Circular Economy in the Textile Sector

Study for the German Federal Ministry for Economic Cooperation and Development (BMZ)

Published by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Executive summary

This report was commissioned by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and funded by the German Federal Ministry for Economic Cooperation and Development. It addresses the concept of a circular economy in the textile industry with a particular focus on fibres in the garment and fashion sector. The contents are based on a comprehensive literature analysis, an expert workshop held during this 2018's Cradle to Cradle (C2C) international congress as well as more than 20 interviews with professionals from the textile sector.

The report outlines the conceptual implications for a circular textile sector, presents the status quo of implementing a circular textile industry at the EU level, assesses innovative recycling technologies and discusses challenges and potential solutions for the transformation to a circular textile sector. In this first part, the following working definition of circular economy in the textile industry is suggested:

> *"A circular textiles economy describes an industrial system which produces neither waste nor pollution by redesigning fibres to circulate at a high quality within the production and consumption system for as long as possible and/or feeding them back into the bio- or technosphere to restore natural capital or providing secondary resources at the end of use."*

Based on this understanding, the transition towards a circular textile industry will require fundamental changes in the way products are designed and used, business is conducted and progress is measured at the corporate level. The background analysis suggests that the transition towards a circular textile industry in Europe and Germany is still in its infancy. This is directly linked to a wide range of socio-economic, environmental and legal barriers which inhibit the adoption of circular solutions on a broader scale. At the same time, a number of potential solutions exist and innovative recycling technologies can help to close material loops at the end of the textile use phase. However, none of them have reached market maturity yet, suggesting that further financial and technical support is needed for commercialisation.

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BAT	Best Available Technologies
BMZ	Federal Ministry of Economic Cooperation and Development, Germany
BMBF	Federal Ministry of Education and Research
BREF	BAT reference document
BMWi	Federal Ministry of Economic Affairs and Energy
C2C	Cradle to Cradle
CE	Circular Economy
ECAP	European Clothing Action Plan
EEA	European Environmental Agency
EMF	Ellen MacArthur Foundation
EoU	End-of-Use
EPR	Extended Producer Responsibility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GOTS	Global Organic Textile Standard
GPP	Green Public Procurement
IPPC	Integrated Pollution Prevention and Control
LCA	Life Cycle Analysis
MENA	Middle East and North Africa region
MSI	Multi-Stakeholder Initiative
NIRS	Near infrared spectroscopy
PET	Polyethylenterephthalat
PRO	Producer Responsibility Organisation
WRAP	Waste and Resources Action Programme
UBA	Federal Environmental Agency
USP	Unique Selling Point

1 Introduction

Throughout recent years, demand for textile fibres, first and foremost in the fast fashion segment, has increased tremendously. Global fibre consumption is expected to reach between 130 and 145 million metric tonnes by 2025 (Ellen MacArthur Foundation 2017a). At the same time, the textile industry is often described as one of the most polluting and resource-intensive industries in the world. In order to transform the textiles value chain towards actively contributing to social, economic and environmental development, public and private stakeholders have started to embrace the concept of a circular economy.[1] Mainstreamed by the Ellen MacArthur Foundation (EMF) (as well as the Cradle to Cradle movement, amongst others), the circular economy is described as restorative and regenerative by design, fostering system-wide innovation and redefining products and services to eliminate the concept of waste whilst minimising negative impacts and creating positively defined (i.e. material health) products for specific circular application scenarios.

The following report is divided into two parts. The first part presents an in-depth analysis of circular economy in the textile sector in EU-countries (including Germany) by providing brief conceptual considerations for a circular textile sector, presenting the status quo of implementing a circularity textile industry at the EU level, assessing innovative recycling technologies and discussing challenges and barriers as well as best practices and solutions for the transformation to a circular textile sector. The second part provides recommendations to the German Federal Ministry of Economic Cooperation and Development (BMZ) and the Partnership for Sustainable Textiles, outlining possible courses of action through which the concept of a circular textile sector can be further promoted within the context of German development cooperation over the next years.

Methodologically, the report draws from a structured literature analysis and background research, 20 interviews with renowned experts with a background in circular economy and the textiles sector. Additionally, adelphi and C2C organised a focus group session as part of 2018's international Cradle to Cradle Congress which focused on circularity in the textile industry (Circular Textiles Symposium, conducted on September 14th 2018, Lüneburg/Germany): 20 textile experts attended this session.

Based on scoping discussions at the beginning of the project period, the analysis focuses mainly on the fashion industry and predominantly addresses circularity and material health of natural and man-made fibres, thus largely omitting other important auxiliary materials in the textiles value chain (e.g. chemicals and water) as agreed with GIZ.

1 The German translation of circular economy "Kreislaufwirtschaft" is often synonymously used for waste management (end-of-pipe-approach) without characteristics of circular design or Cradle to Cradle.

2 Circularity in the textile sector

2.1 Conceptual considerations on a circular textile industry

During the last 20 years, the environmental impacts of the textile industry have received growing public attention and have pushed manufacturers, retailers and brands to reduce their environmental footprint. In the European context, this was guided as early as 2003 with the compilation and publication of the first Best Available Technology Reference Documents (BAT/BREF) document by the European IPPC Bureau. In this context, more recently, circular economy is receiving increasing attention. It is often contrasted by today's prevalent linear economy relying on the extensive extraction of raw materials that are transformed into goods, sold on the market place and, once consumed, simply burnt or landfilled. According to the book Cradle to Cradle – Remaking the Way we Make Things (Braungart & McDonough 2002), this is also being referred to as "take-make-waste" production and consumption patterns. The concept of a circular economy has been influenced by various schools of thought that emerged throughout the last decades. An overview is provided in Annex I.

It is very important to highlight that circularity goes beyond mere end-of-pipe solutions and should not be simply understood as an approach to more efficient management of waste (i.e. less resources, less energy, less waste). Both literature and interview partners highlighted that the transition towards a circular economy represents a fundamental paradigm shift and transformation of industrial operations in which waste is understood as a valuable resource – or, in fact, the concept of waste is entirely eliminated by designing products for defined application scenarios, disassembly and recycling in either biological or technical cycles. In a circular economy, actors collaborate along the value chain to optimize the eco-effectiveness of the entire ecosystem to create shared value (Braungart et al. 2006). Local and adapted production is given priority and down-cycling is avoided wherever possible in order to maintain the material value of products and components for as long as possible.

Linear	Circular
Raw materials & waste	**Raw materials only**
Competition	**Collaboration**
Individuals	**Ecosystem**
Do less bad	**Do good and positive**
Added value	**Shared value**
Standardised production	**Local and adapted production**
Downcycling	**Upcycling**

Figure 1: Circular Economy as a paradigm shift

From a systemic perspective, the circular economy concept often distinguishes between biological and technical cycles (Ellen MacArthur Foundation 2017a). This distinction was initially developed by Braungart and McDonough by formulating the concept of Cradle to Cradle. It presents the idea that materials and components should be designed for well-defined application scenarios.

Accordingly, biological cycles comprise materials that are beneficial to human health and the environment, thus enabling new organic growth as a biological nutrient once they reach the end of use. This can be illustrated by the example of a textile: in the production of a shirt, full "cyclability" in biological cycles can only be ensured if the raw materials (e.g. pesticide-free organic cotton) and all involved dyestuffs and other chemicals applied throughout the production processes are fully biodegradable and do only contain substances that are beneficial to human health and the environment. Technical cycles refer to materials which present primary raw materials of limited availability and, in view of increasing resource scarcity, should be retained in use for as long as possible (e.g. precious metals or plastics). For instance, C2C certified office chairs are manufactured in such a way that all materials used can be disassembled and then sorted according to type and with little effort. This makes it possible to reuse all materials as secondary raw materials at the end-of-use phase. For further information on the differentiation between biological and technical cycles, please refer to the figure in Annex II.

Against this background, the transformation towards a circular textile industry calls for fundamental changes throughout the entire lifecycle of textile apparel products, including design changes in upstream processes to ensure that clothes can be recycled and repaired efficiently. This may for example also require a shift away from using mixed fibres (e.g. poly-cotton) towards predominant use of mono-fibres of garments (e.g. pure cotton). The use of harmful chemicals (i.e. persistent, bio-accumulative, endocrine-disrupting or carcinogenic substances) must be avoided at all times. Following the Cradle to Cradle approach to a circular economy, textile apparel products need to be designed to be safely worn on bare skin and should be fully biodegradable within biological cycles.

In the manufacturing phase, innovative production techniques need to be fostered by incorporating means of zero-waste techniques (e.g. using off-cuts right at the production facility) and use of innovative "green" chemicals. Further, the use of recycled fibres needs to be increased substantially. During the use and consumption phase, new business models and use concepts need to be implemented. These emphasise access over ownership to prolong the product use-phase. In line with the concept, textile apparel retailers are required to shift away from mere sales of fashion goods towards service-based business models. This may, for instance, include renting of garments to consumers via clothing libraries (example: tuxedos for rent for special occasions) or leasing services for which consumers pay a monthly fee in exchange for access to a garment (Esculapio 2018). Furthermore, repair and reuse concepts need to become more pronounced at the business-level, e.g. by offering repair kits and services as well as reselling products that had been in use before.

In downstream processes, end-of-use measures such as recycling, upcycling and reuse are viewed as prominent approaches which can close material loops and retain the material quality of textiles for as long as possible. This includes the development and large-scale adoption of innovative sorting and recycling technologies separating fibres without reducing their inherent material quality. In this context, various technologies have reached the proof of concept stage and now need to be brought to the mass market in order to foster wide-spread adoption.

Looking at the implication of circular textiles industry at the corporate level, the Finnish innovation fund Sitra (www.sitra.fi/en/) conducted a comprehensive assessment of innovative business models in the textile industry in 2015 (Circle Economy 2015). The analysis spanned some 250 different business concepts and resulted in a framework consisting of three main categories and a number of corresponding sub-categories. The main categories are: 1) Circular (creating value from waste); 2) Servitisation (functionality over ownership); and 3) Sufficiency (encouraging effective use of resources). As for 1), circular business models seek to eliminate the concept of waste and by turning waste streams into useful and valuable inputs for other processes. According to category 2), business models based on "servitisation" provide services that satisfy users' needs without having to own physical products. Lastly, category 3) describes sufficiency-based approaches as solutions that actively reduce consumption and production. This classification is displayed in the figure below. For a more detailed presentation of the sub-categories, please refer to Annex III.

Further implications for businesses pertain to changes in the approach to performance measurement. Some initial research has been conducted on performance indicators, with a wide range of varying approaches. In 2015 for instance, the Ellen MacArthur Foundation launched the world's first "Material Circularity Indicator"

CIRCULAR	SERVITIZATION	SUFFICIENCY
CREATE VALUE FROMM WASTE The concept of waste is eliminated by turning waste streams into useful and valuable input for other processes.	**FUNCTIONALITY OVER OWNERSHIP** Provide services that satisfy users' needs without having to own physical products.	**ENCOURAGE EFFECTIVE RESOURCE USE** Solutions that actively seek to reduce consumption and production.
CLOSED LOOP MODELS	REPAIR & WARRANTY	DEMAND MANAGEMENT
REUSE	RENTING & LEASING	CO-CREATION
RECYCLE	PAY FOR RESULT	USE EXCESS CAPACITY

Figure 2: Framework for circular business models in the textile industry (Circle Economy 2015)

which measures the degree of circularity at the company or product level on a scale from 0 to 1 (Ellen MacArthur Foundation b). A similar work was conducted by Griffiths and Cayzer in 2017 (Cayzer et al. 2017). By using a weighted scale, their indicator system follows a scorecard approach, which requires experts' inputs in order to translate a product's performance into a measurable format. Since 2010, the non-profit Cradle to Cradle Products Innovation Institute provides a 5-level certification scheme to indicate product quality and circularity regarding aspects of water treatment, energy consumption, social standards, material health and recyclability (defined as material reutilisation). While these examples seek to define circular business metrics on a generic level, little has been done to adapt these indicator systems to the specific context of the textile industry (Hemkhaus 2016).

According to background research and expert interviews, the transition towards a circular textile industry also requires far-reaching changes at the policy level. Here, public stakeholders are required to implement take-back schemes via Extended Producer Responsibility (EPR) in order to ensure that textile and fashion products are collected at the end of their use and circulated back into the production or consumption sphere. In order to increase policymakers' understanding of the subject, this report proposes the following working definition of a circular textile industry, which was developed based on stakeholder consultations (interviews, workshop), and review of the existing body of literature:

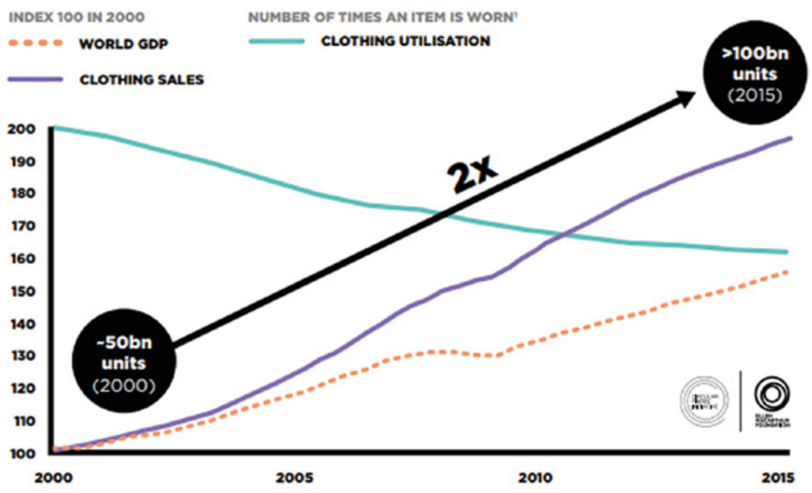
> *"A circular textiles economy describes an industrial system which produces neither waste nor pollution by redesigning fibres to circulate at a high quality within the production and consumption system for as long as possible and/or feeding them back into the bio- or technosphere to restore natural capital or providing secondary resources at the end of use."*

From the perspective of Cradle to Cradle, a circular textiles industry also needs to consider the use of healthy materials for defined usage scenarios. A product which is worn down during its use phase (e.g. a shoe sole) needs to be designed for biological cycles, thus requiring it to be fully biodegradable. On the other hand, products or product parts that may remain entirely in a technical closed loop scenario can also be designed for continuously remaining in technical cycles (e.g. curtain fabrics). Hence, products need to be designed for circularity also with regards to material health. In contrast, end-of-pipe-solutions like incineration or down-cycling keep working within Cradle to Grave paradigms.

2.2 State of play: circular economy in the textile sector across EU and non-EU consumer countries

The current linear economic model in the textile sector has put a huge pressure on the environment. Natural resources, which are used at different stages of clothing manufacturing deplete with time and it is the responsibility of all the market players to make the current textile industry more sustainable. In this regard, the 4Rs of the circular economy model – Re-design, Reduce, Reuse, and Recycle – play a major role in curbing pollution caused due to the industry. This means that the challenges for the textile and clothing sector will refer to the fundamental re-design of reduction of material and energy intensity, lower dispersion of toxic substances, enhancement of the ability to recycle, maximisation of the use of renewable resources, an extension of product durability and increasing the use intensity (Koszewska 2018).

The clothing industry accounts for a combined turnover of 1.13 trillion EUR globally and employs more than 300 million people along the entire value chain. In the last 15 years, clothing production doubled and it is estimated that the demand for textile fibres further increases by 84% in the next 20 years (ibid.). This increase can be attributed to the rising prevalence of fast fashion, releasing an increasing number of collections each year with highly competitive pricing and ever-shorter usage periods. Due to the growing demand for fibres, global textile production continues to grow. In 2017, 99 million tonnes were produced globally, growing at a rate of approximately 2.5 % per year and reaching between 130 and 145 million metric tonnes by 2025 (Ellen MacArthur Foundation 2017a; Qin, Yang (Michelle); Tecnon OrbiChem 2018).



1 Average number of times a garment is worn before it ceases to be used

Source: Euromonitor International Apparel & Footwear 2016 Edition (volume sales trends 2005-2015); World Bank, *World development indicators – GD* (2017)

Figure 3: Growth of clothing sales and decline in clothing utilisation since 2000 (Ellen McArthur Foundation 2017a)

For the two most relevant fibres for the textile industry, cotton and polyester, global production is expected to grow by 40% till 2023. Currently, polyester fibres dominate the global production, whereby synthetic fibres (including polyester, acrylic and other) account for about 60% of the market. Cotton accounts for nearly 33% with an annual production of about 25 million tonnes (Koszewska 2018) (as illustrated by the figure below).

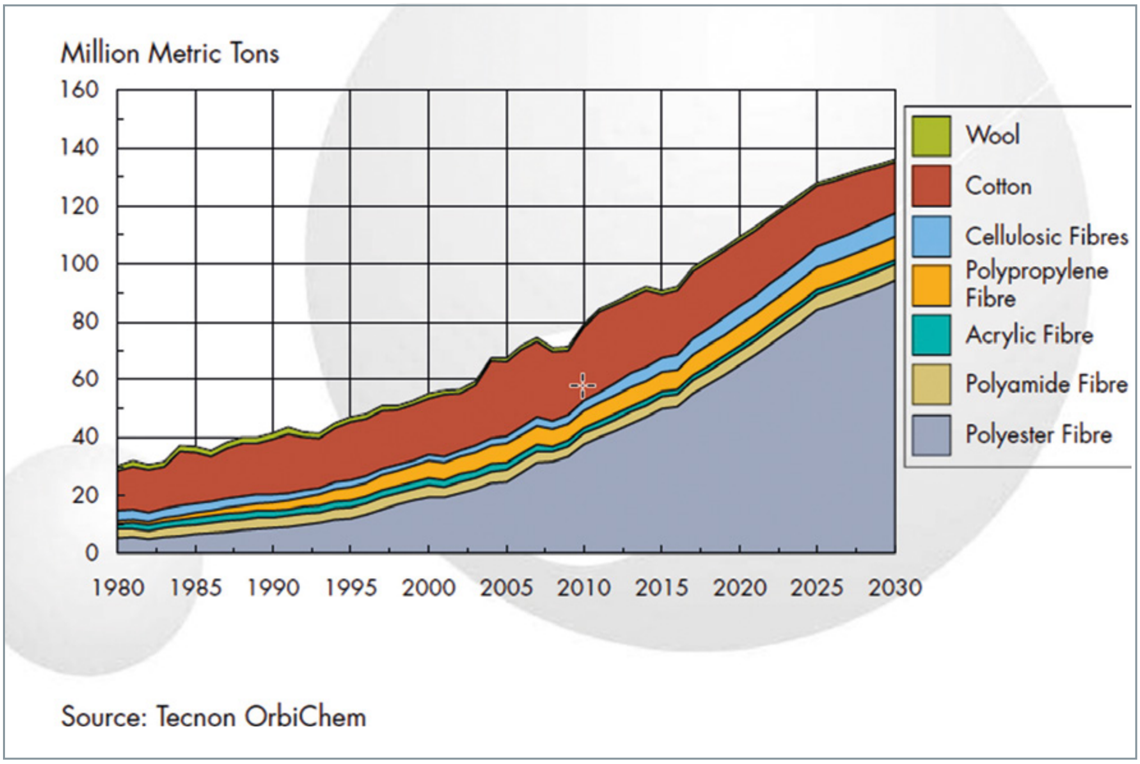


Figure 4: World fibre production 1980–2030 (Qin, Yang (Michelle); Tecnon OrbiChem 2018)

According to the Ellen MacArthur Foundation, less than 1% of the material used to produce clothing is recycled into new clothing in a closed-loop process, resulting in an economic loss of more than 87 EUR billion worth of material annually. Globally, only 20% of clothing waste is collected for reuse or recycling (including down-cycling), leaving the remaining 80% for landfilling or incineration. Infrastructure for collection varies in terms of extent and efficiency, thus resulting in large differences among countries. In some of the largest and more developed economies of the world (e.g. USA and China) collection rates range from merely 10% to 15%, whereas in many low-income countries in Asia and Africa no collection infrastructure can be found whatsoever. As most second-hand textile from high-income countries is exported to those regions this represents a major issue (Ellen MacArthur Foundation 2017a). The top ten exporters of used textiles are presented in the figure below.

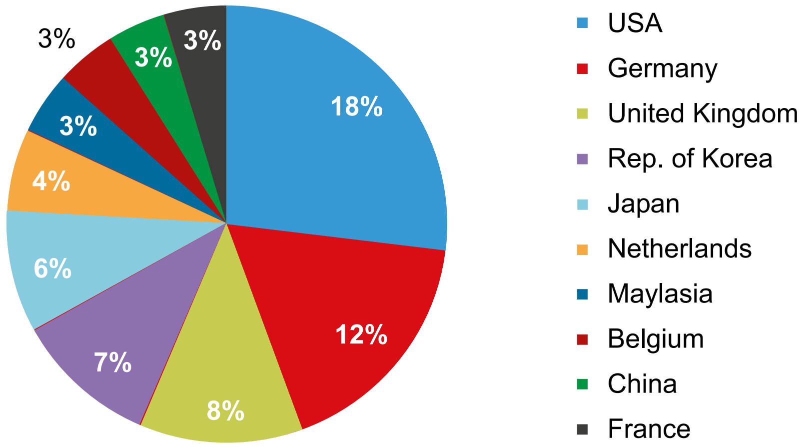
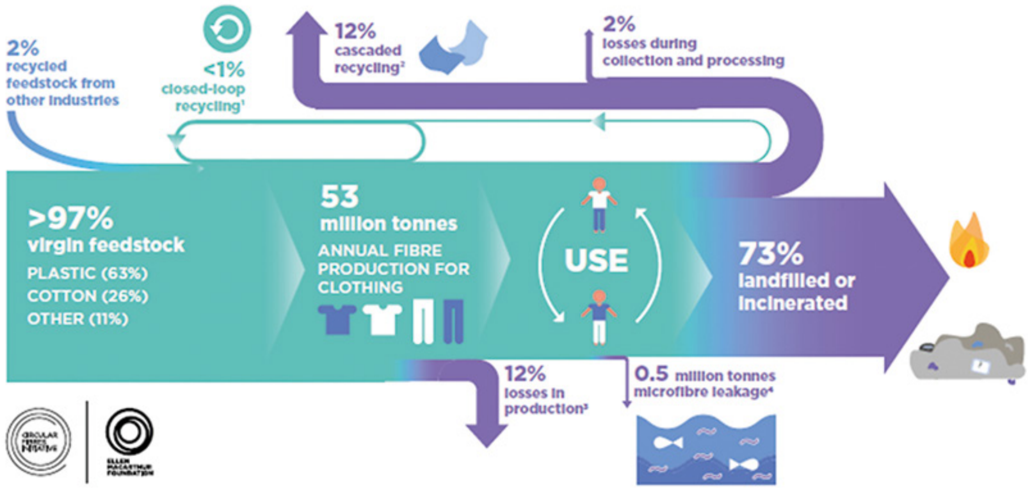


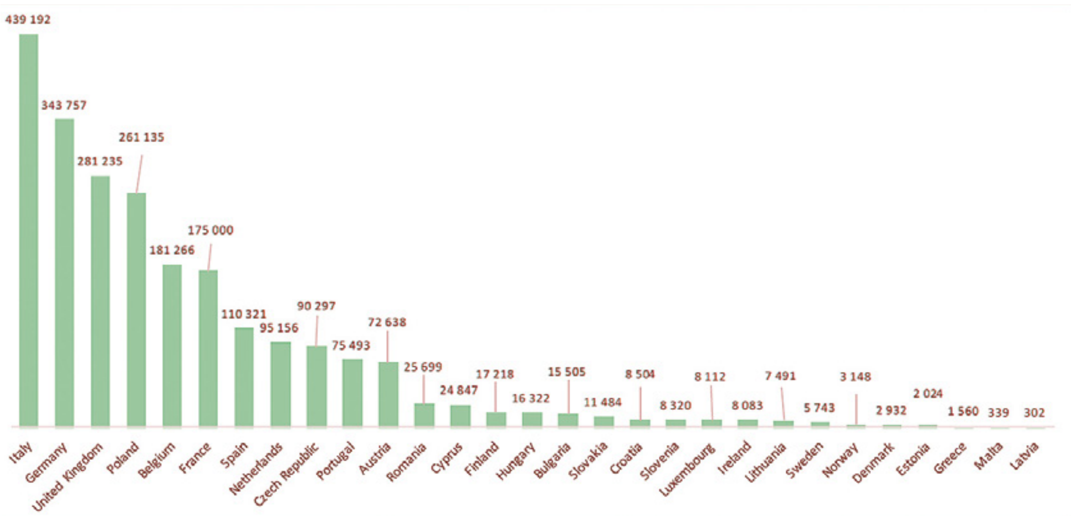
Figure 5: Top ten exporters of used textiles (share of total mass exported globally) (adapted from WRAP 2016)



1 Recycling of clothing into the same or similar quality applications
2 Recycling of clothing into other, lower-value applications such as insulation material, wiping cloths, or mattress stuffing
3 Includes factory offcuts and overstock liquidation
4 Plastic microfibres shed through the washing of all textiles released into the oceans

Figure 6: Global material flows for clothing in 2015 (Ellen MacArthur Foundation 2017a)

The European textile industry reported a turnover of EUR 171 billion in 2016 while directly employing 1.7 million people (EURACTIV 2017). Following global consumption trends for clothing, demand in Europe is increasing continuously: the volume of clothing purchased increased by 40% since 1996. At the same time, collection rates range from 15-20% across EU countries whereas the rest is landfilled or incinerated. Of the collected textiles, about 50% is down-cycled while 50% is reused, primarily through exporting to developing countries. In absolute terms, great variations for the amount of collected textile waste among the European countries can be observed (Sandin and Peters 2018). Also notable are the large discrepancies compared to collection rates for other products, such as packaging material were recycling rates of 79% (Belgium) or even 98% (Germany) are reported (Koszewska 2018).



Source: created by the author based on Eurostat data

Figure 7: Textile waste generated across EU countries in tonnes, 2014 (Koszewska 2018)

While the output of the textile industry is continuously increasing, most EU member states managed to reduce their textile waste levels from 2004 to 2014. An overall decrease of 48% from about 4.4 million tonnes to 2.3 million tonnes of waste was reported; yet, Poland, Belgium and Germany reported increasing volumes of waste. The top ten European waste generators are shown in the table below.

Country	2004 [tonnes]	2014 [tonnes]	Change [%]
EU (28)	4,430,000	2,290,000	- 48%
Poland	79,402	261,135	229%
Belgium	106,766	181,266	70%
Germany	222,336	343,757	55%
Netherlands	115,935	95,156	- 18%
United Kingdom	378,233	281,235	- 26%
Spain	188,762	110,321	- 42%
Italy	753,187	439,192	- 42%
Austria	138,121	72,638	- 47%
France	489,600	175,000	- 64%
Czech Republic	310,438	90,297	- 71%
Romania	261,032	25,699	- 90%
Portugal	963,633	75,493	92%

Table 1: Change in textile waste in European countries from 2004 to 2014 (Koszewska 2018)

Collection rates vary significantly across European countries, with little to no reliable data available. According to expert interviews, the amount of textiles exported are commonly used as proxies for collection rates due to the lack of official collection statistics. Based on this, only 11% and 19% of textile waste is separately collected in Italy and Sweden respectively, and the rest ends up in the mixed waste stream (Watson et al. 2018).

Country (data year)	DE (2013)	DK (2010)	FR (2016)	IT (2015)	NL (2012)	SE (2013)	UK (2010)
Consumption [kilo tonnes]	1347	89	600	881	240	121	1693
Consumption [kg/capita]	16.7	16	9	14.5	14	12.6	26.7
Share of quantity placed in market [%]	75	44	36	11	37	19	31

Table 2: Estimated separate collection rates for clothing and household textiles in selected European countries (Watson et al. 2018)[2]

2 Due to the lack of reliable and uniform data, a consolidated overview of textile collection rates across EU members states does not exist. Hence, the table only provides a summary of the most recent studies on collection rates in different years and should not be understood as a comprehensive and viable comparison.

Frontrunners of post-consumer textile collection in Europe include Germany, Denmark, the Netherlands, France and the UK. In Germany, it is estimated that some 1.01 million tonnes of post-consumer textiles are collected annually, mainly due to a well-established collection network run and maintained by charitable organisations. Thereof, about 930,000 tonnes are reused or recycled in some way or the other, whereas 60,000 tonnes are incinerated. While the annual collection rates have increased by roughly 20% since the mid-1990s due to ever-shorter fashion cycles, consumption ranks among the highest across all European countries. At the same time, the amount of collected textiles of high quality, which are suitable for reuse and recycling, has decreased steadily. Some 20 years ago, about 65% of collected post-consumer textiles were suitable for reuse. Nowadays, this share has reduced to 50%. This trend has subjected collectors to increasing economic pressure as the marketization of second hand goods is effectively cross-subsidising the collection of non-reusable textiles which are predominantly down-cycled at the end of life (personal communication 2018).

In Denmark, textile collection rates are relatively high in comparison to other EU countries. Around 44% of textiles put on the market are collected, mostly by charities and private collectors, via containers and in second-hand shops. It is estimated that around 70% of the Danish citizens donate used textiles on a regular basis and around 8% dispose all used garments in the mixed waste (Watson et al. 2018).

In France, a lack of policy measures resulted in very low collection rates of around 18% in 2010. The sharp increase to 36% in 2016 can be attributed to the implementation of a dedicated Extended Producer Responsibility (EPR) scheme for textiles. The activities of the corresponding Producer Responsibility Organisation (PRO), EcoTLC, and its associated partner charities, private collectors and municipalities have significantly improved the network of collection points and mobilised financial resources for textile sorting, R&D activities in recycling initiatives and awareness/communication campaigns (Watson et al. 2018). These measures are reflected in the increasing collection rates.

In the Netherlands, clothing collection is organized by several commercial and charity organizations that sell the collected textiles to national and international sorting companies (Texperium 2018). Around 89,000 tonnes were collected in that manner (Watson et al. 2018).

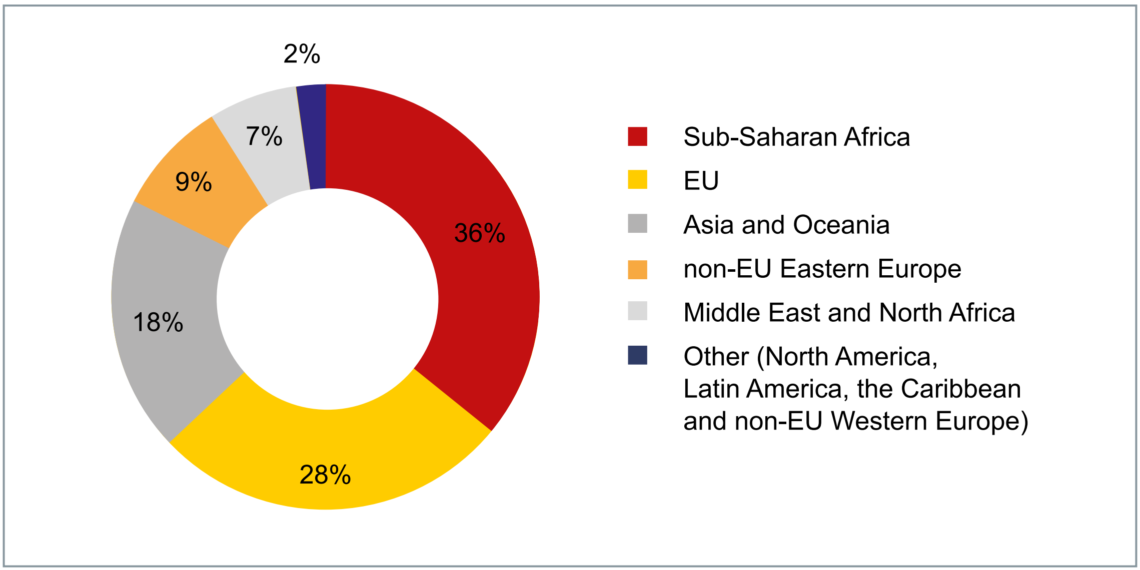


Figure 8: UK exports of used textiles in 2014 (% of total mass) (WRAP 2016)

The United Kingdom is a major exporter of used textiles, while most shipments are directed to countries in Sub-Saharan Africa, Hungary, Poland and other European countries (please refer to Fehler! Verweisquelle konnte nicht gefunden werden.). About 31% of the total material input is recycled in some way, mostly by the use in other industries as lower-value resources (e.g. insulation material). The landfilling of clothing and other household textiles accounts for costs of around EUR 94 million each year (WRAP 2016).

Through recent years, the Nordic region has started to position itself as a global sustainability and circularity leader in the textile sector by launching various initiatives and extending research activities. This is reflected by the Nordic Textile Commitment and the Action Plan for Sustainable Fashion and Textiles.

EU legislative framework and references

The concept of the circular economy reflects the recognition that European systems of production and consumption need to be fundamentally transformed to achieve the EU's 2050 vision of 'living well within the limits of our planet' (EEA 2016). The European waste hierarchy prioritises prevention before reuse, recycling and ultimately disposal (in order of decreasing importance). Currently however, no targets concerning re-use or recycling of textile waste exist which could support the waste hierarchy and lead the way towards circularity for textiles in the European Union.

As part of a new circular economy package, the EU Commission presented an action plan for the circular economy, as well as numerous legislative proposals on waste in December 2015. These came into force as the European Union Circular Economy Package in 2018. The revised legislative proposals on waste set clear targets for reduction of waste and establish an ambitious and credible long-term path for waste management and recycling. Key elements of the revised waste proposal include a common EU target for recycling 65% of municipal waste by 2030 and a binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030.

In this framework EU member states will be obliged to establish separate collection for textiles from 2025 onwards. The EU also proposes to set updated targets for textiles. So far, the application of the EPR policy for the textiles industry is not a common practice. The first legal framework for managing textiles waste using the EPR policy was declared in France in 2007 (ref. Article L-541-10-3 of the Code de l'Environnement, in effect as of 1 January 2007) which aims to hold textile producers responsible for collection and recycling of end-of-use clothing, linen and shoes (Bukhari et al. 2018). A similar approach is currently under study in Nordic countries. All in all, it should be highlighted that the EU's understanding of circular economy in the textiles sector remains strongly linked to more efficient waste management and does not sufficiently address other important aspects of circularity (e.g. design approaches, use concepts or new business).

As per the EU CE action plan report, it is intended that guidance on circular economy will be included into BREFs for several industrial sectors. Yet, it remains to be seen whether the ongoing revision of the BREF/BAT document for textile will reflect CE aspects (EC 2017). An EU initiative called the European Clothing Action Plan funded under the EU Life programme has been launched to significantly improve the sustainability of textiles across their life cycle from design to end of use by 2019 (Moorhouse & Moorhouse 2017).

Funding

Besides the EU Life programme, further funding mechanisms have supported innovative recycling projects in the textile sector at European level. The table below depicts a list of relevant funding programmes and project examples, which received support by those initiatives.

Programme	Area of funding	Project example	Source
EU Life	Funding of nature conservation, environmental protection as well as climate action project with a volume of 3.4 billion € in the 2014-2020 period	European Clothing Action Plan (ECAP) as the first LIFE-project for sustainability in the textile sector (3.6 million € EU funds) focussing on the whole supply chain including sustainable design, production, consumption, public procurement, collection, recycling and reprocessing	ECAP; European Commission 2018a
EU Ecoinnovation Initiative	Eco-innovative projects, which aim at the prevention or the reduction of environmental impacts or which contribute to the optimal use of resources (maximum EU contribution of 50% of its total eligible costs for each project, total funding of 86.8 million € from the EU)	- Bringing recycled fibre products to market based on composites waste (RECYCLED FIBER) - Textiles for Textiles (T4T) automated sorting technology	European Commission 2015
Horizon 2020 - Focus Area "Connecting economic and environmental gains - the Circular Economy"	Funding of e.g. raw materials innovation for the circular economy: sustainable processing, reuse, recycling and recovery schemes	- Resyntex (circular redesign in the textile sector, SOEX demonstration plant for sorting, pre-treatment, and biochemically process of pure and blended input textiles, EU contribution 400,000 €) - Bio-based Industries (supporting market development for bio-based products and processes) - FORCE project (minimise the leakage of materials from the linear economy and work towards a circular economy)	Resyntex 2018; European Commission
INTERREG	Support for cross-border projects	- Expert Network on Textile Re-Cycling (1.6 million € EU funding) - Market demonstration and validation of FIBERSORT technology (1.95 million € EU funding)	BBR

Table 3: Funding programmes and project examples supporting circular economy projects in the textile sector

Programme	Area of funding	Project example	Source
BMWi - Zentrales Innovationspro-gramm Mittelstand (Central Innovation Programme for SMEs, ZIM, total budget 559 million €)	Grants for ambitious research and development projects leading to new products, technical services or better production processes with 100% support for research institutions	Network projects in the textile and circular economy sector (e.g. RecyKon)	BMWi 2015
Funding programmes of the Deutsche Bundesstiftung Umwelt (DBU - German Foundation for the Environment)	Support of innovative model projects for environmental protection	Upcycling of textile waste materials - VAUDE Sport GmbH & Co. KG (70.000 €)	Henkel 2018
Mistra Future Fashion research programme (funded by Mistra, the Swedish Foundation for Strategic Environmental Research)	Research funded of Life Cycle Assessments; Guidance on design for recycling, Sorting technologies etc. (total budget of 10.6 million €)	Research paper funded "Using the planetary boundaries framework for setting impact-reduction targets in LCA contexts"	mistra future fashion
Trash-to-Cash	Research to develop methods for creating new virgin quality fibres from pre- and post-consumer textile waste (EU contribution: 1.1 million €)	Relooping Fashion Initiative, Infinite Fiber (VTT, Swerea)	Norden 2017
Vinnova (Sweden)	Funding of research and innovation projects	SIPTex received ca. 850.00 € from Vinnova for developing an automated sorting process of used textiles for recycling	Norden 2017

Programme	Area of funding	Project example	Source
Waste Prevention Loan Fund (UK)	Providing GBP 1.5 million support to support waste prevention and reuse like innovative business models which increase re-use, repair and recovery capacity for products (including textiles)	The Sustainable Clothing Action Plan (SCAP) - cooperation of organisations from across the clothing supply chain to re-invent how clothes are designed and produced to e.g. re-define what is possible through re-use and recycling	Norden 2014 WRAP b
C&A Foundation	Corporate foundation with The aim to support programmes and initiatives that bring fair and sustainable change to the fashion industry	Circle Textiles Programme (256,000 € from C&A Foundation) including Fibersort; online marketplace "Circle Market"; high value-recycling pilots; circular business model analysis; Fashion for Good; Ellen MacArthur Foundation's Make Fashion Circular and Global Fashion Agenda's 2020 Circular Fashion System Commitment	C&Aa
Fashion For Good	Explicitly funding circular economy innovations in the textile industry; founding partner is C&A Foundation	Offers two types of support pro-Grammes: Accelerator Programme: Free training for start- ups driving inno-vations in sustainability, circularity and transparency Scaling Programme: Support of 1-2 years of business development	Fashion For Good 2018
H&M Foundation	Funding of local projects in the focus areas: education, water, equality and planet	Closed-Loop Apparel Recycling Eco-System Program in collabora-tion with the Hong Kong Research Institute of Textiles and Apparel (5.8 million € by H&M Foundation) with additional support by the “Hong Kong Government Fund: Innovation and Technology” (total project in-vestment 30 million €)	H&M Foundation 2018

2.3 Technology assessment: closing material loops through textile recycling

Using secondary raw materials as an input for new clothes is an already well-developed way to increase the recycling content of garments. However, this method is mainly applied for producing clothes made of synthetic fibres and various plastic products can serve as an input (e.g. Polyethylene terephthalate (PET) bottles). Regarding biological waste as a substitution of raw materials for innovative textile materials (e.g. waste from food production), no commercialised approaches exist yet but research and development activities are currently carried out.

Concerning the end-of-life-phase, fibres of used clothes are recovered to produce fabrics that are used for other purposes than creating new garments as a form of open-loop recycling (mainly down-cycling). Full closed-loop recycling of post-consumer-waste requires specialised recycling technologies that follow processes like sorting, separation, shredding and discolouring. Single-origin pre-consumer-waste (i.e. clothes made from mono-fibres) requires less complex technologies for a closed-loop recycling. The following chapter assesses well established as well as innovative recycling technologies, which can deliver solutions for various recycling approaches.

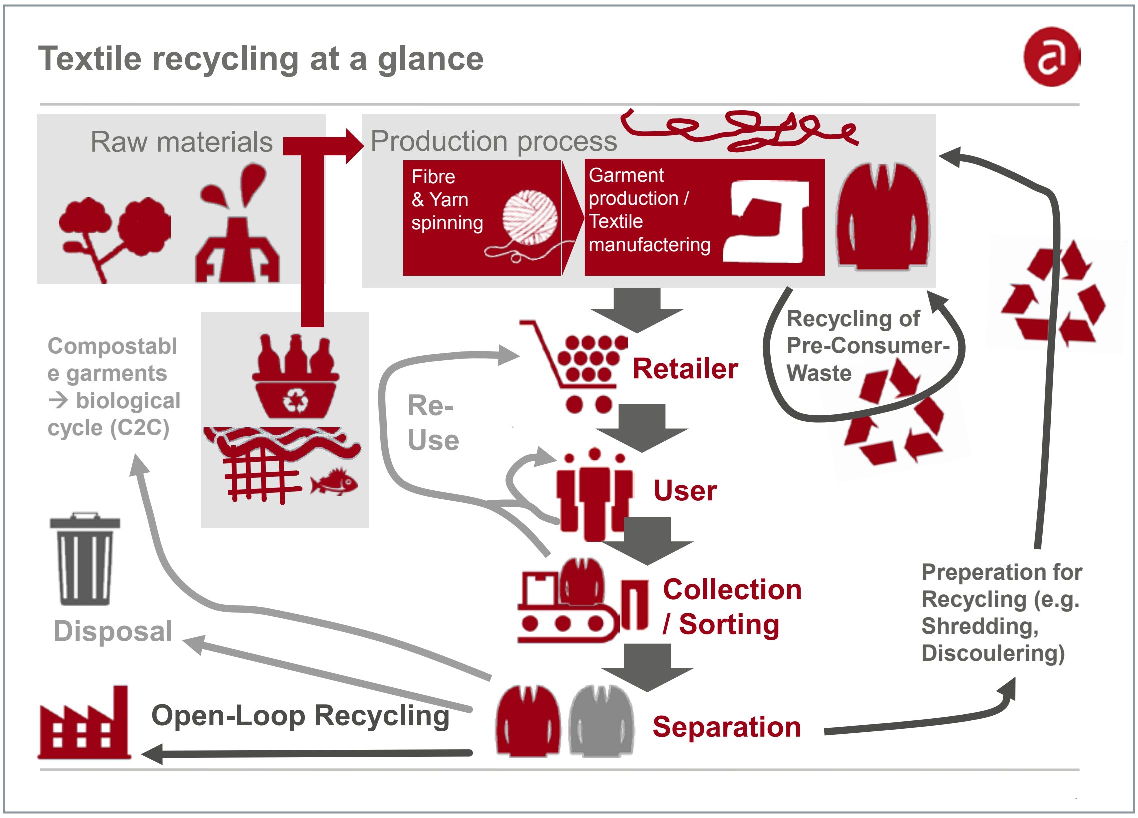


Figure 9: Textile recycling approaches as well as technologies and their integration into product life cycle (own depiction based on Ellen MacArthur Foundation 2017a, Greenblue 2017, Norden 2014, Norden 2017, Re:newcell 2018)

2.3.1 Established recycling technologies

Currently, the most developed process for the recycling of synthetic fibres (with polyester being the most commonly used one) is chemical recycling. Roughly, cut textile materials are broken down by the addition of various chemicals into their components up to individual monomers that are of the same quality than monomers from virgin materials (FairWertung e.V. 2018). In principle, recycling of a mixed-fibre product is feasible but the end-product is restricted to mono-fibre articles like functional sports shirts from polyester. Concurrently, most recycled fibres are not made from post-consumer garments but from other sources of used plastics, such as PET bottles. A commercially available process of post-consumer textile recycling is conducted in Japan by the company Teijin where polyester is recycled from used clothing, PET bottles and production waste PET (Norden 2016). While the technology can be described as mature, it still has its shortcomings as not all polyester products can be fed into the process. A similar quality to virgin materials is achieved and the production of 100 percent recycled polyester is possible. Although the reduction in energy consumption is 84 percent compared to other recycling processes according to Teijin calculation, the process remains ten to twenty percent more expensive than using virgin materials (Norden 2014). In addition, the majority of today's pre-consumer PET on the market is not designed for secondary use scenarios within the textiles industry. For example, the catalyst antimony is used in most of the PET production and presents a toxic substance, which remains within the product during its entire lifetime (Bundesinstitut für Risikobewertung 2015).

Another example for established chemical recycling is the cooperation of Parley and Adidas that use old fishing nets and plastic waste from the oceans to produce functional sports ware. This approach is suitable for creating awareness on the topic of maritime waste pollution (especially when famous football clubs play in those kind of jerseys), however interviewed experts mentioned that this can neither serve as a solution for reducing plastic waste in the ocean nor for closing the loop in textile industries. Due to the comparatively high level of energy consumption (Leonas 2017) chemical recycling poses its own environmental challenges. Material must be sorted, washed, and decoloured. In addition, additives like plasticisers in used plastics present a challenge (FairWertung e.V. 2018). Currently, the price for recycled polyester fibres is on par with conventional ones (Piatschek 2017) but the technology requires high capital investment in order to reach commercial scale (Leonas 2017).

Chemical monomer recycling for non-plastic based fibres like cotton and wool is currently in the research stage. The EU project RESYNTEX funded under Horizon 2020 (H2020) is addressing this issue. A potential process would be costly mostly due to the separation of monomers but could remove harmful substances. Despite some research activities, chemical recycling technologies are not yet technologically or economically mature for natural fibres (Ellen MacArthur Foundation 2017a).

Natural fibres like cotton fabrics are mainly recovered via mechanical recycling. Clothes are sorted by colour as well as material and fibres are shredded torn down (FairWertung e.V. 2018), including processes of unravelling, grinding, defibrating and cutting (Bukhari et al. 2018). As the fibres are shortened, weakened and damaged during the sorting process, their properties, functionality as well as quality deteriorate, making the supplement of new and high quality fibres necessary (Ellen MacArthur Foundation 2017a). Consequently, just 30 percent of natural fibres can be presently replaced by recycled ones. Admixtures in the input material further reduce the quality of recycled fibres. Due to the limitations of this mechanical recycling, most natural fibres are not recycled into new clothes, but down-cycled for application of insulating materials, industrial cleaning cloth, bath mats, industry wipes or oil absorbent mats (Norden 2014). H&M uses this kind of recycling approach for their in-store collected post-consumer-waste; management and recovery is conducted by SOEX and its subsidiary I:Collect (Piatschek 2017).

In general, the environmental benefits of mechanical recycling processes correspond to the mitigated environmental impacts of the substituted material (e.g. negative impacts of cotton farming). However, trade-offs exist as the process consumes energy and harmful substances continue to circulate if these are not filtered out before

(FairWertung e.V. 2018). For example, bleaches are used for decolouring. Due to its complexity the process is relatively expensive. According to some experts, fabric recycling of factory offcuts and leftover materials (i.e. pre-consumer waste) are not yet common practice but would offer advantages as those materials usually offer a high degree of purity. This process can also be used for remanufacturing, e.g. by re-sewing pieces of complete fabric to create new garments without advanced technology. Yet, the quality of pre-consumer waste can be too low and the shortening of fibres by shredding necessitates the addition of virgin fibres. Nonetheless, reaching a recycled content of up to 90 percent from pre-consumer waste appears possible (Ellen MacArthur Foundation 2017a). In general, the process is environmentally-friendly and chemical use can be avoided as there is hardly any need for removing colours. Yet, the process is labour intensive, leading on the one hand to increasing costs but on the other hand to the creation of additional jobs. A major challenge is the currently inconsistent influx of materials and insufficient amounts of fabrics to maintain economically viable operations. Interviewed experts mentioned networking of manufacturers as a possible solution to stimulate industrial symbiosis and match supply and demand of pre-consumer-waste.

According to a recent study by McKinsey the structure and key influencing factors of the international apparel value chains are expected to undergo significant transformations during the next 15 to 25 years (Andersson et al. 2018). In this context, attention would have be paid to emerging trends such as "nearshoring" (the relocation of sourcing basis closer to the market) and "automation" which are considered key in building up a more sustainable, circular value chain in the fashion/textile sector (an illustration can be seen in Annex V).

2.3.2 Innovative closed-loop recycling technologies

The technologies above mentioned represent mostly solutions for open-loop recycling which predominantly leads to down-cycling. Closed-loop textile-to-textile recycling processes are still under development and have not reached commercial stage or market penetration on a large scale yet. However, various innovating approaches exist for both synthetic as well as natural fibres. Currently, the substitution of wood by waste garments from natural fibres as input for the production of viscose fibres is studied intensively; some of those technologies are on the verge of upscaling and commercialisation. The following section assesses these new technologies assessed regarding their advantages as well as potential trade-offs. A comprehensive summary is presented in Annex IV.

Infinited Fiber (Relooping Fashion Initiative)

The "infinited fiber" is a recycled fibre produced from cotton rich textile waste and other biomaterials like wood. As the name suggest the fibre can be recycled theoretically infinitely. The process was developed by the VTT Technical Research Center of Finland and the Infinited Fiber Company which got established in this context. A carbamate cellulose dissolution technique constitutes the centrepiece of the process and common methods from the pulp industry are utilised to remove polyester residues from the cotton (EurekAlert! 2017). As no downgrading takes place during this process, the fibre has the same quality as a typical viscose fibre. Additionally, environmental benefits in comparison to viscose manufacturing exist. For instance, one third less CO2-equivalents and 98% less water are needed and harmful chemicals like carbon disulphide can be avoided. According to details provided by the developer, the technology should be 20 to 40% more economical than competing solutions. Currently testing on industrial scale takes place while the process is being further refined for large-scale industrial production (The Infinited Fiber Company 2018).

re:newcell pulp

The re:newcell pulp was developed at the Royal Institute of Technology in Stockholm. SKS Textile and H&M are partners of the company re:newcell which was founded for commercialisation of this technology. Since 2017, it is engaged with the operation of the first demonstration plant opened in Sweden. In the re:newcell process, post-consumer garments are shredded and a chemical solvent breaks down the pieces to molecular level, thus producing a recycled dissolving pulp and in a further step a viscose fibre (Norden 2014). No harmful chemicals are needed in the process (Launch 2017) and the produced fibre has at least the same quality of a virgin fibre. In case of pure cotton, no addition of virgin fibre is necessary and 100 percent recycling can be achieved. The output fibres are biodegradable and in general the recycling process is more environmental-friendly than wood processing (personal communication 2018). According to interviewed experts, the process is still energy intensive due to the drying process but does not exceed the energy demand of conventional viscose production. Although the fibre quality is very high, certain characteristics of end-products compared to virgin materials may lead to issues in further processing steps. The current annual capacity of the demonstration plant is 7,000 tons, with a full-scale plant being planned to produce 30,000 tons of re:newcell pulp per year. The small scale of the current plant leads to high costs but in a larger scale cost advantages are expected to be achieved because the input material is mostly free of charge.

Refibra (Lenzing)

The Austrian company Lenzing uses undyed cotton pre-consumer waste as input replacing part of the wood as raw material in pulp fibre production to integrate recycling material in the company's conventional Lyocell production process. The resulting Refibra fibre is used by companies, for example, Patagonia. According to expert interviews, the fibre quality is the same as for raw material from wood if undyed, homogenous pre-consumer waste is used (personal communication 2018). Additionally, a life cycle assessment (LCA) conducted by the company showed that Refibra entails significant environmental benefits compared to a conventional viscose fibre. However, up to now, just 20% recycled content is possible in Refibra fibres. Considering that Refibra fibre is mainly used in addition to virgin cotton (e.g. 20% Refibra content in jeans), the actual content of recycled fibres is even lower. Moreover, costs are higher than using wood as raw material. Research is conducted in order to increase the recycled content and on the utilization of post-consumer waste which is stated as a long-term goal by Lenzing (ibid.).

Innovative chemical polymer recycling (Worn Again/HKRITA/Evrnu)

An innovative chemical polymer recycling approach for synthetic as well as natural fibres (namely polyester and cotton) has been developed by Worn Again. The company is working together with brands and retailers such as H&M and Puma. The first step in the process is the separation and recapturing of polyester and cotton followed by different processing approaches depending on the fibre type. Polyester is dissolved, embedded contaminants are extracted and a resin as the intermediate product is produced. The resin is then processed into a polymer and converted into virgin equivalent polyester. According to interviews, the innovative aspect of the process is that polyester is not depolymerized into monomers but recaptured directly, thus leading to energy savings in comparison to other recycling technologies (personal communication 2018). However, energy consumption is still comparatively high. In the case of cotton, dissolving takes places accompanied by the decoupling of dyes as well as contaminants and is followed by separation to produce a pulp, which is equivalent to viscose. 20% of impurities can be filtered out and a broad range of inputs is possible as pure and blended materials can be used (Greenblue 2017). The process is currently costly but the goal is to compete with virgin material in terms of price. One potential social benefits of commercialisation is that the establishment of chemical recycling plants in Europe could boost job generation.

Another approach of textile-to-textile recycling was developed by H&M at the Hong Kong Research Institute of Textiles and Apparel (HKRITA). The process is comparatively well developed and currently applied in a pre-industrialised plant opened in Hong Kong in September 2018. Based on chemical and hydrothermal treatment under pressure this approach is also able to recycle cotton and polyester blends into new fabric and yarns (H&M Foundation 2018). However, cotton which is processed to cellulose powders is not used for new garments in a closed loop but functional products like super-absorbency materials. A biodegradable green chemical is utilized but energy consumption is quite high due to generated heat and pressure.

The US-based company Evrnu developed an innovative recycling approach for the recovery of cotton fabrics, which is currently in prototype status. In collaboration with Levi Strauss & Co. the company created the first jeans made from post-consumer cotton waste (Leonas 2017). The process removes dyes and contaminants followed by pulping and breaking down cotton to fibre molecules. This process allows for the production of filament that is finer than silk and stronger than cotton (ibd.). A particular feature of the process is that it allows engineering certain characteristics of the new fibre. 98% less water is used than for virgin cotton mostly because of avoiding the need for cotton farming (Moorhouse & Moorhouse 2017).

2.3.3 Sorting technologies

In general, recycling technology processes require a relatively high grade of purity of input materials. Therefore, sorting technology will gain importance and need to be developed in parallel.

Fibersort

Circle Economy, a Dutch social cooperative enterprise, developed the so-called Fibersort technology together with collectors, sorters and recycling experts (Ellen MacArthur Foundation 2017a). Fibersort is an automatic sorting system of mixed post-consumer textiles (simultaneously by colour and fibre type) using near infrared spectroscopy (NIRS) which allows the detection of garments from cotton, wool, viscose, polyester, acrylic and nylon (Ellen MacArthur Foundation 2017a). The sorted fibres have a low level of contamination and can serve as mono-fibre inputs in mechanical as well as chemical recycling for high value textile-to-textile recyclers (Greenblue 2017).

SIPTex

Another innovative sorting technology is SIPTex established by Vinnova in collaboration with Boer Group, amongst other partners. Like Fibersort, SIPTex is also based on NIRS as well as visible spectroscopy technology (Norden 2015). The separation of identified clothes is conducted by compressed air. This technology does not allow for the separation of fibres as it is only sorting garments by those fibre type, which accounts for the majority of a garment (Ellen MacArthur Foundation 2017a).

Textiles4Textiles

Textiles4Textiles (T4T) is another NIRS sorting technology that separates clothing items (Norden 2015). Wieland Textiles and the Laserzentrum Hannover (LSH) as one amongst various partners developed the technology. It can separate used textile material according to fibre composition and colour allowing the separation of 300 fractions in theory. Currently however, it is just applied for less than ten fractions.

In case of sorting by colour, there is no need for bleaching or re-dyeing before the subsequent recycling stages avoiding chemicals and thus environmental benefits. Moreover, these innovative sorting technologies can generate cost savings for the substitution of manual sorting but commonly require high upfront investments as well as large volumes of textiles in order to be cost effective (Norden 2015). Large facilities, investors and demand for unmixed used clothes will be necessary for market penetration of these technologies. Job implications can occur if replacement of manual sorting takes places but the creation of high-skilled jobs can also apply if these facilities will be engineered.

2.4 Transitioning towards a circular textile industry

2.4.1 Challenges and barriers

Based on the reviewed body of literature, expert interviews and inputs gathered from the Circular Textiles Symposium, a wide range of challenges and barriers could be identified which inhibit the transition towards a circular textile economy. In Germany and other EU countries, the concept of fast fashion dominates the market with rapidly changing fashion collections per year and permanently changing trends. Overconsumption and consumer habits with a focus on cheap, unsustainable and non-circular garments are the norm, taking into account that 25% of garments in German wardrobes are not worn. Besides, making sustainable purchasing decisions is highly complex for consumers; in fact, the majority of point of-sale purchase decisions are being made on basis of price and quality. Further, the number of available sustainability labels has steadily increased over the last ten years and provides an opportunity towards increasing transparency; however, consumers still lack an understanding of what the different label represent.

- **Low-grade quality of collected textiles, insufficient data on amount of collected textiles and lack of standards for collection and processing**

The current conventional manufacturing infrastructure in many of the garment factories does not support the circular economy model. Factories have to undergo various changes to install recycling machines in the current factory-setups. The separation process is often considered tedious due to the complex fibre composition of the textile waste, which makes it difficult to extract the desired component. The extent of recycling ability also depends on the quality of the textile product, its degree of wear, physical condition and the presence of accessories on it such as buttons, logos, labelling etc. Decisions made during the design stage of apparel, influence the circular economy model to a greater extent. Based on the design of the product, specifications like colour, material usage, manufacturing method, finishing etc. will be finalised. To increase the product quality and durability, harsh chemicals and different blends of fibres will be used which mostly do not meet the sustainable clothing requirements. In addition, the trend towards fast fashion has resulted in ever-higher quantities of low-quality textile waste, which cannot be recycled or resold at an economic margin (Koszewska, 2018). In fact, low-quality textiles do not yield any profits for collectors but effectively induce costs. Currently, these costs are offset and cross-financed via the decreasing fraction of high-quality textiles that can be resold via second hand stores or exported to foreign markets.

Furthermore, interviewed experts repeatedly mentioned that reliable data on the amount of collected textiles in Germany and other EU member states is practically inexistent. Instead, export statistics are used as proxies for estimating the amount of textiles collected via charities and dedicated take-back schemes. In addition, German experts mentioned that there is an acute lack of standards for collection, thus leaving it open to the collectors to what degree collected materials need to be separated for further processing. Consequently, sorting for subsequent reuse and recycling becomes very expensive, thus leading to cost ineffective down-cycling (personal communication 2018).

- **Lack of consumer awareness and insufficient education on circularity across schools for textile (design)**

A growing number of consumers are increasingly concerned about environmental, social and economic issues, and increasingly willing to act on those concerns (Global Fashion Agenda & The Boston Consulting Group 2017). However, consumer willingness often does not translate into sustainable consumption behaviour because of a variety of factors – such as availability, affordability, convenience, product performance, conflicting priorities, scepticism and force of habit (WBCSD 2008). Additionally, there is a lack of incentives to change consumption habits and promote concepts of sharing, leasing, re-using or wearing garments for a longer period. The concept of a circular economy as well as the C2C in the textile sector are not commonly known and practiced, with the exception of few frontrunners such as C&A. Circular economy is still predominantly understood as recycling which at times even has a negative connotation for consumers due to presumably lower quality of fibres. Only the second-hand shop trend is popular among the younger generation. Missing knowledge on recycling strategies and materials (e.g. use of mono-fibres versus mixed fibres) are also barriers for customers to adopt more circular consumption practices (personal communication 2018).

With regards to textile designers, they often lack knowledge regarding sustainability challenges, solutions and practices towards circular textiles because both sustainability and circularity is not integrated in most curricula of universities or design schools. Instead, it is mainly freelance practitioners who put circularity on the agenda. A shift in education is needed and research on circular technologies and practices can be crucial. Professorships and research groups on circularity in the textile sector only exist in a niche. However, even if textile designers embrace the concept of a circular economy, they sometimes lack the position to determine circular material and manufacturing techniques due to structural barriers in large-scale companies and competitiveness as a predominant element of the textile market (ibid.)

Limited information exchange, low market penetration of innovative start-ups and path dependencies for established businesses in competitive market environments

At the business level, competitive advantages rely on intellectual property, patents and competitiveness, making sharing of best practices and internal lessons learnt from adopting circularity principles an exception. Experts also raised the question of how businesses can survive in a competitive market environment if they openly share their knowledge because this may pose the risk of losing a unique selling proposition (USP). Hence, collaboration through sharing of knowledge and practices towards circularity is still in its infancy.

Furthermore, experts also highlighted that data on externalities of a product is often scattered along the life cycle or the entire value chain, thus hampering the adoption of circular performance indicators. Global value chains with multiple contractors and sub-contractors are immensely complex and present a major challenge for transparency and circularity.

Small and medium-sized enterprises (SMEs) face the challenge of scalability and limited advantage on the market place. They lack financial resources and the capacity to make aggregated orders (e.g. for fashion goods with high recycled contents or good recyclability) while large companies can order larger quantities and have a competitive advantage by selling at low prices. At the same time, large companies that actively seek to introduce circular practices or products face the challenge of traditionally established business models and a fear of losing customers. Hence, they are less likely to follow innovative approaches and fundamentally change their business models towards “servitisation” approaches.

Externalisation of costs, underdeveloped infrastructure for separate collection and recycling, textile exports and lack of funding

In addition, there is a wide range of macro-economic barriers that inhibit the adoption of circularity in the textile industry. In principle, using recycled fibres is more costly than using virgin materials. This can be attributed to the lack of internalisation of external costs of virgin fibre production – even though recycling and reuse entail a wide range of environmental benefits (e.g. lower greenhouse gas emissions, decreased energy consumption, mitigated use of fertilisers, pesticides, dyestuffs etc.), the associated economic costs are not borne by manufacturers or fashion brands. In addition, competitive markets hinder a rapid transformation because the separation of mixed fibres is too costly and recycling technologies are not (yet) producing similar qualities.

In regards to the end-of-life phase of a product, there is a need for an entire new sector of collecting post-consumer goods and re-designing/re-producing garments, which is yet to develop. This is a major challenge but a possible solution for waste management and innovative business models in Germany and other EU countries. In order to tackle the growing amounts of textile waste effectively, infrastructure for collection and recycling needs to be developed in most EU countries. Notable exceptions include Germany, Great Britain and (to some extent) France and some Nordic countries which are viewed as frontrunners when it comes to collection infrastructure. However, other EU countries continue struggling with the increasing generation of textile waste. Additionally, garments which are not good enough for donations would still be suitable for recycling plants but this waste stream ends up in residual waste and therefore is not sorted out before incineration or landfilling.

In Germany, there is a traditional and historically grown sector of post-consumer clothes along the "charity" agenda of donating post-consumer clothes to low-income countries. Germany and UK are world leaders in collecting used garments (evaluated by garment exports per year), but also consume and waste enormous amounts. Germany gains profit through garment export (e.g. to African countries) but, due to the economic rationale of textile exports, fails to take advantage of post-consumer textiles as unused resources.

The practice of exporting used textiles has been widely criticised because it is said to destroy local markets in importing countries and effectively hinder the development of a thriving local manufacturing industry. In response, countries of Eastern Africa as well as Turkey have started to restrict import of post-consumer garments. However, experts repeatedly mentioned that this argument is not entirely valid, as the market for used textiles is not directly competing with the market for new textiles in developing countries. Instead, the sheer amount of clothing produced at low-cost, which is exported predominantly from China was understood as a much larger threat to the competitiveness of textile industries in the global south.

Moreover, interviews suggest that a lack of infrastructure impedes commercialisation of recycling technologies. Currently no automated sorting technologies exist which could deliver sufficient and affordable input for recycling processes at a larger scale. Manual sorting cannot provide sufficiently high amounts of suitable input as it is labour intensive as well as costly and usually there is no clear indication on the label of the exact composition of the fibres or the consumer has even removed the label completely (Piatschek 2017). Sorting will be important because different types of plastic also require different recycling processes. Producers are not able to use a high recycling content in their garments, as there is a low availability of recycled materials of certain types of fibres at high quality (Norden 2017). This is caused by a lack of mature, industrialised recycling processes. Standard mechanical recycling is not able to provide closed-loop recycling as fibres loose length and quality, ultimately leading to down-cycling.

Experts also mentioned that there is a lack of funding for technological development in recycling and re-production processes. While some funding opportunities are available for researching framework conditions for a circular textiles economy, only Nordic countries have started to provide higher levels of funding as part of their overarching strategy to become the world's leading region for sustainable use of clothing. A lack of funding currently exists in taking the step from prototypes to industrialised processes, as there are hardly any financial resources available for technologies that reached a higher technology readiness level than a demonstrated proof-of-concept.

- **Absence of extended producer responsibility (EPR), inconsistent policies, lack of global governance mechanism for textile supply chains and regulatory barriers**

Discussions also revealed that in the specific case of Germany, there is an acute lack of harmonisation of regulation on waste collection for post-consumer garments. Federal states are concerned with rewarding the rights to collect post-consumer garments and there is differing statutory interpretation. For example, in Hamburg brands are allowed to collect all types of garments and in North-Rhine Westphalia (NRW) brands are only allowed to collect their own post-consumer goods. This creates barriers for brands in NRW to integrate post-consumer collecting stations in their stores.

In general, governance actors and organizations are not adequately regulating businesses on global markets. There is a need for an extended circular regulation on EU or even on a global level (similar to REACH, EU) to foster collaboration between brands for sharing circular agendas and business models and shifting the industry towards circularity. Moreover, experts highlighted that current policies also impede the development of new recycling technologies as too strict and rigid environmental regulation can create excessive administrative and technical expenditure. The legal definition of waste imposes another barrier. Trade restrictions in export and import occur when textiles are declared as waste; yet developing recycling infrastructure at large scale will require a high input of used textiles that partially will have to be covered by imported post-consumer textiles.

2.4.2 Solutions and best practices

Based on the analysed body of literature as well as the conducted expert interviews and workshop results, a number of potential solutions to overcoming the abovementioned challenges were identified. In some cases, these have been applied and tested in real-life situations and can be illustrated by best practice examples from Germany and other member states.

- **Campaigns on consumer awareness and integration of learning modules on circular economy into curricula for secondary and higher education**

There is a need to strengthen knowledge of consumers on sustainable value chains and externalities of manufacturing processes from cradle to grave/cradle to cradle through consumer campaigns. This may particularly address the increasing generation of clothing waste, e.g. as successfully implemented by the Waste and Resources Action Programme (WRAP) from the UK. As part of the Sustainable Clothing Action Plan (SCAP), a consumer campaign termed "Love Your Clothes" aims to educate consumers on how they can make their clothes last longer, reduce the environmental impact of laundering, deal with unwanted clothes (including disposal via e.g. charities) and make the most of their wardrobe (WRAP 2017, 2018). Experts suggested that through such campaigns, consumers should be able to identify negative externalities more easily. This could be supported via online applications (e.g. QR-codes) which present relevant information in a clustered and explanatory way for fostering adequate consumption and recycling practices.

Furthermore, it has been repeatedly highlighted that the concepts of sustainability and circularity need to be mainstreamed in education in a multi- and interdisciplinary way in schools, training facilities and universities for all actors along the textile life cycle. One practical example is the PUSCH initiative from Switzerland that has developed ten educational modules (amongst others on textile recycling and disposal) in order to integrate it into curriculums at high schools (Pusch). Other dedicated educational activities are implemented by the Sustainable Textile School, which was founded by TU Chemnitz and Gherzi Group in 2017. Hosted as an annual event, the textile school covers five different strands related to circularity (i.e. resources, fabric production, chemistry, supply chain, and policies) and seeks to establish a global platform for sustainable textile engineering (Sustainable Textile School 2018).

Furthermore, experts and workshop attendants also called for dedicated partnerships between circular economy specialists and textile design schools in higher education. Some work in this area has been pioneered by the Beneficial Design Institute and the Circular Fashion platform based in Germany, yet a wide-spread and more systemic adoption is yet to be fostered (Beneficial Design Institute 2017; Circular. Fashion; personal communication, 2018).

Incremental innovation and disruptive business models which encourage circular production and consumption patterns

Both literature and industry experts repeatedly highlighted the role of the private sector leading the implementation of circularity across textile value chains. Companies may follow varying approaches by implementing incremental (e.g. process-related, campaigns etc.) or disruptive innovation (e.g. new business models).

With regards to incremental innovation, a prominent example is fashion company C&A which recently introduced a C2C certified collection of t-shirts in 2017 and has been producing various other products in accordance with the C2C certified standard (C&A). C&A's strategy was focused on presenting fashionable garments without explicitly advertising the certification scheme as part of their overarching campaign. In order to leverage consumer preference for circular products, brands and retailers will be required to implement marketing strategies which promote circular solutions as fashionable without overwhelming their customers with excessive information. In this context, experts mentioned that circularity could present a USP for brands and create a long-term advantage in a highly competitive market environment.

Hvass (2015) distinguishes between two broad approaches for circular business models: in-store take back schemes versus reuse and reselling platforms. By pursuing the first approach (i.e. in-store take-back schemes for subsequent recycling), companies incentivize customers to return products at the end of life in exchange for a shopping voucher. A prime example for this is fast-fashion giant H&M (2015) which announced, "to move towards a 100% circular business model" by "only using recycled or other sustainably sourced materials and taking a circular approach in how products are made and used". According to Hvass (2014), such schemes appear to be more appropriate for companies, which offer products of lower quality and lower resell value. Further, creating and maintaining a commercially viable cost-structure largely depends on the handling of reverse logistics, the effectiveness of the collection system, recycling efficiency and the degree of customer engagement (ibid.).

Following the second approach (reuse and resell) and leaning more towards the disruptive side of innovation, companies may seek to prolong the product lifetime while capturing the resell value of used textiles. Examples include US brands such as Patagonia and Eileen Fisher as well as Swedish companies like Filippa K (EILEEN FISHER Inc.; Filippa K.; Patagonia). Based on a case study with Filippa K, reselling can attract new customer groups, increase customer loyalty and generate additional income from used products and samples. Yet, the success of such activities depends on a various key conditions, including market maturity, strong brand awareness, high product quality and high perceived resell value. Moreover, the avoidance of cannibalism appears to be of great importance, implying that reselling via external stores is preferable over store-in-store solutions.

Other new business models can decrease overproduction and waste along the life cycle of textiles and lead towards circular mind-sets of customers. This may include the implementation of repair services at zero cost (e.g. as pioneered by Swedish denim brand Nudie Jeans), promoting sharing approaches (e.g. in sharing cafés), renting (Tchibo) as well as leasing or prescription-models (e.g. e.g. LENA fashion library and Mud Jeans in Amsterdam) (Lena 2017; MUD Jeans; Tchibo). Moreover, individualisation through digital wardrobes, 3D printing and holistic management can be named as innovative practices (Innovation in Textiles 2018; Savory). According to interviews and workshop inputs, new strategies such as a defined user period for clothing and block chain technologies for value chain transparency also have great potentials. The defined user period can help brands to plan their input schemes for recycling processes and bond customers. Block chain technologies are under development (e.g. Lablaco) but are in need for holistic data collection throughout the value chain (personal communication 2018).

According to an assessment of five apparel business models by WRAP, buy-back and reselling models provide the greatest financial viability vis-á-vis environmental savings, followed by formal clothing hire. Other models including repair services as well as leasing and peer to peer exchange platforms (e.g. of for baby clothes) were deemed as unprofitable even within a ten year timeframe (Buttle et al. 2013). The differences in profitability can be explained by various assumptions for required upfront investments in conjunction with labour costs and profit margins for goods and services offered. The report concludes, "that there is potential for a business case to be made that combines strong financial performance with reasonable savings in the numbers of garments going to waste" (ibid: 77). Following a similar approach, the Ellen MacArthur Foundation suggests a business model for online clothing rental ("Netflix for clothing"). According to simplified calculations, this business model could even be more profitable than conventional online retail due to a decrease in clothing production that results in considerable material savings.

International collaboration and the role of multi-stakeholder initiatives

In the presence of globalised, interconnected and highly complex textile supply chains, there is a need for implementing joint processes, which foster a shift towards a circular textile sector. In terms of international cooperation, Ethiopia's and Myanmar's textile and clothing markets have recently started to emerge, thus offering valuable opportunities for bilateral partnerships for integrating and mainstreaming circular economy practices into textile production. Given the importance of the design phase for reusability and recyclability of textiles at the end of life, experts also discussed the role of academic partnerships for circular designs of textiles between higher educational facilities from countries of the global north (e.g. Germany) and south (e.g. Bangladesh).

Due to the absence of global regulating institutions, interviewed experts suggested that multi-stakeholder initiatives (MSI) on a national, European or global level should involve all relevant actors to transcend national borders and push for more circular practices along the supply chain. Albeit slow, such self-regulating mechanisms were perceived as vital to advancing circularity in the textile sector, e.g. by collectively stipulating minimum values for contents of recycled materials in textile production. Furthermore, experts highlighted that detailed information of externalities need to be accessible. In order to produce reliable data, standards on data collection and performance reporting need to be established. Once again, MSIs were seen as appropriate vehicle to drive such changes on a broader scale (personal communication 2018).

Further, sharing of information and best practices amongst different actors was perceived as particularly important in order to advance circular practices in the textile industry. At the brand-level, companies could share experiences from implementing new business models (e.g. leasing) and disclose lessons learnt on the introduction of certification schemes or specific design approaches (e.g. Cradle to Cradle) to leverage the demand for circular textiles. At the supplier-level (i.e. textile manufacturers) trading platforms for off-cuts could further curb the generation of pre-consumer textile waste.

Enabling regulations, soft policies as well as research and development for circular economy principles in the textile sector

Furthermore, experts frequently highlighted the enabling role of policies. Depending on the specific level of intervention (national to global), a mix of hard laws and soft measures was advocated. At the European level, experts emphasised that there should be a focus on joint efforts towards European or global legislation towards circularity (e.g. REACH, EU), e.g. in the form of a comprehensive circular economy law on textiles where manufacturing (and/or procurement) processes are mandated to adhere to pre-defined standards (e.g. Best Available Technologies which employ C2C-thinking). To some extent, textiles are now covered under the EU Circular Economy Package, which foresees separate collection by 2025 (European Commission 2018b). According to interview opinions and discussion held during the workshop, this needs to be addressed more explicitly and implemented at the member state level. In this context, the French Extended Producer Responsibility (EPR) scheme for textiles EcoTLC was mentioned as a best practice example.

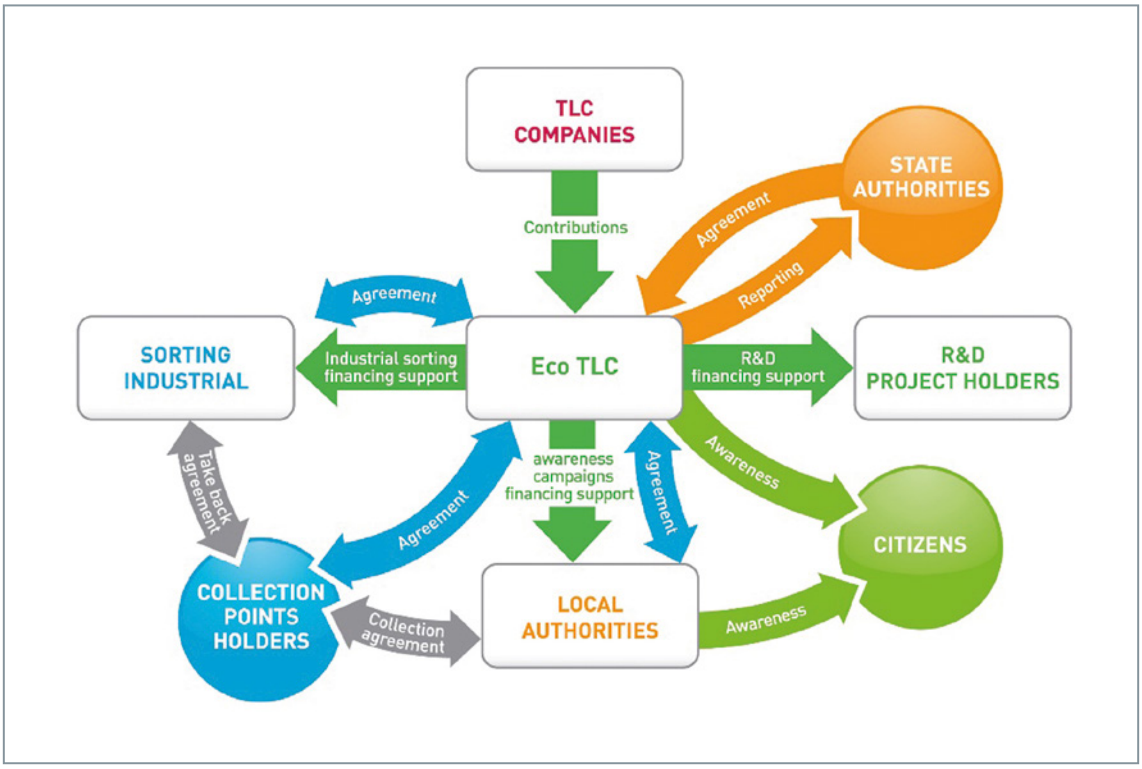


Figure 10: French EPR system EcoTLC (EcoTLC)

According to this scheme, legal entities selling textiles on the French market are responsible for the end-of-life phase of their products. This can be accomplished either by setting up their own take-back programmes or by joining Eco TLC as a centralised Producer Responsibility Organisation which coordinates collection their behalf (Bukhari 2018). In this context, the French government currently stipulates a textile collection target of 50% for annual sales of clothing, linens and footwear as well as a material recovery rate of 95% of the collected products (ibid.). Founded in 2008, Eco TLC now presents more than 93% of the industry in France. According to expert opinions, EPR systems were perceived as highly beneficial for increasing collection rates, mobilising funds for waste management infrastructure as well as providing financial resources for innovation.

The current German coalition agreement explicitly mentions textiles as an important waste stream, which needs to be managed more efficiently. This was perceived as a potential leverage point for introducing an EPR system in Germany (personal communication 2018). Consequently, a new sector of collecting post-consumer garments for re-design/re-production could develop and encourage the adoption of circular business models. At the same time, funding schemes, research and technological development should be increased. Scientific knowledge on technologies and social transformation towards circularity are to be supported by governmental actors and ministries.

Further hard regulations could include mandatory eco-design criteria that promote design approaches for non-toxic application scenarios as well as design for repairability, disassembly and recycling. Moreover, brands could be required to address environmental and social externalities into their profit and loss statements, which summarises the revenues, costs and expenses incurred during a specified period. In future, this could become part of the non-financial reporting obligations amongst European member states. Moreover, workshop participants discussed tax incentives for circular products or even tax penalties on conventional products represent possible solutions. Post-consumer goods should be declared as valuable resources. In this context, the reduced value-added tax on repair services introduced by the Swedish Government was mentioned as a positive example that could encourage customers to use their clothes for a longer period of time (Orange 2016).

With regards to soft policies, various best practices examples can be found at the European level. For one, the EU's green public procurement (GPP) guidelines for textiles already incorporate aspects of circularity, such as durability and lifetime extension, design for reuse and recycling and overall recycled content (European Commission 2017a). As part of the recently published Circular Procurement Brochure, the Cradle to Cradle certification system is prominently featured. In addition, some references are made to the Dutch Ministry of Defence, which, in 2017, procured towels, and overalls with at least 10% recycled content (European Commission 2017b). Such approaches could also be followed across other member states to leverage demand for recycled fibres.

Furthermore, various research and innovation projects are currently being implemented across EU member states. The European Clothing Action Plan (ECAP) can be mentioned as a positive example promoting principles of a circular textiles economy. Being conceptualised as a 3.6 million EUR project funded by the European LIFE programme, ECAP seeks to reduce clothing waste across Europe and embed a circular economy approach by stimulating waste prevention along the entire value chain, encouraging resource-efficient design and creating consumer awareness. The project runs for three and a half years, ending in March 2019. Research, case studies and recommendations are shared via a public website even after implementation of the project to help the sector continue its path to sustainability (ECAP).

Through recent years, Nordic countries have emerged as frontrunners in transforming domestic markets towards more sustainability and circularity. This is reflected by, inter alia, the Nordic Textile Commitment on Reuse and Recycling published in 2014 (Norden 2014a). The commitment was developed in close coordination with collectors, municipalities and waste companies and strives towards a ten year goal of at least 50% of collected textiles whereof 90% is reused or, where not possible, recycled. It further provides a third party certified system for legitimate sustainable collection, sorting, reuse and recycling of textiles by the participating actors. Following this commitment, the Nordic Council of the Ministers launched the Nordic Action Plan for Sustainable Fashion and Textiles in 2015 termed "Well Dressed in a Clean Environment" (Norden 2015). The action plan outlines a vision for the year 2050 and seeks to define framework conditions for more sustainable use of fashion products by 2020. It specifically addresses linear "buy-it-and-throw-it-away" culture prevalent in Nordic countries and promotes a shift towards circular design, production and consumption models.

At the individual project level, Mistra future fashion aims to deliver insights and solutions that will be used by the Swedish fashion industry and by other stakeholders to significantly improve the environmental performance and strengthen the global competitiveness.

In the UK, the Sustainable Clothing Action Plan (SCAP) is implemented by the Waste and Resources Action Programme. Conceptualised as an industry-led multi-stakeholder action plan, SCAP addresses five focal areas related to a circular economy: resource efficient business models, design for extending clothing guidelines, fibre and fabric selection, consumer behaviour as well as reuse and recycling (WRAPa). According to WRAP's evaluation, SCAP signatories have cut water impacts by 13.5%, carbon impacts by 10.6%, waste impacts arising across the product life cycle by 0.8% and contributed to a reduction in household residual waste by 14%, per tonne of clothing in 2017 (WRAPb).

Further, various research projects and private initiatives referred to in earlier sections of this report are currently operating within the context of a circular textiles industry. This includes, amongst others, the as the Interreg-funded "Fibre Sort" project which develops an innovative sorting technology (see section 2.3.3) and the H2020-funded Resyntex project which aims to create a new circular economy concept for the textile and chemical industries based on industrial symbiosis as well. The approach targets the entire value chain - from textile waste collection to the production of new raw materials for the textile and chemical industries. Collection approaches are improved by sensitizing the public, data aggregation allows the traceability of textile waste. In addition, a complete biochemical reprocessing line for basic textile components will is piloted (Resyntex 2018).

Strategies to overcome challenges in recycling technologies

The figure in Annex VI shows strategies suitable for tackling the challenges that currently impede the use of recycling materials in textiles. Without communication and cooperation in the supply chain between collections, sorting technologies, and recycling processes no closed-loop recycling can be achieved. In addition, supply chains have to be created. Stronger consumer awareness can create demand for recycling products and increase the willingness to pay more for sustainable products until technologies are improved and prices can compete with virgin fibres. A lot of research and development has already been conducted on recycling technologies but most approaches need further financing for upscaling and commercialisation.

3 Conclusion and outlook

The analysis presented above suggests that the transition towards a circular textile industry will require fundamental, system-wide changes in the way products are designed and used, business is conducted and progress is measured at the corporate level. Further, it appears that the transition towards a circular textile industry in Europe and Germany is still in its infancy due to a wide range of socio-economic, environmental and legal barriers which create path dependencies and inhibit the adoption of circular solutions on a broader scale. At the same time, a number of potential solutions could be identified and innovative recycling technologies can help to close material loops at the end of the textile use phase. However, none of them have reached market maturity yet, suggesting that further financial and technical support is needed for commercialisation. Moreover, a fully circular, closed-loop textile industry must to go beyond mere recycling of end-of-use fibres and needs to reimagine the way clothes are designed, produced and kept in use for as long as possible.

One issue to be kept in mind is that the whole perspective taken on circular economy originated in countries of the Global North and the approach of the Ellen MacArthur Foundation is Eurocentric (Griffiths, P. Cayzer, 2016). While this may not be considered as inherently flawed, it cannot be expected from those countries acting as manufacturing hubs outside Europe to think and act as Western nations; this is even more understandable since significant technological disruptions heralded as circular solutions (e.g. the introduction of sew bots) raise concerns about the future and implications on traditional manufacturing hubs that rely on intensive manual labour.

Overall, it is expected that the adoption of automation technologies and demand-driven business models will contribute to a significant reduction in textile wastes. For example, advances in knitting technology, such as computer-controlled or 3-D knitting, enable customisation and improvements in design and fit already reduced material waste by 80% (example: Nike's Flyknit product line). At the same time, demand-based sourcing and replenishing models as well as increasing customisation of production thanks to digitisation and interlinkage of consumers and manufactures will drastically reduce the stock of unsold apparels.

However, the increased automated production may imply less reliance on labour intensive low-cost manufacturing. Speed and flexible response to fast changing customer demands can be achieved by shifting automated production closer to or even directly into key markets (e.g. Europe, USA, India and China). Such "nearshoring" or even "reshoring" of CMT operations are commonly viewed as important enablers for the transformation towards a circular textile industry. However, such trends may severely undermine the overall economic development strategies of manufacturing hubs, which rely on a low-cost labour intensive production approach.

In case of the European apparel market, it is expected that supply will come from the emerging nearshore manufacturing hubs in the Middle East and North Africa (MENA) region. Traditional manufacturing hubs such as Bangladesh or Pakistan may have to reorient towards Asian markets, such as the large domestic markets in India and/or China. However, even in these manufacturing hubs, which mostly serve the mass-market apparel sector, the move towards a demand-focused, agile supply model and adoption of the circular economy principle will likely affect the employment profile. In view of Mr. Mostafiz Uddin, Founder and CEO of Bangladesh Denim Expo and Bangladesh Apparel Exchange (BAE) and a young technology savvy denim manufacturer in Bangladesh, the industry in his country is not ready to respond to on-demand apparel manufacturing and circularity. As part of its ongoing cooperation engagement, BMZ may consider exploring in which way it can support the affected manufacturing countries in developing adaptation or mitigation strategies.

Annex I. Schools of thought

Concept	Rationale and Scope
Cradle to Cradle / Cradle to Cradle Certified[CM]	Design concept and certifications scheme; differentiates between biological nutrients and technical nutrient cycles; waste should be eliminated, instead, materials should continuously flow within the biological or technical cycle; certification of products and materials (micro level).
Biomimicry	Design concept that seeks to create sustainable solutions by emulating patterns found in nature; applied to the micro- and meso-level through product and infrastructure innovations.
Industrial Ecology	Framework for environmental management of industrial systems; views industries and their environment as man-made ecosystems which are connected through flows of matter and energy; strives for meso-level optimization by closing material loops in industrial complexes.
Natural Capitalism	Economic model which aims to increase the productivity of natural resources through the use of biologically inspired production models and materials; promotes service-based business models and investments in natural capital.
Performance Economy	Economic concept which seeks to reduce environmental impacts by selling services instead of goods; emphasizes longevity of products; highlights the need for innovations at the business-level; demands regulatory changes to create (e.g.) tax incentives.
Regenerative Design	Design approach; focuses on processes rather than single products or system components; systems should be design in such a way that they regenerate their own resource base; rooted in landscape architecture (meso-level).

Table 4: Schools of thought which influenced the conceptualisation of the circular economy

Annex II. Circular economy system diagramme

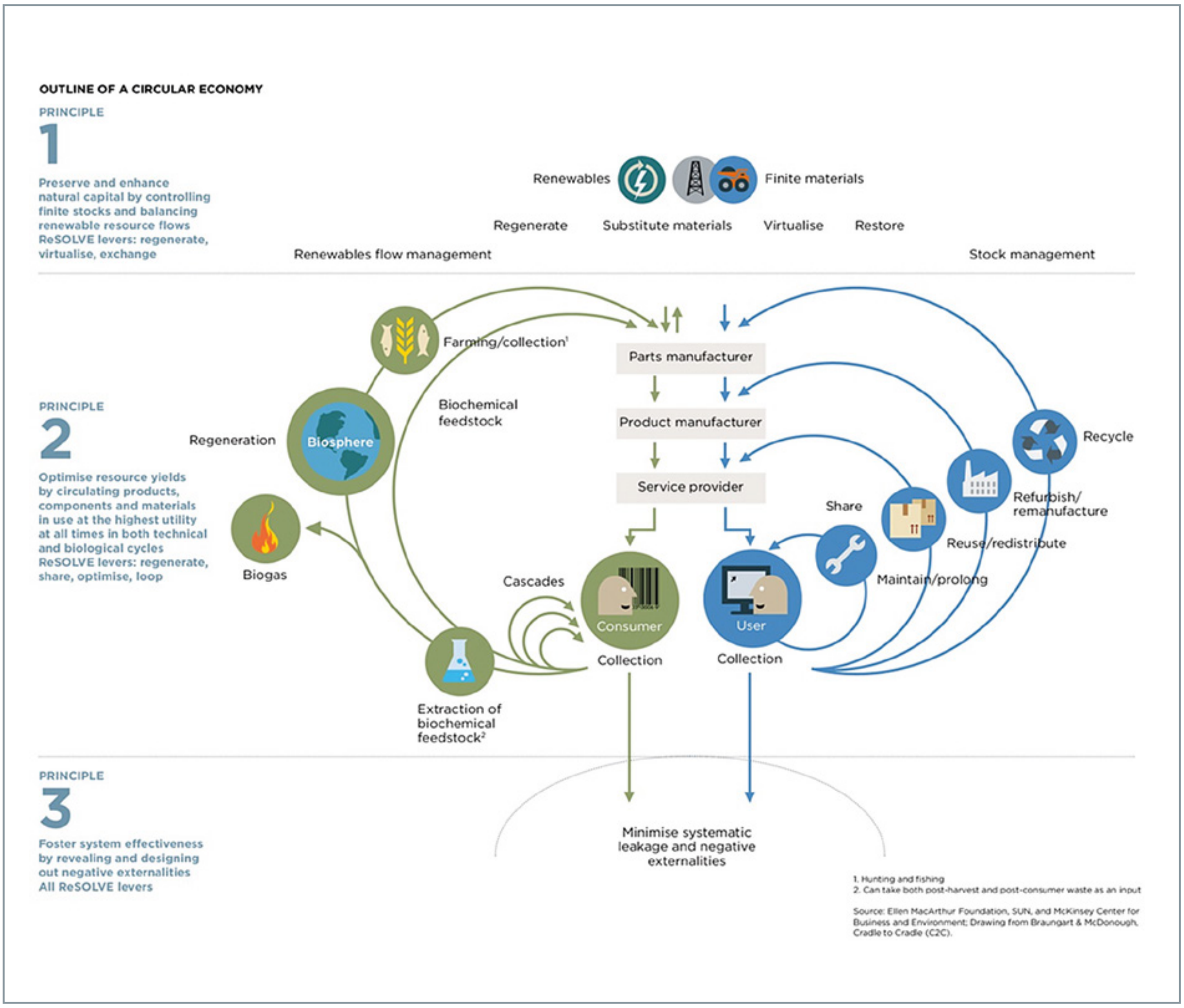


Figure 11: Circular Economy system diagramme (Source: Ellen MacArthur Foundation 2017b, drawing from Braungart & McDonough, Cradle to Cradle)

Annex III. Detailed framework for circular business models in the textile industry

CIRCULAR	SERVITIZATION	SUFFICIENCY
CREATE VALUE FROMM WASTE	**FUNCTIONALITY OVER OWNERSHIP**	**ENCOURAGE EFFECTIVE RESOURCE USE**
The concept of waste is eliminated by turning waste streams into useful and valuable input for other processes.	Provide services that satisfy users' needs without having to own physical products.	Solutions that actively seek to reduce consumption and production.
CLOSED LOOP MODELS	**REPAIR & WARRANTY**	**DEMAND MANAGEMENT**
Business models that include products and business process designed to enable 'waste' at the end of the use phase to be used to create new value.	Business models that include the service of extending a product's useful life through repair & maintenance and/or by selling a durable product through warranty.	Business models involving the use of a system, software or other communication channels in order to forecast and plan for the demand of a certain product.
REUSE	**RENTING & LEASING**	**CO-CREATION**
Business models that are based on the reselling of used products enable the extension of the useful life of a product and involve schemes for collection or take back of products or materials.	Business models based on selling the performance of a product, which is delivered through a combination of product and services and where ownership of the product is retained by the service provider.	Business models based on turning customers' heterogeneous needs into an opportunity to create value (mass customization), challenging the 'one size fits all' assumption of traditional mass production.
RECYCLE	**PAY FOR RESULT**	**USE EXCESS CAPACITY**
Business models that include products and business processes designed to enable 'waste' at the end of the use phase to be used to create new value.	Business models based on selling a 'result', where the 'means to an end' or the products and services that achieve the 'result' are determined by the provider.	Business models that re-capture under-utilised assets, capabilities and human capital through shared ownership and .collaborative consump-tion approaches (includes both community based and profit driven models).

Figure 12: Framework for circular business models (Circle Economy 2015)

CIRCULAR	SERVITIZATION	SUFFICIENCY
• This category is included to reflect business models that have a **focus on product and material reuse** and closing material loops, keeping all resources in the system and thus effectively eliminating the concept of 'waste'. • The goal behind these business models is to **generate new revenue streams based on turning 'waste' into useful and valuable input** to other production cycles. • To enable the cycling of products and materials, **take back management is an essential element in the business model.** This can be arranged through a combination with servilization models where the producers stays owner of the product, through collection schemes based on incentivized return or by making use of existing public waste management systems available. • In addition to closed loop, reuse and recycling included in the framework, other strategies like industrial symbioses, C2C and remanufacturing can also be considered 'circular'.	• Servilization models **provide access to services that satisfy users' needs without users having to own physical products.** In this way, these models have great potential to change consumption patterns. The product is still important, but customer experience is fundamental to the offering or value proposition. • These models allow for the **disconnection of profit and production volume** (decoupling economic growth from resource use) and provide incentives to deal with end-of-life issues as the manufacturer relains ownership of assets. • However, literature and practice indicate that servilization models are **not inherently more eco-efficient** and that careful attention to detail is required to realise the benefits. In combination with Circular and Sufficiency stratgies these models have the most potential to reduce resource use.	• This category reflects business models that **actively promote reduced production and consumption** and encourage a 'do more than less' mentiality. • In addition to product durability, sufficiency models can have a strong influence on consumer behaviour and lead to greater product and/or brand attachment. • Social and environmental benefits of sufficiency-based business models include reuse of products and resources across generations, **reductions in product use, and societal education**. • The business rationale behind these models is typically derived from **premium pricing, consumer loyalty, and gaining market share** from better (e.g. longer lasting) products. • In addition to demand management, co-creation and use excess capacity, other strategies like product longevity, consumer education and responsible product distribution can also be considered to promote 'suffiency'.

Figure 13: Main categories for circular business models (Circle Economy 2015)

Annex IV. Assessment of recycling technologies

#	Recycling technology	Type of flbre / Technology	Developer & Other Involved Institutions	Advantages	Disadvantages	Environmental, social and economic implications	Development state / Possible future Improvements	Description
1	**Standard mechanical recycling (Fibre Recycling)**	Natural fibres (Cotton fabrics)	Developed process (E.g. SOEX with H&M)	- Reduction in use of new fibres - Substitution of raw material production (cotton farming)	- Max 30 % recycled Fibres - Fibres are damaged during the sorting process -> shortens and weakens fibres -> less functionality/ quality (worse properties) - supplement of new high quality fibres is necessary (Ellen MacArthur Foundation 2017a) - quality reduction through admixtures	- Ecologically questionable (e.g. energy use, magnitude of the overall environmental impacts depend on impact of sub-stituted type of material) - Possible continued circulation of harmful substances if not filtered Out before - Down-cycling (most fibres not recycled to clothes, but other materials)	- Increase in share of recycled fibres - Currently less than 0.1% of recycled amounts textiles is recycled into yarn and new textiles Norden, 2014)	- Sorting by colour and material - Mechanical tearing of fibres - Unravelling, grinding, defibrating and cutting (Bukhari et al. 2018)
2	**Standard chemical Recycling**	Synthetic fibres (synthetic polyester as mostly used fibre)	Developed process (e.g. Parley for the Oceans)	- Recycling without affecting quality - Potentially recycl-ing of mixed fibre products is possible	- Restriction to single-origin articles - In most cases fibres not made from used cotton, but from other used plastics - Material must be sorted, washed, decoloured - Additives e.g. plasticizers in used plastics	- Ecologically questionable due to high energy consumption (Leonas 2017) - Harmful substances can be removed through the process (Ellen MacArthur Foundation 2017a) - Recycled polyester fibres are not more expensive than conventional ones (Zeit 2017) - High capital investment (Leonas 2017)	- Concerning natural fibres not techno-logically or economi-cally mature (Ellen MacArthur Foundation 2017a)	- Textile materials are roughly cut up and decomposed into individual monomers by the addition of various chemicals - Feedstock to pro-duce monomers of virgin quality

Table 5: Technology assessment matrix

#	Recycling technology	Type of fibre / Technology	Developer & Other Involved Institutions	Advantages	Disadvantages	Environmental, social and economic implications	Development state / Possible future Improvements	Description
3	**Fabric Recycling of factory offcuts and leftover Materials (Pre-Consumer-Waste)**	Natural and synthetic fibres	Developed process	- Does not require advanced technologies	- Limited application - Labour intensive - Quality of "pre-consumer" waste can be too low - Shortening of fibres by shredding makes supplement of longer fibres necessary (20% - 90% recycled cotton content is possible)	- In general environmental-friendly - Just chemical use if decolouring is necessary (bleaches, dyes) - Labour intensive process could lead to creation of additional jobs - Inconsistent and too small supply of fabrics	- Increase share of recycling content - Networking of companies in order to coordinate supply and demand of "pre-consumer-waste"	- Re-manufacturing: Pieces of complete fabric mostly from "pre-Consumer-waste" are re-sewed to create new garment
4	**Relooping Fashion Initiative (unique cotton dissolving technology), Infinited Fiber**	Natural fibres (Cotton fabrics)	VTT Technical Research Center of Finland, Infinited Fiber Company	- Same quality as viscose fibres - No downgrading of fibres through recycling ("infinite recycling") - No use of harmful chemicals	- Reliability is an issue that has to be improved by further research and development (EurekAlert! 2017) - Requires raw material in large quantities	- Highly ecological compared to alternatives, like viscose manufacturing process: No poisonous chemicals (no CS_2), saves one third in carbon footprint, 98 percent in water - Technology is 20-40% more economical than competing solutions	- Currently test-base on industrial scale, development towards industrial production - polyester residues are removed from cotton by methods familiar from the pulp industry (EurekAlert! 2017)	1. Activation 2. Carbamate cellulose dissolution technique 3. Fractioning (The Infinited Fiber Company 2018) - fibre produced from cotton rich textile waste and other bio-materials, like wood
5	**re:newcell pulp (Garment made entirely from recycled cotton)**	Cotton, viscose and other cellulosic fibres	re:newcell (developed at the Royal Institute of Technology in Stockholm; partners: SKS Textile, H&M)	- Recycled fabrics can even contain a mix of cotton and other materials (however, best results with pure cotton recycling) - No addition of virgin fibre (almost 100 % recycling of pure cotton) - Same quality as virgin fibres - No harmful chemicals (Launch 2017)	- Different characteristics of end-products than virgin materials can lead to issues in further processing steps - Small scale leads to high costs in initial stage	- Compostable pulp output - Energy intensive, mostly due to drying process - In general more environmental-friendly than wood processing - In larger scale cost advantage compared to wood processing due to input mostly free-of-charge	Since 2017 demo plant in Sweden (capacity: 7,000 tons of re:newcell pulp); full sale plants with 30,000 tons planned	- Post-consumer clothes are shredded and broken down to molecule level by chemical (solvent) dissolution; a high cellulosic portion fabric is transformed into recycled dissolv-ing pump that is later transformed to inter-mediate product viscose fibre (Norden 2014)

#	Recycling technology	Type of fibre / Technology	Developer & Other Involved Institutions	Advantages	Disadvantages	Environmental, social and economic implications	Development state / Possible future Improvements	Description
6	**Refibra (based on pre-Consumer cotton waste)**	Natural fibres (Cotton fabrics)	Lenzing (e.g. Patagonia)	- Same quality as raw material from wood	- Up to now just 20% recycling content possible - Just possible for undyed, homogenous pre-consumer waste	- Environmental advantages proven by LCA (conducted by Lenzing) - Integration of recycling material in conventional Lyocell production process - High costs (high than using wood as raw material)	- Commercially available - Research on increasing recycling content and use of post-consumer waste (long-term goal)	- Undyed cotton pre-consumer waste as input for fibre production - Replaces part of wood as raw material used in pulp fibre production
7	**Innovative chemical polymer recycling**	Natural fibres (Cotton fabrics)	Evrnu (e.g. Levi Strauss)	- Possibility of engineering certain characteristics of the new fibre - Production of a filament that is finer than silk and stronger than cotton	- Just working for cotton fabrics - High energy consumption - Higher costs than virgin materials	- 98% less water than virgin cotton (Moorhouse & Moorhouse)	- Prototype status	- Collection of post-consumer cotton garment waste - Removement of dyes / contaminates - Pulping and breaking down cotton to fibre molecules
8	**Innovative chemical polymer recycling**	Polyester and Cotton	Worn Again (e.g. H&M, Puma)	- Pure as well as blended materials can be used (broad range of inputs) (Greenblue 2017) - polyester of same quality as virgin equivalent - 20% of impurities can be filtered out	- High energy consumption - Higher costs than virgin materials	- Lower energy consumption than other processes due to avoidance of depolymerization (direct recapturing of polyester) but still quite high - Establishment of chemical recycling plants in Europe can create skilled jobs - Goal is to compete with virgin material in terms of price	- Small scale - Establishment of Recycling plants (Upscaling) planned	- Separation and recapture of polyester and cotton - Polyester: Dissolving; taking out contaminants; resin; finishing polymer - Cotton: Dissolving; Decoupling dyes and contaminants; separation to produce pulp which is equivalent to viscose - Converted into virgin equivalent polyester or a cellulose pulp that can be used to produce viscose

#	Recycling technology	Type of fibre / Technology	Developer & Other Involved Institutions	Advantages	Disadvantages	Environmental, social and economic implications	Development state / Possible future Improvements	Description
9	**Innovative hydro-thermal (chemical) recycling**	Polyester and Cotton	Hong Kong Research Institute of Textiles and Apparel (H&M)	- Recycling cotton and polyester blends - Self separation without the need of prior high-quality sorting	- High energy consumption due to thermal processing and pressure - No direct textile-to-textile recycling for cotton	- Hydrothermal process with heat, water and less than 5% biodegradable green chemical (H&M Foundation 2018)	- Pre-industrial size facility opened in September 2018 in Hong Kong (H&M Foundation 2018)	- Chemical and hydro-thermal treatment under pressure to recycle cotton / polyester blends into new fabric and yarns - Cotton extracted as cellulose fibre suitable for functional products as well as cellulose powders (for super-absorbency materials)
10	**ECO CIRCLE**	Pure Polyester	Teijin	- Similar quality as oil-based virgin materials - 100% recycled polyester is possible	- System does not accept all polyester products - No closed loop recycling as input is mostly no textile waste	- Reduction in energy consumption by 84% (Teijin calculation, Norden 2014) - 10 to 20% more expensive than using virgin materials (Norden 2014)	- Commercially available process (Teijin plant in Japan) (Norden 2016)	- Recycling of polyester from used - clothing, PET bottles and production waste PET 1. Material is cut and washed 2. Compounding / Solving in ethylene glycol 3. Reaction with methanol (Norden 2016)
11	**FIBERSORT**	Sorting technologies	Circle Economy (with collectors, sorters, recycling experts (Ellen MacArthur Foundation)	- Serve as single-origin input for high value textile-to-textile recyclers (mechanical and chemical recycling) (Greenblue 2017)	- High volumes of textiles are necessary for cost-effectiveness	- In case of sorting by colour, no need for bleaching / re-dyeing - low level of contamination (Greenblue 2017) - Job implications if replacement of manual sorting takes places - High investment costs (Norden 2014)	- Upscaling necessary, mostly due to cost-effectiveness - Detection of contaminates in garments could be possible	- Automatic sorting of mixed post-consumer textiles by fibre type by using near infrared spectroscopy (NIRS) - Detection of garments from cotton, wool, viscose, polyester, acrylic, nylon, and certain - Sorting by colour at the same time (Ellen MacArthur Foundation 2017a)

#	Recycling technology	Type of fibre / Technology	Developer & Other Involved Institutions	Advantages	Disadvantages	Environmental, social and economic implications	Development state / Possible future Improvements	Description
12	**SIPTex**	Sorting technologies	Vinnova (e.g. Boer Group as partner)	- Provides sorted, homogenous input for further recycling processes as a basis for further recycling steps	- No separation of exact fibre compositions - Recycling processes could still require more exact separation (by fibre type) - High volumes of textiles are necessary for cost-effectiveness	- In case of sorting by colour, no need for bleaching / re-dyeing - Job implications if replacement of manual sorting takes places - Cost savings for manual sorting - High investment costs (Norden 2014)	- Currently small scale, larger scale facility would be necessary for an cost-effective process	- Based on visual and near-infrared spectroscopy (NIRS) and VIS technology (Norden 2014) - Sorting for the majority fibre type of each garment - Separation of identified garments by compressed air (Ellen MacArthur Foundation 2017a)
13	**Textiles4 Textiles (T4T)**	Sorting technologies	Wieland Textiles (LZH LASERZENTRUM HANNOVER E.V. is a partner amongst others)	- Provides sorted, homogenous input for further recycling processes as a basis for further recycling steps	- No separation of exact fibre compositions - Recycling processes could still require more exact separation (by fibre type) - High volumes of textiles are necessary for cost-effectiveness	- In case of sorting by colour, no need for bleaching / re-dyeing - Job implications if replacement of manual sorting takes places - Cost savings for manual sorting - High investment costs (Norden 2014)	- Currently small scale, larger scale facility would be necessary for an cost-effective process	- Automatic near-Infrared (NIR) sorting Installation which will be able to sort used textile material according to fibre composition and colour - Possible separation of 300 different fractions (currently just applied for 5-10 fractions) - Separates of clothing items from each other

Annex V. Nearshoring and automation as enablers for a circular textile value chain

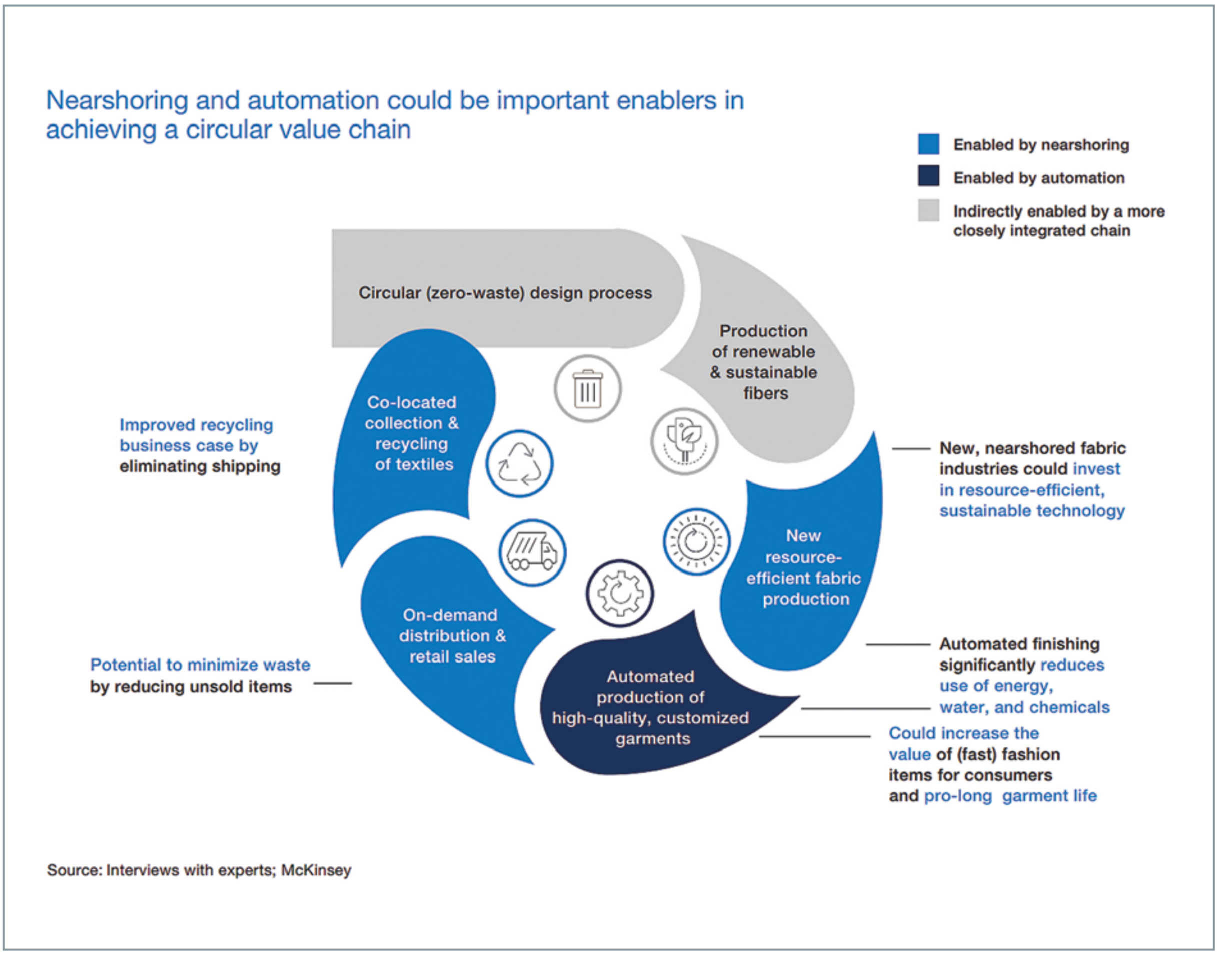


Figure 14: Nearshoring and automation as enablers for a circular textile value chain (McKinsey & Company, Is apparel manufacturing coming home?; Andersson et al. 2018)

Annex VI. Strategies for overcoming challenges to use of recycled materials

Figure 15: Strategy for use of recycled materials (Norden 2017)

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Imprint

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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Edited by:
Franzsica Markschläger, Andreas Edele

Layout:
Gudrun Näkel

Photo credits:
Cover: Mikhail Gnatkovskiy – shutterstock.com

GIZ is responsible for the content of this publication.

On behalf of:
German Federal Ministry for Economic Cooperation and Development (BMZ)
Division 114 – Sustainable Supply Chains, Sustainability Standards

January 2019

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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