into account. Given that from a global perspective twice as much polyester as cotton is produced and ten times as much polyester as nylon, quite a different picture is drawn for overall energy and water use.

Figure 14 Water and energy, including feedstock energy of synthetics, required for global annual fibre production, 2018



Source: Sandin et al. (2019) and Textile Exchange (2019)

Apart from synthetics from virgin sources, recycled synthetic fibres are also becoming widely available. For example, rPET is made mainly from recycled PET bottles but can also be generated from marine litter, discarded polyester textiles or from fabric scraps (Textile Exchange, 2019). The production of recycled polyester is less resource dependent, requiring 30–50 % less energy to make and reducing the need for primary extraction of oil (Textile Exchange, 2018b). Nylon can also be recycled from pre- or post-consumer waste. While pre-consumer waste consists of processing scraps, sources of post-consumer waste are mainly discarded fishing nets and carpets (Textile Exchange, 2019).

Finally, bio-based synthetic fibres are often mentioned as environmentally friendly alternatives to traditional, virgin fossil-based ones. This might be true in terms of fossil resource use, but the key to bio-based synthetics lies in innovative bio-based feedstocks that do not compete in land-use terms with food, that do not rely heavily on water or chemicals and that can be cultivated sustainably (Textile Exchange, 2019). In environmental terms, feedstocks that are waste based, agricultural residues and organic waste, are preferable to crop-based ones such as maize or sugar cane (Textile Exchange, 2018a). Finally, most bio-based synthetic fibres, such as bio-PET, are developed to have the same properties and therefore chemical composition as their fossil-based counterparts. While the production process differs, they have similar environmental implications during the use and end-of-life phase. It is important to note that the bio-based origin by no means implies that the fibres are bio-degradable.

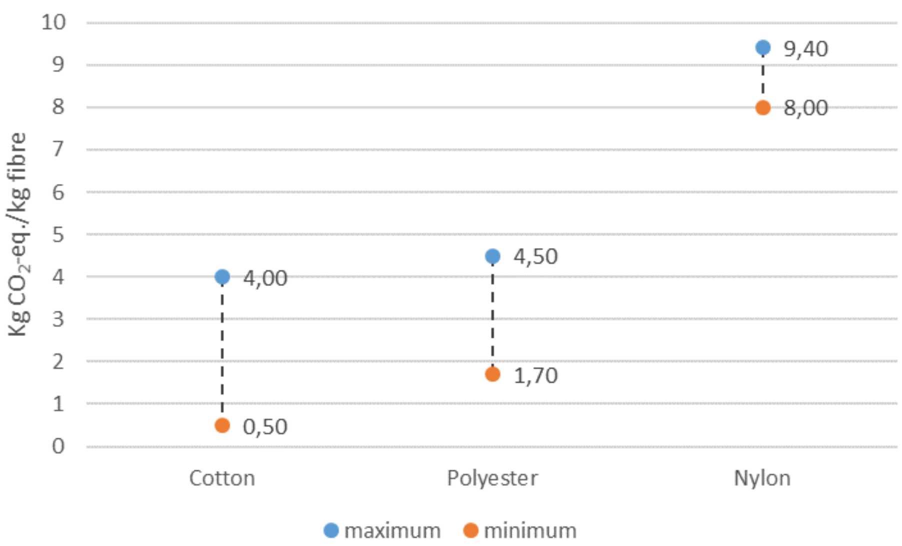
3.3. Greenhouse gas emissions

As mentioned, synthetic fabrics require large amounts of energy for the production of their raw materials, heavily contributing to the emission of greenhouse gases. Additionally, the use of energy in the finishing process plays an important role; the formation, weaving or spinning; printing and dyeing of fabrics require large amounts of electricity (Beton et al., 2014).

The full lifecycle of 1 kilogram of polyester fabric is estimated to be responsible for the release of more than 30 kilograms of carbon dioxide equivalent, while only around 20 kilograms are associated with cotton (Beton et al., 2014). The production of nylon emits nitrous oxide, a potent greenhouse gas that per kilogram contributes almost 300 times as much to climate change as carbon dioxide (Fletcher, 2014). Figure 15 shows the greenhouse gas emissions related to the production of a kilogram of different fibre types while Figure 16 illustrates emissions for global annual production volumes. Since different sources show significant variations in climate change estimates, the figures show both minimum and maximum numbers as reported by Sandin et al (2019).

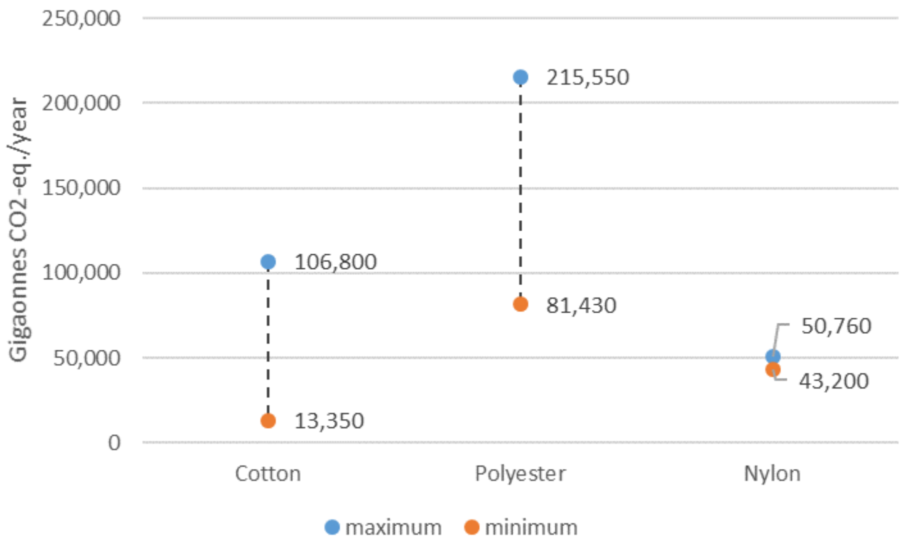
Figure 16 shows that polyester has the largest overall annual impact, due to the large volumes that are produced, while although the production of nylon fibre contributes heavily to climate change, its overall impact remains relatively low due to smaller production volumes.

Figure 15 Greenhouse gas emissions from the production of fibre, kilograms of carbon dioxide equivalent per kilogram of fibre



Source: Sandin et al. (2019)

Figure 16 Greenhouse gas emissions from global annual fibre production, 2018, gigatonnes (10^9 tonnes) of carbon dioxide equivalent per year



Source: Sandin et al. (2019) and Textile Exchange (2019)

3.4. Chemicals and health

As discussed in Section 2.2.4, chemical additives are used in all stages of the fibre and textile manufacturing process, from the raw material production through spinning, weaving and dyeing to finishing. Some are added to improve textile function, including flame retardants and repellents, or for effect such as dyes. Others are auxiliary chemicals, required to facilitate the manufacturing process but not providing any specific properties to the final product (KEMI, 2014).

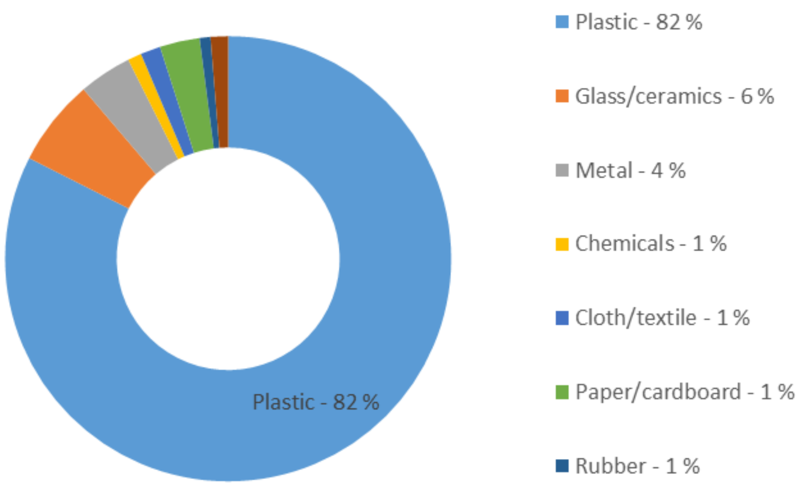
Compared to cotton, synthetic fibres require fewer chemicals for their production (Natural Resources Defense Council, 2012). In 2014, 3.9 % of global herbicide sales, 5.7 % of pesticide sales and 16.1 % of insecticide sales were made for cotton cultivation (Ferrigno et al., 2017). Heavy metals, such as antimony, a known carcinogen if inhaled, are often used as a catalyst in the production of polyester (Brigden et al., 2014) and these are also emitted during the recycling process (Common Objective, 2019). To avoid these potentially harmful substances, along with others including cobalt, manganese salts, sodium bromide and titanium dioxide, being released into the environment, wastewater treatment is critical in polyester production facilities (Muthu, 2020).

Furthermore, synthetics are often the main fibre type making up protective, outdoor and sportswear in which properties such as durability and fast drying are desired. These textile products are typically heavy on chemical use as they require specific finishing treatments to be flame or water resistant, or fluorescent. It therefore might appear that synthetic fibres require the use of more chemicals than natural ones, which is actually not the case – chemical use is related to the end application rather than the fibre type.

3.5. Microplastics

Plastic pollution in the oceans is a widely acknowledged problem, which attracts a lot of attention as pictures of seashores covered in plastic waste appear in the media regularly. Around 82 % of macro-sized marine litter is plastics, and a further 1 % identified as textile or cloth, of which an unknown part is synthetic textiles (Figure 17). However, it is estimated that only around 6 % of the total mass of plastic entering the oceans is actually visible (Sherrington, 2016); the majority of the plastic pollution in the oceans is fragments, particles or fibres smaller than 5 millimetres in diameter, so-called microplastics (Koehler et al., 2015).

Figure 17 Distribution of marine litter by material, per cent



Source: EEA (2020)

Microplastics are shed from synthetic textiles along their entire lifecycles: from fibre and fabric manufacturing, through use and washing, to their final disposal whether by landfilling, incineration or recycling. Although also large volumes of natural polymer fibres like cellulose and fibres of animal origin are detected (Suaria et al., 2020), it is estimated that between 0.2 and 0.5 million tonnes of microplastic fibres from textiles enter the marine environment each year (Ellen MacArthur Foundation, 2017; Eunomia, 2016).

Domestic washing during textile use is considered a relatively large source of microplastics leaking into the environment. It is estimated that one laundry cycle with synthetic textiles can emit between 700,000 and 6 million microplastic fibres, representing up to 0.5 % of the product's total mass (OECD, 2020; Ziajahromi et al., 2017). In this way, the washing of synthetic textiles may account for up to 35 % of total annual microplastic releases (OECD, 2020). Together with fabric composition, laundry parameters including machine load, washing temperature, water consumption and the length of the wash cycle are all expected to influence the level of shedding of synthetic textiles (Vesper, 2019), but little evidence is yet available on the mechanisms of microplastics release (Salvador Cesa et al., 2017). There is also insufficient proof of whether or not the use of recycled fibres influences shedding rates (Roos et al., 2017).

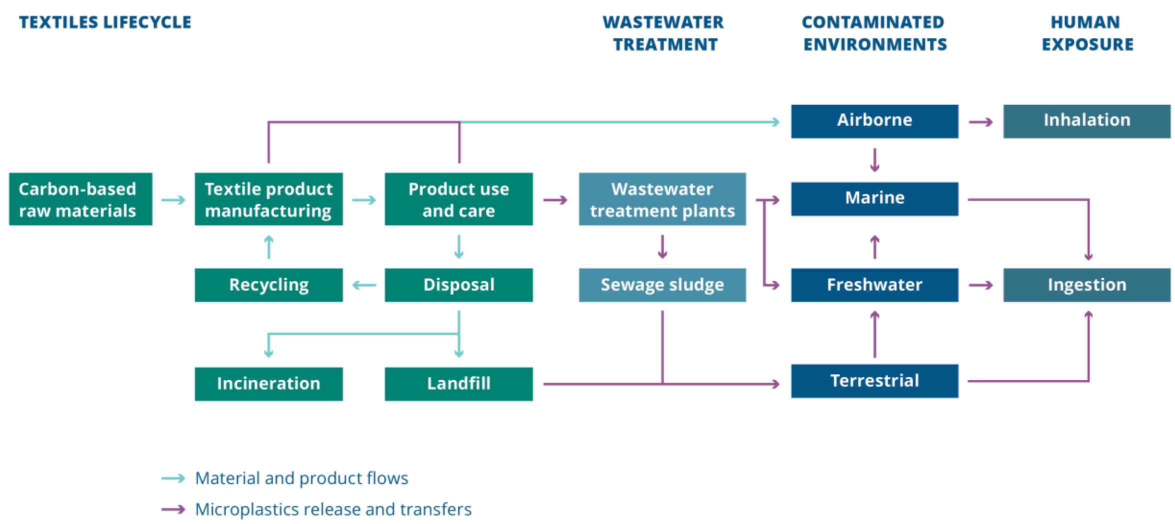
Fibres are the most common type of microplastic found in wastewater treatment plants, mainly polyester, followed by acrylic, nylon and polypropylene (Salvador Cesa et al., 2017). The use of nutrient-rich wastewater sludge in agriculture poses an additional environmental problem as this can lead to terrestrial microplastics contamination (OECD, 2020).

It is important to note that microplastics may also be released to air. For example, up to 65 % of microplastics may be emitted to aerial environments during drying and wearing of garments (OECD, 2020).

In common with all plastics, microplastics do not degrade in the short term and accumulate in natural habitats, potentially degrading into even smaller fragments – so-called nanoplastics. Potentially toxic chemicals and additives from the textile industry form an additional risk. They can be present in the microplastic fibres themselves or in the surrounding waters where they can be absorbed by the microplastic fibres (Salvador Cesa et al., 2017).

Although the long-term effects of microplastics on the marine ecosystem are still unknown, microplastic pollution raises risks for both the natural environment and human health. They are ingested by all kinds of aquatic species, ranging from plankton to larger mammals, leading to false sensations of satiation, irritation and injuries in internal parts of the digestive system. When ingested, microplastics can also impact on an animal's fitness and reproduction (Koehler et al., 2015). For land species there is additional exposure risk from the inhalation of airborne microplastics and the ingestion of contaminated drinking water. It is becoming clear that chronic exposure to microplastics, at least to some degree, is becoming inevitable as microplastics work their way up through the food chain, ending up in human food products. Unfortunately, the long-term potential negative health impacts of chronic human exposure to current levels of microplastics are not yet fully understood (Henry et al., 2019; SAPEA, 2019), and for nanoplastics, which are smaller than 1micrometre ([5]), an even bigger knowledge gap exists (OECD, 2020).

Figure 18 Potential release points, transfers and exposure routes of microplastics during the lifecycle of a textile product



Source: Henry et al. (2019), illustration by CSCP

[5] 1 micrometre is one thousandth of a millimetre.

4 Towards a circular economy for synthetic fibres and textiles, and the potential to reduce environmental and climate impacts

In recent years, awareness of the environmental and social impacts of textiles production and use has grown. Initiatives are being taken, at policy levels as well as within industry, to make the textiles system more circular and sustainable.

In the Circular Economy Action Plan, the European Commission has identified textiles as a priority product category with significant potential for circularity. The Action Plan recognises that "textiles are the fourth highest pressure category for the use of primary raw materials and water, after food, housing and transport, and the fifth for greenhouse gas emissions" (European Commission, 2020a; EEA, 2019). Responding to these challenges, the Commission is preparing a comprehensive EU Strategy for Textiles with concrete policy measures to strengthen industrial competitiveness and innovation in Europe, and boost the EU market for sustainable and circular products, services and business models. Foreseen measures include encouraging a market for textile reuse, promoting ecodesign and the use of recycled content, phasing out hazardous chemicals, and empowering businesses and private consumers to choose sustainable, reusable, durable and repairable products and product-as-service models such as sharing and renting. Demand for circular products could be boosted by encouraging public authorities to lead by example and adopt green public procurement, for example by supplying sustainable uniforms for the police and hospital staff.

In 2019, the first Product Environmental Footprint Category Rules (PEFCR) for textile products (T-shirts) were developed, based on the Commission's Product Environmental Footprint Guide in collaboration with the textiles and apparel sector (Pesnel and Payet, 2019). These Rules set a standardised method that producers should use to determine the environmental impact of their products – in this case, T-shirts. The aims are to allow benchmarking, to assure comparability between environmental claims that different brands use in communications, to inform consumers' purchasing decisions and to prevent greenwashing (Elsen et al., 2019).

As far as textile waste management is concerned, following the revision of the EU Waste Framework Directive, Member States will be obliged, by 1st January 2025, to collect discarded textiles separately, thereby facilitate sorting, re-use and the recycling of textiles.

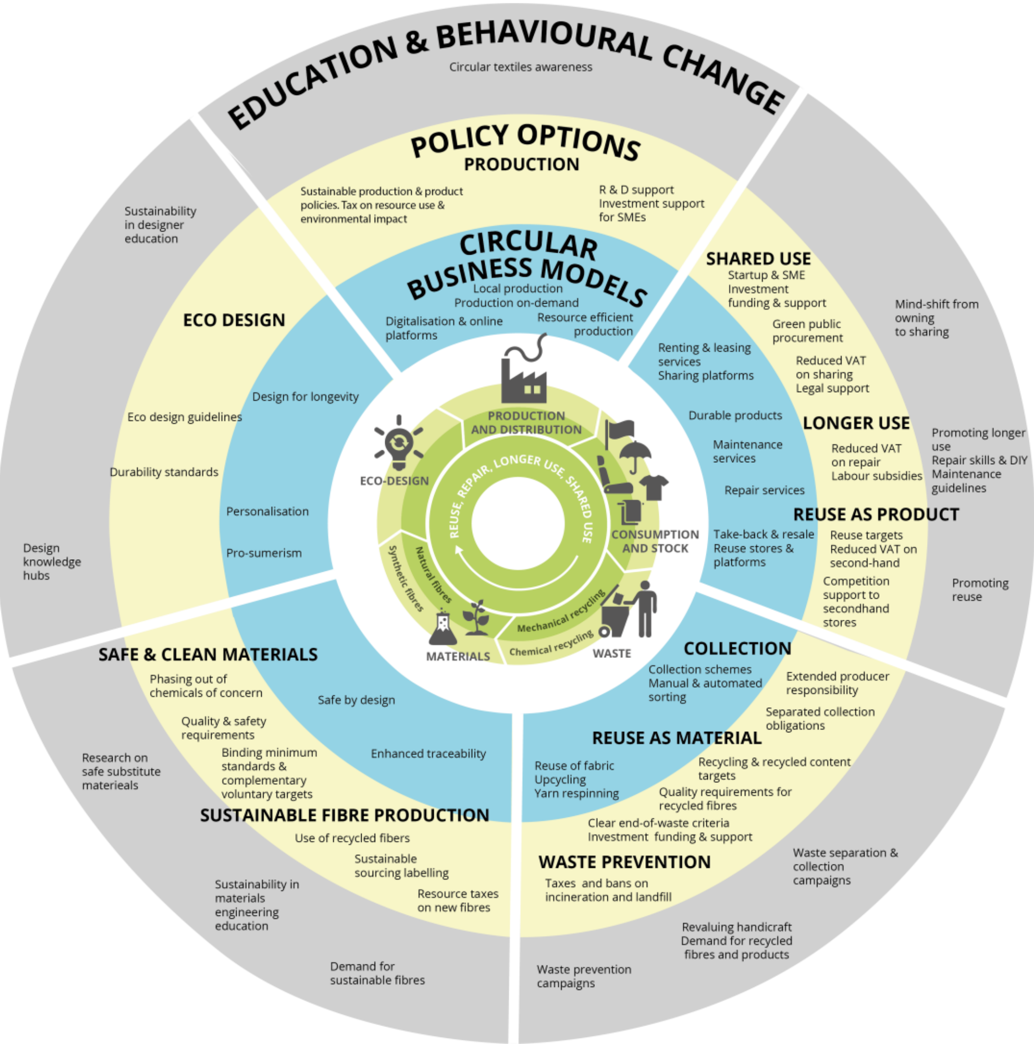
Within the textile industry, action is also being taken to move towards the development and use of more sustainable fibres, the improvement of efficiency in production processes and the reduction of the use of energy, water and chemicals throughout the value chain. In the fashion industry, many brands are making commitments to promote textile reuse and to replace conventional synthetic fibres by more sustainable alternatives, such as recycled polyester and nylon (Global fashion Agenda, 2020a). Other initiatives focus on uniting fashion brands to develop a vision on circular fashion (Fashion Positive, 2020), supported by innovation and value chain collaboration to improve industry sustainability and circularity (Euratex, 2020b). To encourage businesses to adopt more circular ways of working, business inspiration and support is provided (Fashion for Good, 2020), including information exchange, the development of standards and benchmarking across the industry (Textile Exchange, 2020b), as well as monitoring tools such as the Higg Index (Sustainable Apparel Coalition, 2020). On the waste side, the aim is to improve the valorisation of clothing waste in the EU by better collection (ECAP, 2020) and the development of large-scale automated sorting technologies such as Fibersort (Circle Economy, 2020).

As a result of the COVID-19 crisis, the EU textiles and apparel industry proposed a recovery plan for the textile, apparel and footwear industries, as an input to the EU Green Economic Recovery plan. This proposal includes both short- and medium-to-long-term measures to support the textile sector in overcoming the consequences of the crisis. The measures outlined in the proposal aim, in the short term, to ensure the economic recovery of the sector, including financial support, such as conditional loans, to companies and small and medium-sized enterprises (SMEs) to mitigate cash-flow problems and avoid job losses. These measures should, in the long term, accelerate the transition to a circular, resilient and low-carbon textile sector, creating new business opportunities and jobs in Europe. The proposed measures include, among others, incentives for stimulating market demand for circular products and services, such as tax measures to promote circular business models including renting, repairing and sharing, and the use of recycled fibres. Support is needed for research and development to facilitate circular design and sustainable material choices and to help scale-up textile waste collection and high-quality recycling. Finally, incentives for increasing traceability and transparency across the textile value chain are required, complemented by accessible product information for the consumer (Policy Hub and Boston Consulting Group, 2020). In addition, Euratex has proposed a “strategy for recovery from the COVID-19 era” together with five flagship initiatives, including the ambition to establish five large-scale textile recycling hubs near the major textile and apparel districts in Europe to support the collection, sorting, processing and recycling of post-production and post-consumption textile waste (Euratex, 2020c).

A shift towards a sustainable and circular textiles system requires a profound systemic change, including innovative production methods, new business models and social practices, more sustainable behaviour and supporting policy measures at all stages of the value chain.

The 2019 EEA briefing and ETC report *Textiles and the environment in a circular economy* presented an overview of options for circular business models, regulation and behavioural change in each phase of the lifecycle of textiles (Figure 19).

Figure 19 Circular economy options for textiles



Sources: EEA (2019); ETC/WMGE (2019b)

While many circular economy business models and policy measures are independent of the type of textile fibre used, involving, for example the phasing out of hazardous chemicals; promoting longer use, shared use and reuse; and improving separate textile waste collections, some specific focus points for synthetic textiles can be identified.

Without being exhaustive, the following sections provide an overview of some pathways to make synthetic textiles production and consumption more circular and sustainable,

- **Sustainable fibre choices**: in the design stage, important choices are made on the fibre types to be used for a particular product or application. These choices significantly affect the environmental impact of the resulting product and influence the fate of the synthetic textiles throughout the rest of their lifecycle.
- **Control of emissions of microplastics**: concern is rising about emissions of microplastics from synthetic textiles across their entire lifecycles. Several initiatives have been set up recently to study the factors that influence microplastics shedding and assess its effects on human health and the environment. The design and construction of textile products are crucial here. At the same time, many strategies to reduce the emission of microplastics to water and air are being explored.
- **Improved separate collection, reuse and recycling**: reuse and recycling are critical to reducing the demand for virgin fibres and moving towards a circular economy. At the end-of-life stage, accurate sorting and high-quality textile reuse and recycling have considerable potential to reduce the

environmental impacts associated with textile consumption. Fibre recycling is especially challenging in the case of synthetic textiles, due to technical and economic limitations.

These pathways will be further explored in the following sections.

In addition to these, improved market surveillance is needed to assure that all products put on the European market are compliant with sustainability criteria. Building awareness and changing consumer behaviour and public procurement protocols are also key to encouraging conscious textile buying, even when the price is higher; longer use; buying second-hand; repair and better textile collection. Awareness raising campaigns, clothes swapping events, vintage fairs, upcycling workshops, collection campaigns and similar initiatives involving young people can help create a shift in mindsets towards more sustainable textile consumption (ECAP, 2019).

4.1. Sustainable fibre choices

The design stage is crucial in the development of a circular value chain for synthetic textiles, with fibre types usually the first choice made for products or applications.

Low-impact, durable and recyclable fibres

Selecting the right fibre can generate significant environmental benefits along the lifecycle of a textile product. As discussed in Section 3.1, environmental profiles differ considerably among fibre types. The overall environmental burden is influenced by the fibre type itself, as well as the intended use, caretaking, lifetime and end-of-life treatment of the product.

Given that each fibre has specific mechanical, comfort and aesthetic properties, it is crucial to select the best-in-class fibre for the final application and to use each fibre to its full potential. One way of achieving this can be to take the expected speed of product cycles into account in the fibre selection process. This means that more durable fibres can be used for long-lasting slow fashion and heavily-duty technical textiles, while more brittle fibres can be used for fast-fashion products (Sandin et al., 2019).

Compared to cotton, polyester textiles and polycotton blends have superior mechanical properties in terms of strength, abrasion and resistance, making them more durable and longer lasting. That is why, for products which require technical strength, for example, synthetic fibres might be the most sustainable choice (Sandin, et al., 2019).

Once a suitable fibre type has been selected, it remains important to look for the lowest impact variants, such as organic or recycled ones (Natural Resources Defense Council, 2012), and to use them in their pure, non-blended form if possible – single fibre textiles are easier to recycle after use (Section 2.3.2) as it is challenging to separate and recycle fibre blends such as polycotton. Nonetheless, any textile recycling strategy should be careful not to compromise durability, as extended product lifetimes rather than early recycling are preferable (Watson et al., 2017).

The importance of fit-for-purpose fibre selection implies that no fibre types, such as synthetic ones, should be entirely ruled out and that there is no go-to fibre type which of itself would guarantee a sustainable textile industry. On the contrary, reducing textiles' environmental footprint requires a great diversity of fibres in terms of raw material input, manufacturing processes and properties. This diversity also contributes to healthy ecosystems and allows the building of resilient supply streams (Sandin et al., 2019).

Bio-based and biodegradable fibres

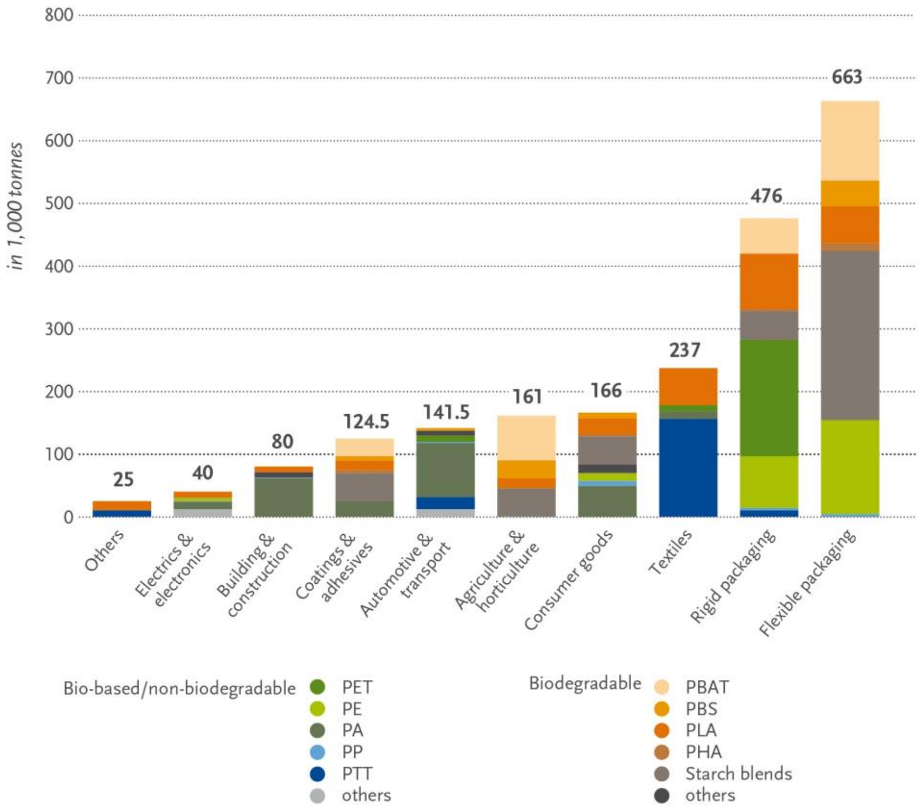
Another option that is often put forward is the development of renewable, bio-based synthetic fibres. Some bio-based fibres, including bio-PET, are structurally and functionally equivalent to their fossil-based counterparts – these are called 'drop-in polymers', which means they can easily replace conventional fibres in similar applications. Other bio-based fibres are completely new polymers with new combinations of properties for new applications. Some bio-based fibres, such as polylactic acid (PLA), are biodegradable but it is important to note that many, including bio-PET, are not.

Although data on the production and use of bio-based polymers are scarce and scattered (Ronzon et al., 2017), it is clear that current production and consumption levels are low. It is estimated that the production of bio-based plastics accounts for nearly 1 % of global plastics production, slightly more than 2 million tonnes (European Bioplastics, 2020; van den Oever et al., 2017). About a quarter of the world's bio-based plastic production capacity is located in Europe, while about 45 % of bio-based plastics are produced in Asia (European Bioplastics, 2020).

While the main application of bio-based plastics is in packaging, 54%, the equivalent of 1.14 million tonnes in 2019 (Figure 20), about 240,000 tonnes, around 11 % of global production, were used in textiles, mainly polytrimethylene terephthalate (PTT) and PLA. The latter is similar to PET and is often used to replace it, mainly in food packaging. Its fibers are also used in the production of a variety of textiles, such as outdoor clothing, curtains, non-woven infant wipes and durable landscape textiles (Babu et al., 2013).

Fibres made from PTT unify the best characteristics of nylon, polyester and elastane: they are very durable, resilient and dirt-resistant, with excellent elasticity. Compared to other synthetic fibres, PTT is softer, easier to dye and has better shape-recovery properties. The most common applications are carpets and leisure and sportswear (Fibre2fashion, 2020b; McIntyre, 2005).

Figure 20 Global bioplastic consumption by sector, 2019, '000 tonnes



Source: courtesy of European Bioplastics (2020)

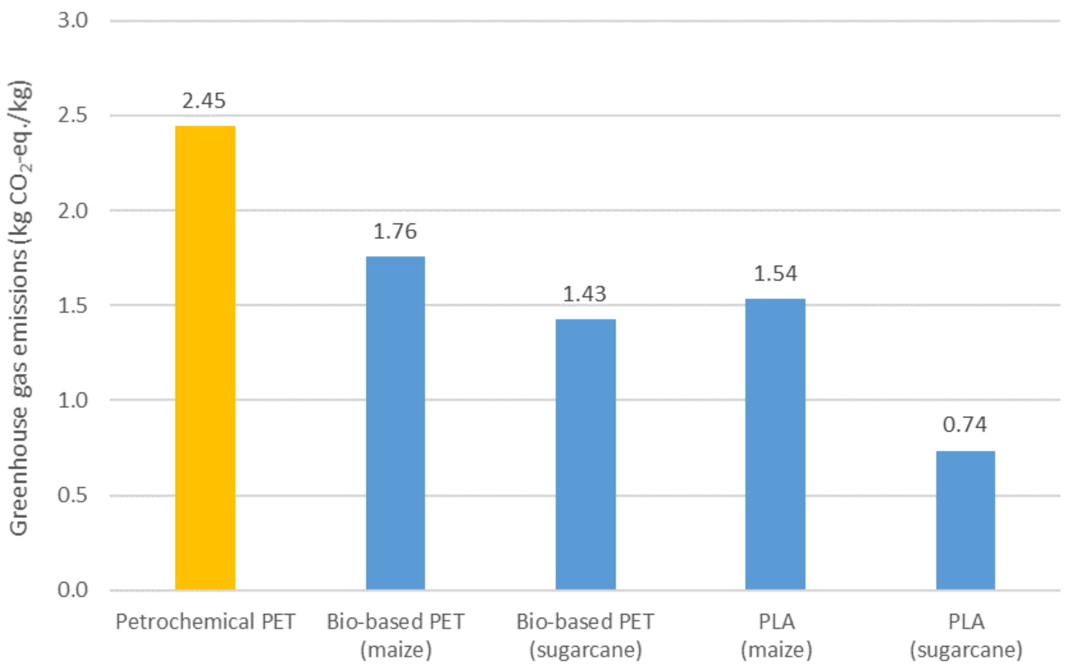
Current industrial initiatives focus mainly on bio-versions of conventional synthetic fibres, such as bio-PET or bio-nylon. While they are plant-based, mainly maize, sugarcane or plant oils, they have exactly the same structure and properties as their fossil counterparts, and thus can be easily integrated into existing production processes. Nevertheless, market shares of these bio-based fibres are still very low. It is estimated that bio-based PET and bio-based nylon account for less than 1 % of their markets. The global production of bio-based nylon amounts to about 0.24 million tonnes per year. Depending on the brand, bio-based nylon is derived from castor oil, beans or other plant sources (Textile Exchange, 2019). Bio-based fibres can also be used in blended fabrics such as wool/PLA and cotton/PLA (Textile Exchange, 2019).

Moving away from the use of fossil resources is key in the fight against climate change and resource depletion. The Ellen MacArthur Foundation has estimated that around 48 million tonnes of oil are used each year for the production of synthetic textile fibres (Ellen MacArthur Foundation, 2017). Bio-based polymers are mainly made by bacterial fermentation processes from starch and sugars, such as maize and sugarcane, although concerns about competition with food crops has brought about a shift towards using organic waste as a resource. Lifecycle assessment data have shown that bio-based products potentially have a lower impact on climate change than fossil-based alternatives (Box 3).

Box 3. Environmental and climate impacts of bio-based fibres

A study by Semba et al. (2018) calculated that greenhouse gas emissions from the production of 100 % bio-PET polymer are 24–58 % lower than those of petroleum-based PET, depending on the feedstock used and the production process. A comparison made by Shen et al. (2012) shows that the greenhouse gas emissions from the production of (partially) bio-based PET and 100 % PLA fibres are considerably lower than those of petroleum-based PET fibres (Figure 21). It has to be noted, however, that while the functionalities of PET and bio-PET are identical, the properties of PLA are not fully comparable.

Figure 21 Comparison of climate change impacts of (partially) bio-based PET containing 30 % bio-based ethanol and 100 % bio-based PLA fibres, cradle to gate, kilograms of carbon dioxide equivalent per kilogram



Source: Shen et al. (2012)

Nonetheless the production of bio-based raw materials has other sustainability issues, such as the use of land, water, fertiliser and pesticides. Land use is a particular area of debate, since the cultivation of biomass for bioplastic production and other non-food uses can compete with food production for arable land . It is estimated that the cultivation of crops for bioplastics amounted to 0.8 million hectares in 2019, which is about 0.016 % of global arable land (European Bioplastics, 2020). Such competition for land could, however, become more significant if the global demand for biomaterials and bioenergy resources takes off. The shift to bio-based materials and energy production requires coordinated action to tackle sustainability trade-offs. The development of a bio-economy definitely needs to go hand in hand with the creation of a circular economy if it is to be sustainable (EEA, 2017).

Although there is growing interest from textile sector stakeholders in bio-based fibres, there are few actual commitments to replacing fossil synthetics with bio-synthetics (Textile Exchange, 2019) and many barriers still limit the further commercialisation of bio-based fibres. Production costs of bio-based polymers are higher than for conventional oil-based ones; process efficiencies are still low and the supply of biomass feedstocks is cumbersome, hindering the building of large-scale plants that would allow economies of scale. Additionally, as some new bio-based fibres have different structures and properties than conventional ones, they often cannot yet be handled in current textile production processes.

These issues could be overcome by blending bio-fibres with other polymers or using additives to improve their performance (Babu et al., 2013). Nevertheless, many initiatives to manufacture various high quality, cost efficient bio-based fibres are currently underway (Kaeb et al., 2016). The use of carbon dioxide as an alternative feedstock for elastic fibres is also being explored, but is still at the research stage (Covestro, 2019). Such waste-based feedstocks and new processing routes may further decrease the environmental footprint of bio-based materials.

4.2. Microplastic emission control

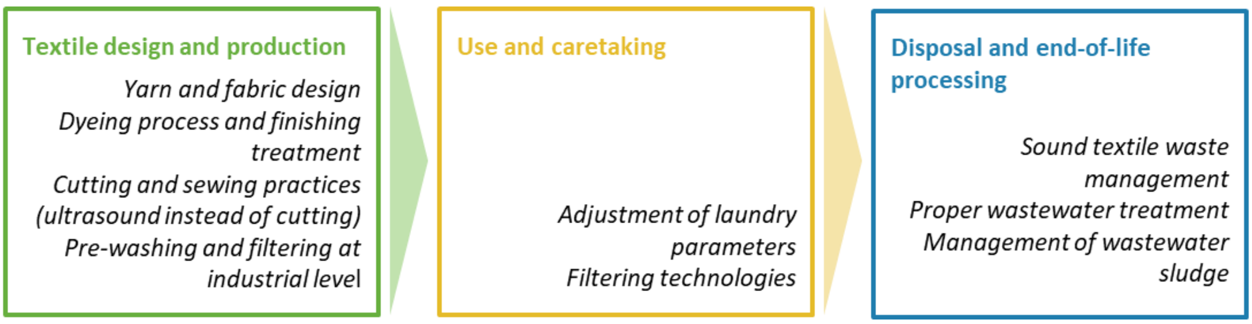
As discussed in Section 3.5, synthetic fibres are a major contributor to the problem of microplastics release into marine, freshwater, aerial and terrestrial environments. Although this emerging issue has gained a lot of attention from research and policy over recent years, the topic is still characterised by many unknows. Improved understanding and extended knowledge sharing are required on the composition of the fibres released, microplastics shedding mechanisms, the associated ecosystem and health risks, and potential mitigation approaches. To this end, the European Committee for Standardization's (CEN) testing methods to identify and quantify microplastics present in the marine and other environments are currently in the final stages of development (British Standards Institution - Project, in press). Another requirement is the introduction of harmonised and reproduceable sampling and measurement methods to quantify release rates along different lifecycle stages of textile products, and to assess scalable measures for mitigation (Pero, 2019).

Interventions are recommended as far up the textile supply chain as possible to limit microplastics shedding further downstream. This does by no means imply that interventions during the use and end-of-life processing of textiles should be omitted, as complementary measures covering the entire product lifecycle are indispensable in optimally tackling shedding (OECD, 2020).

Of course, the problem of microplastics shedding is only one aspect of the multidimensional challenge of improving the environmental performance of the textile industry as a whole. Interventions on microplastic pollution, therefore, need to be embedded in larger policy frameworks aimed at addressing the wider environmental impacts of the sector.

Although more extensive research is required, Figure 22 provides an overview of potential mitigation pathways along the lifecycle of a synthetic textile product. These are discussed in the following sub-sections.

Figure 22 Possible mitigation action to prevent microplastics release along a textile product's lifecycle



Source: OECD (2020)

Design and production

As mentioned earlier, it makes sense to intervene as early in a textile's lifecycle as possible to avoid the release microplastics later on. Alterations in the design and production of synthetic textile products could decrease shedding rates in later stages of the lifecycle by as much as 80–90 % (OECD, 2020). While improved design and manufacturing techniques are still under research and development, some key areas of attention are already identified

First steps are to prevent fibre irregularities and to preserve yarn strength. This can be realised by melt spinning at lower temperatures, choosing continuous fibres over staple fibres to create yarns (OECD, 2020) and using the right knitting technique (Vesper, 2019). In terms of the dyeing process, yarn dyeing has some benefits over garment dyeing when it comes to the release microplastics. There are also some mechanical and chemical finishing treatments which form a layer over the textile product, protecting and preserving it. Although these measures may increase a fabric's resistance to shedding (OECD, 2020), one important drawback is that they might influence the final product's properties in ways that are not always desirable. Applying ultrasound or laser techniques in the cutting process instead of scissors further reduces the shedding risk (Roos et al., 2017).

Finally, synthetic fabrics tend to release the highest amount microplastics during the first 5–10 washings, but this could be reduced by increased pre-washing and filtering in the manufacturing plant (OECD, 2020).

Use and caretaking

In Section 3.4 the high volumes of microplastics shed by synthetic textiles during domestic and/or industrial washing was discussed. To a certain extent the shedding rate depends on the laundry parameters applied. While a lot of research is still ongoing, there is some consensus that washing at low temperatures, in full machine loads and the use of fabric softeners decrease shedding rates (Vesper, 2019; OECD, 2020).

There are some technical solutions and laundry supplements available that limit microplastic shedding during home washing (Textile Exchange, 2019). Examples include laundry balls that claim to collect microplastics into visible fuzz (Coraball, 2020); a micro-filter washing bag that aims to collect microplastics (Guppyfriend, 2020); and filters at the outlet of the washing machine that collect microplastics (Filtrol, 2020; Xeros, 2020). Some trade-offs might, however, have to be made, especially for these filters, as the energy efficiency of the appliance might be influenced as well as the duration of washing cycles (OECD, 2020). It should also be guaranteed that the collected microplastics can be disposed of safely (Roos et al., 2017), which might prove challenging.

One way of informing consumers about the risks of microplastics shedding and possible precautions that can be taken is to include labels on synthetic textiles.

Disposal and end-of-life processing

The risk of microplastic emissions is especially high if textile products are landfilled at the end of their useful lives. Synthetic fabrics do not degrade completely but instead break down into smaller fragments and ultimately into micro- and nanoplastics. The aim should be to recycle as much textile waste as possible, avoiding landfill whether in or outside Europe. If mitigation pathways are developed for microplastic shedding within Europe, it would become especially important not to export textile waste to countries where these might not be in place.

When it comes to contaminated wastewater, conventional wastewater treatment plants are not designed to remove microplastics entirely (Salvador Cesa et al., 2017), although up to 98 % of microplastics can be removed by primary and secondary treatment and there are already some technologies available which can retain up to 99.9 % of them (OECD, 2020). However, an unfortunate drawback, discussed in Section 3.4, is that microplastics collected from wastewater end up in sludge. This is widely used in agricultural applications, leading to the contamination of terrestrial environments. Common sludge treatment does not appear to retain microplastics so solutions to address this pathway of microplastics leakage are required (OECD, 2020).

4.3. Improved collection, reuse and recycling

While selective textile collection rates vary across Europe, it is estimated that about 4 million tonnes of textile waste are not collected separately and end up in mixed municipal solid waste, while 1.5 million tonnes of collected worn textiles are eventually exported beyond the EU (ETC/WMGE, 2019a). Tapping into the potential of high-quality textile reuse and recycling is an opportunity for European industry and could at the same time bring significant reductions in greenhouse gas emissions.

Collection and sorting

Collection systems for textiles need to be put in place and improved as, across Europe, only about a third of used textiles is collected separately, with large differences in collection rates between countries (European Commission, 2020b; Watson et al., 2018). To increase this share, several measures could be deployed including awareness raising campaigns and the establishment of accessible collection points close to consumers' homes – in shops, schools, community centres, etc. – or door-to-door collections. Of course, if large volumes of used textiles are to be collected, sufficient sorting and recycling capacity need to be available (Hardy, 2020). To facilitate sorting it could be advisable to install different collection systems for different product types – separate collection of carpets, reusable clothing, non-reusable items – however, such guidelines need to be clear and simple and should be carefully balanced with associated costs for collection logistics. Separate collection of textile waste will be obligatory in all Member States after 1 January 2025. Harmonisation of sorting procedures and criteria among Member States could be beneficial in supporting efficient intra-EU trade in sorted textiles for recycling.

Textile sorting is often a manual process, limiting throughput capacity. Moreover, the huge variety of fibre types; the widespread use of blended fibres; and the presence of contaminants, such as non-textile elements, dyes, coatings, etc., makes identification and sorting challenging. Technical innovation in the field of sorting is needed to increase capacity and accuracy through automation and identification of textiles through, for example, the use of near-infrared spectroscopy. Additionally, better pre-sorting by consumers, through separate collection boxes for shoes, T-shirts, denim, etc. in stores, for example, could facilitate subsequent industrial sorting processes.

Unfortunately, the logistics and cost of collection, sorting and recycling often hamper the economic viability of the processes and thus the incentive for investment. It is important to note that economics are driven by the share of reusable items, as non-reusable textiles have no value (Watson et al., 2020). Transport costs can be reduced by developing sorting and pre-processing of post-consumer textiles facilities close to their source, or at least in-country, to avoid cross-border transport. Changes in regional regulations or waste definitions may be needed to ease the transport of used textiles and recycled materials. To optimise sorting at small-scale collectors, such as charities, shared sorting facilities could be created (WRAP, 2019). The introduction of an extended producer responsibility scheme for textiles, including eco-modulation of fees, could be used to raise funding to support investment in collection, sorting and recycling capacity in the EU, as well as investment in research and development of efficient sorting and recycling processes (Hardy, 2020).

Reuse

Textile reuse refers to various means for prolonging the practical service life of textile products by transferring them to new owners, with or without prior modification. The reuse of textiles has considerable environmental benefits, since it offsets primary textile production (Schmidt et al., 2016). Customer surveys in the Nordic countries revealed that about 60 % of clothing reuse replaces new purchases and thus contributes to reduced consumption (Farrant et al., 2010).

The potential for reuse is significant. It has been estimated that about 40 % of clothes and shoes in residual household waste in the UK could have been directly reused (Laitala, 2014). As a matter of fact, research has shown that many consumers prefer to deliver clothing for reuse rather than disposing of them, but convenience is paramount. In general, consumers are more likely to donate used clothes to charities and/or friends and family rather than selling them (Savers, 2018; Laitala, 2014). At the same time, there is a need for consumers to embrace the full cycle of reuse, not only donating, but also shopping for used or upcycled products – a recent study (Savers, 2018) indicates that the proportion of people regularly purchasing pre-owned goods is still a minority. Nevertheless, the market for second-hand clothing is growing, especially online when shoppers were stuck at home due to COVID measures (Marketplace, 2020; ThredUp, 2020). Some sources expect the reuse market to become larger than the market of fast fashion in the next 10 years (Textile Focus, 2020; ThredUp, 2020).

Some service-based business models – renting, sharing or leasing of textile products – also make use of reuse principles (Sandin and Peters, 2018b). The most prominent examples are clothing and equipment libraries from which consumers can rent items (Adam, 2018) or leasing systems for hotel linens, uniforms or workwear (Watson and Trzepacz, 2019). For the customer, such services reduce the need to invest in expensive products and concerns related to storage (Glusac, 2019; Hu et al., 2014). As these service models imply more intensive product use and the provider bearing maintenance and replacement costs, they can steer a company's product design choices towards higher quality, greater durability and increased reparability (Holtström et al., 2019; McCann, 2015). Leasing systems for professional textiles, such as hotel linens and uniforms, also offer the opportunity for improved recycling, since large quantities of homogenous textiles can be collected and processed.

A number of sports brands have initiated sustainability programmes involving a commitment to buy back own-label used clothing in good condition. Some have also introduced a repair policy for own-label clothing sent back by customers either for free or for a fair price (McCann, 2015). A recent analysis (Baier et al., 2020) indicated that returning used products for reuse/recycling is attractive for sports equipment consumers, although the overall importance of sustainability as a purchasing criterion among consumers is still marginal compared to other drivers including appearance, comfort, and quality. Reuse platforms such as rental services and fashion libraries could, however, combine both values in accordance with consumer attitudes (Baier et al., 2020).

Nevertheless, business models aiming at reuse, shared use and longer use face many potential obstacles. Financial challenges entail the need for start-up investment and difficulties in convincing financing institutions to provide funding to these new and relatively unknown business models; and increased operating costs of labour, servicing and logistics. Non-financial obstacles are various, such as difficulties in finding textiles for reuse, organising logistics, upscaling, marketing, raising customer awareness and legal issues related to waste legislation (Elander et al., 2017). Governments can support businesses in overcoming these barriers by adopting suitable policy instruments (Watson, Gylling, and Thorn, 2017).

Recycling

Although reuse has far greater environmental benefits than recycling (Schmidt et al., 2016), it is not always a feasible option, for example, when a product is damaged or worn out. In those cases, textile recycling is the next option in line.

More and more brands are setting ambitious targets for the use of recycled fibres from post-consumer textiles in their products as a result of an increased awareness of the environmental impacts associated with textiles (Global fashion Agenda, 2020a; Watson, Gylling, Andersson, et al., 2017). This suggests a great potential for high-quality fibre-to-fibre recycling although currently the recycling of textile fibres into new ones is negligible. This illustrates a supply-demand gap present in the textiles value chain.

The current textile recycling processes are mainly mechanical, aimed at cotton recycling. These processes suffer from quality loss and are unable to separate different polymers present in blends. To achieve fibre-to-fibre recycling for synthetic textiles, alternative (bio)chemical recycling processes are under development (Box 4). Some of them have already been applied industrially but most are in research and development or at a scale-up stage, for example, in the framework of Horizon2020 or Interreg research projects (Decoat, 2020; Enter, 2020; Resyntex, 2020; Retex, 2019).

Box 4. Chemical recycling of polycotton blends

Cotton-polyester blends can be chemically recycled into cellulose pulp (from the cotton) and a polymer fraction (PET). The recovered polymers are then processed into pellets, which can re-enter the yarn manufacturing process, or can be used in other plastic applications.

Prior to chemical recycling, the feedstock needs to be carefully sorted to meet the process specifications. All non-textile elements and contaminants – buttons, zips, etc. – that may interfere with fragmentation or with later stages in the process need to be removed. Since manual sorting is too inaccurate as care labels in garments are often missing or washed-out, automated near-infrared identification techniques are required.

The first step in the recycling process is the shredding of the feedstock into millimetre-sized fragments to facilitate the dissolving process. The choice of solvent forms is a key element of the recycling process. Each solvent selectively dissolves or degrades a specific fibre fraction, which then can be separately recovered from the solvent. The recovery of synthetic fibres involves depolymerisation followed by downstream processing to produce polymer pellets. From the cotton, a cellulosic pulp can be recovered that can be processed into a viscose-like material. Finishing chemicals, dyes and other products end up in a waste fraction that is typically incinerated or landfilled. Spent solvents are typically recovered to minimise waste and reduce processing costs (WRAP, 2019).

A financial model, created by the Waste & Resources Action Programme (WRAP, 2019), suggests that chemical fibre-to-fibre recycling of polycotton blends could be financially viable. However, such viability depends on the price and availability of sufficient volumes of well-sorted textile waste and the market value of the resulting cellulosic pulp and polyester pellets.

Chemical recycling still suffers from many knowledge gaps and technical hurdles. Sorting capacity and accuracy remain a challenge, while the economic viability is still questionable. Moreover, there are many uncertainties about the environmental impacts of the process (Zero Waste Europe, 2019).

Other major barriers for high-quality textile recycling from a design point of view are the use of coatings, dyes and non-textile objects, such as buttons and zips (ETC/WMGE, 2019b). To tackle these issues, collaboration between designers, manufacturers and recyclers is essential to align product design choices and manufacturing techniques with end-of-life treatment options. Aiming for single fibres, the phasing out of persistent hazardous substances and enabling the removal of buttons and zips, for example, would improve the recyclability of products at end-of-life. Modulated extended producer responsibility fees, depending, for example, on the recyclability of products put on the market, could stimulate the choice for materials and designs that are easier to recycle (Scalia, 2020).

To support the uptake of recycled fibres in manufacturing processes, a marketplace for recycled fibres needs to be developed, with adequate standards and specifications and with prices that are able to compete with the those of virgin equivalents. Internalising the environmental costs of virgin fibres by introducing taxes on virgin raw materials in the form of, for example, refunded virgin payments (RVP) schemes, which refund producers proportionally to the share of recycled textile fibres they use, could be effective in creating an economic advantage for recycled fibres and material reuse (Elander et al., 2017).

Furthermore, demand for recycled fibres could be stimulated by the introduction of targets for recycling and recycled content (EuRIC, 2020) or sustainability criteria in public procurement. The development of suitable product codes, such as HS or Prodcom, to register trade in recycled fibres would also allow better monitoring of recycled fibre use, which is currently based on estimates (CIRFS, 2020c).

Better transparency and traceability in the supply chain would further decrease uncertainties about product/fibre quality (Elander and Ljungkvist, 2016) and partnerships between textile product brands, fibre manufacturers, recyclers and authorities need to set up to educate each other and work together to bring about a circular economy for textiles (Euratex, 2020a).

5 Lessons for the European plastics and textiles strategies

The new Circular Economy Action Plan is one of the building blocks of the European Green Deal, Europe's roadmap for achieving sustainable growth. Plastics and textiles are mentioned in the Action Plan as two of the key product value chains for which the development of a circular economy in Europe should be prioritised (European Commission, 2020a). As such, plastic-based, synthetic textiles are positioned at the crossroads of these priority areas. Synthetic textiles play an important role in our everyday lives; they are used in clothing, footwear, household linens and home furnishings, as well as in a wide range of technical applications, such as protective wear, in transport and machinery. While Europe is the largest importer of synthetic textiles, its domestic fibre production is significant and it is also a large exporter of synthetic textile products to the rest of the world, with the EU industry specialising in specialty fibres and high-value technical textiles.

Polyester (PET) is the most commonly used synthetic fibre; it has outgrown cotton at the most used fibre in textiles. Synthetic fibres have particular properties that contribute to high-quality, high- performing and durable textile products, which, for example, support long product lives and easy maintenance – qualities that contribute to a circular economy. Nevertheless, the production and consumption of synthetic textiles contribute significantly to environmental impacts such as fossil resource and energy use, greenhouse gas emissions and to a lesser extent to impacts related to the use of chemicals. This implies that trade-offs need to be made between the environmental impacts of synthetic textile production and desirable properties that improve product performance and longevity. Also, there is a need for innovation that decouples textiles production and consumption from the use of resources with negative environmental impacts.

A particular point of concern is the release of microplastics, the small plastic fibres that are shed from synthetic textiles during the production, washing and end-of-life treatment. The long-term consequences that these microplastics have on the marine, terrestrial and aerial environments, soil health, aquatic and terrestrial species and human health are still unclear, as are the specific conditions that promote or reduce their release. A lot a research is going on to better understand shedding behaviour and sources, quantifying volumes and risks, and finding solutions at different stages of fabrics' lifecycles to prevent shedding and remove microplastics from wastewater.

It is clear that general initiatives that support the creation of a circular textiles system are also very relevant. These include products designed for durability and repair, innovative and resource-efficient production methods, new business models that focus on reuse and shared use, awareness raising campaigns that promote sustainable consumer behaviour and supporting policy measures that encourage repair, reuse and recycling (ETC/WMGE, 2019b).

Since synthetic textiles have a few characteristics of their own, this report explored some pathways that have the potential to improve the sustainability and circularity of synthetic textiles in particular.

- **Sustainable fibre choices**: the choice of fibres does not only define product properties and performance, but also determines the environmental impact of the resulting product and will influence the fate of the synthetic textiles throughout the rest of their lifecycles. While a shift to natural or bio-based fibres may reduce the impact related to the use of fossil resources, these fibres do not always have equivalent properties and are not necessarily more sustainable. A guiding principle is that the choice of fibre should match the anticipated application – the properties required, expected lifetimes and expected end-of-life processes.
- **Microplastics emission control**: although the discovery of this issue is fairly recent, several initiatives have been set up to study the factors that influence the shedding of microplastics and assess its effects on human health and the environment. At the same time, many strategies, such as adapted textile construction and filters in washing machines, are being explored to reduce the

emissions to water and air during a textile's lifecycle. The EU Plastics Strategy will target increasing the capture of microplastics, for example, by filters; improving and harmonising measuring methods; and building the knowledge base related to the risk and occurrence of microplastics in the environment (European Commission, 2020a).

- **Improved separate collection, reuse and recycling**: improved separate textile collection, accurate automated sorting and high-quality textile reuse and recycling have a significant potential to reduce environmental impacts. Many technical, economic and social challenges, however, will have to be overcome to facilitate and encourage reuse and to make fibre-to-fibre recycling technically and economically viable. Following the EU Waste Directive, separate collection of textile waste will be obligatory in all Member States from 1 January 2025. This calls for the installation of sufficient sorting and recycling capacity.

Unfortunately, the COVID-19 crisis has led to a decrease in consumer demand for textiles, and consequential cash-flow problems and unemployment in the textiles sector and raised concerns that these factors could slow down the shift to a low-carbon and more circular textile sector. At the same time, it demonstrates the fragility of the current way of working and offers a momentum to fundamentally change the textile system in favour of a circular system with positive economic and environmental outcomes. Already, a trend towards longer use and reuse of textiles is emerging as 71% of consumers indicate they are more interested to invest in higher quality clothing and would consider buying second hand, reselling, refurbishing or renting (Global fashion Agenda, 2020b; ThredUp, 2020).To achieve a sustainable and circular textile system, while at the same time supporting economic recovery, the textile and apparel organisations have proposed a list of measures (Euratex, 2020a; Policy Hub and Boston Consulting Group, 2020). Apart from financial support to companies and small and medium-sized enterprises to mitigate short-term cash-flow problems and avoid job loss, the measures include a set of options aimed at sustaining and accelerating the transition to a circular, resilient and low-carbon textile sector.

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