MSc Program
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Towards circular resource use: the potential of Extended Producer Responsibility for textile circularity in the EU

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Affidavit

I, **BRIGITTE SIMONE GERSTMANN, BSC MSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "TOWARDS CIRCULAR RESOURCE USE: THE POTENTIAL OF EXTENDED PRODUCER RESPONSIBILITY FOR TEXTILE CIRCULARITY IN THE EU", 83 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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I. Abstract

The textile industry has come into the policy spotlight due to growing evidence on negative social and environmental impacts and insufficient resource circularity. However, little is known on how the according policy goals by the EU will look like and how member states can achieve them. The aim of this study was to evaluate Extended Producer Responsibility (EPR) schemes for their applicability in the textile context, since these instruments proved beneficial in increasing recycling of other product groups. By performing expert interviews, complemented by literature research, this study first explored textile streams along the "waste hierarchy", followed by an analysis of EPR instruments. The results of this study show that EPR is specifically applicable for clothing, suggest promising textile products to achieve ambitious recycling targets and propose a combined, fourfold EPR approach for textiles: (1) design regulations coupled with product take-back, (2) financial responsibility as advanced fees dedicated to reuse, recycling and disposal, (3) organizational responsibility that integrates pre-existing collection infrastructure and (4) legal initiatives that ensure maximum transparency. Such a combined approach may increase textile circularity, assist in long-term environmental responsibility and create room for innovation in this market that also plays important social roles. Further research is needed to obtain more quantitative data on textile streams and to evaluate the recycling potential of technical and industrial textiles, in particular. This Master's Thesis contributes to the understanding of EPR applicability in the textile industry. The results may serve as an orientation for the implementation of upcoming EU legislation on textiles.

II. List of contents

III. List of abbreviations

C & I waste	Commercial and industrial waste
DG ENV	Directorate-General for the Environment
EC	European Commission
EcoTLC	L'écoorganisme du textile, du linge et de la chaussure
EPR	Extended Producer Responsibility
EU	European Union
EURATEX	European Apparel and Textile Confederation
EURIC	European Recycling Industries' Confederation
EXPRA	Extended Producer Responsibility Alliance
ICT	Information and communication technology
ILO	International Labor Organization
MA46	Magistratsabteilung für Verkehrsorganisation und technische Verkehrsangelegenheiten der Stadt Wien
MA48	Magistratsabteilung für Abfallwirtschaft, Straßenreinigung und Fuhrpark der Stadt Wien
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
PPE	Personal Protection Equipment
PRO	Producer Responsibility Organization
REPANET	Re-Use und Reperaturnetzwerk Österreich
SAC	Sustainable Apparel Coalition
TU Wien	Technische Universität Wien; Vienna University of Technology
UBA	Umweltbundesamt; Environment Agency Austria
WFD	Waste Framework Directive
WU	Wirtschaftsuniversität Wien; Vienna University of Economics and Business

IV. Acknowledgements

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1. Introduction and Research Question

"This is Europe's man on the moon moment. Our goal is to reconcile the economy with our planet and to make it work for our people ", these were the words of Ursula von der Leyen when she introduced the *European Green Deal* in December 2019. The strategic roadmap presents an ambitious plan to make the EU climate neutral until 2050, as von der Leyen is "[…] convinced that the old growth model based on fossil fuel and pollution is out of date and out of touch with our planet" (EC, 2020a; Simon, 2019) With the European Green Deal, the new European Commission (EC) under von der Leyen's presidency assigns a clear political task to the member states of the European Union. It covers policy plans not only for climate neutrality, but also for "mobilizing industry for a green and circular economy" (EC, 2020a).

In this scope, a New Circular Economy Action Plan was issued in March 2020 to strengthen European competitiveness, innovation, growth and employment (EC, 2020b). One word that appears 21 times in this plan, is the word "textiles". It appears in the context of priority value chains besides electronics, high-impact intermediate products, furniture and ICT (information and communication technology) and in the context of microplastics in the environment as well as finally, in its very own section. In this section, the EC announces a "comprehensive EU strategy for Textiles" by 2021 with input from stakeholders and industry, aiming at "strengthening competitiveness, innovation, EU markets for sustainable and circular textiles including reuse and addressing fast fashion and driving business models". The measures to achieve these goals are four-fold: (1) applying the new product framework with eco-design measures, empower business and consumers to make sustainable product choices and ease reuse and repair opportunities, (2) improving business and regulatory environments, (3) achieving high degrees of waste separation and (4) advancing sorting, re-use and recycling of textiles (EC, 2020b).

But why textiles? The EC defined textiles as a priority sector because unsustainable practices of the industry that contradict clearly to the circular economy approaches by the EU. With a production volume of about 100 million tons of fiber each year, the sector has not only substantial demand for raw material input, but also entails substantial environmental and social repercussions along its value chain (CIRFS, 2020; Ellen MacArthur Foundation, 2017). Clothing is one group of textile products and presents a

special case since product life often does not end with the post-consumer phase: reuse is common for clothing yet does not inhibit that the majority (74%) of textile products end in incineration plants or landfills (Ellen MacArthur Foundation, 2017). These are some of the reasons why the EU decided to make textiles one of their priority sector on the agenda of the new European Commission (DG ENV Officials, personal communication, April 15, 2020). However, what instruments are chosen specifically to realize the upcoming EU measures and targets, remain unclear.

Textiles come in considerable quantities, in heterogenous composition and applications and their wastes have been growing in both volume and complexity. All of these factors limit the recycling potential of textiles and thereby the circular economy concept of the European legislation. One proposed set of instruments that was effective in increasing resource circularity in other sectors, is *Extended Producer Responsibility* (EPR). The surge in EPR policies world-wide contributes to the likelihood of an upcoming European EPR policy for textiles.

This master's thesis addresses the question which EPR model has the greatest potential to increase textile circularity in the European Union with a special focus on Austria. In particular, this study aims at exploring the applicability of existing EPR models with regards to specific textiles (e.g. clothing) in Austria and the European Union. This includes (i) identifying a priority list of textile products for which EPR is best suitable, (ii) a comprehensive review of existing EPR models and (iii) the analysis of the applicability of these models with regards to the Austrian/European situation.

Thus, this Master's Thesis will aim at answering the following research question:

Which EPR model is most applicable with regards to textile circularity, in particular clothing, in the European Union and in Austria?

The study seeks to address this question by analyzing the responses of a sample of professional experts active in the fields of economy, EU and EPR policy, government authorities, municipal waste management and fiber and recycling technology. This Master's thesis will contribute to the understanding of EPR applicability in the textile industry. The results may serve as an orientation for the implementation of upcoming textile-recycling-related EU legislation on the national level in Austria.

2. Methodology

In order to answer the research question posed, this study relies on two complementary research methodologies. A literature review was conducted (2.1) and expert interviews were undertaken (2.2) for data and information collection and assessment. The evaluation was performed based on qualitative means.

2.1 Literature review

A comprehensive literature review was conducted browsing primarily scientific journals, databases and online resources such as libraries, technical and working papers, policy documents by the EU or the OECD, official national websites, NGO and fashion retailer and other reports, media and press articles.

2.2 Expert interviews

Expert interviews were chosen as a complementary data-gathering means as the timeliness of the chosen topic reduces the availability of published literature and data. To allow data collection despite this challenge, a total number of eight expert interviews were conducted. While selecting potential interviewees, emphasis was put on the experts' complementarity. All interview partners shared significant proficiency and long-term experience in the context of textile waste circularity, yet their individual disciplinary angles towards this topic complemented and partially overlapped each other. The experts were identified through their institutional affiliation, reputation or network. Once contact to the first professionals was established, a "snow-balling" effect became soon operational via the experts' networks and project partners or further directions were pointed out during the interviews.

First contacts were established through various channels, yet primarily e-mail correspondence or telephone calls. The interviews were then undertaken in Vienna, Austria, during April and May 2020 via remote video or telephone calls.

The interview questions followed the regular scheme of introductory questions into the respective field. This part was tailored to each individual interview partner. The second question set was specific on EPR schemes and aimed at probing the expert's assessments

on different approaches and their applicability in the textile sector. Finally, two general questions were posed. In the first question, the experts were asked to indicate "low hanging fruits" (textile products with large impact) and in the second question, if they expect changes in the field in the near future. For each interview, a verbatim transcript or a memory map was issued right after the interview. The documents were then made available to the respective expert(s) and potentially amended before approval.

Overall, voices of 10 experts were heard in 8 interviews covering the following five angles on textile circularity: (i) EPR policy, (ii) EU policy and the member state perspective, (iii) fiber and recycling technology, (iv) international economy and global supply chains, (v) waste prevention and the reuse/repair sector.

(i) *EPR policy:* The Principal Administrator at the OECD's Environment Directorate and one of his colleagues were interviewed in their roles as EPR policy experts–hereafter referred to as "OECD Officials". Another expert in this field, was interviewed based on his practical experience and expertise as Managing Director of EXPRA (Extended Producer Responsibility Alliance)– an umbrella organization for national packaging EPR organizations across Europe. This person is referred to as "Packaging EPR Expert".

(ii) *EU policy:* Representing the EU policy angle, three officials of the EU Commission's Directorate-General for the Environment (DG ENV) were interviewed on the evolution of the emerging EU legislation on textile circularity and potential member state implementation. These experts are referred to as "DG ENV Officials". An interview on the EU member state's perspective on the upcoming EU legislation was conducted with a representative of an Austrian Federal Ministry and an expert from the Environment Agency Austria (Umweltbundesamt). These experts are referred to as "Austrian National Experts".

(iii) *Fiber and recycling technology:* Two technical experts on fiber and fiber recycling shared their views on the prepared question set: A senior scientist in chemical engineering at TU Wien, referred to as "Fiber Expert TU Wien" and

Quality and Environment Expert in the rental textile sector, referred to as "Textile Expert Industry".

(iv) *International economy and global supply chains:* This interview partner was selected in the capacity as Assistant Professor at WU Wien. Referred to "International Business Expert", the scholar was inquired on questions on global value chains in the pre- and post-consumer phase of textile products.

(v) *Waste prevention and re-use repair sector:* The waste prevention angle and re-use/repair sector was covered by a representative of the city of Vienna, in the capacity of the Waste Prevention and European Affairs Division at MA48. This Expert is referred to as "Waste Prevention Expert; City of Vienna".

After the completion of the interview stage, the audio recordings were transcribed and provided to the respective interview partners for approval. The transcript material was then structured, sorted according to themes and analyzed. Additional figures were researched in publicly available literature to complement statements and findings from the interviews. The analysis of the interview transcripts was conducted along the following 24 subject matters:

BACKGROUND:

1. Textile Production
2. The textile producer (Definition, etc.)
3. Other stakeholders (e.g. charity organizations, recyclers)

WASTE HIERARCHY:

4. Prevention
5. Re-Use
6. Recycle
7. Recovery
8. Disposal

EPR:

9. General on the EPR instrument (aim, applicability)

10. Product take back and recycling quotas
11. Design/minimum content
12. Ban of materials
13. Information-based instruments

TECHNOLOGY:

14. Technological Progress
15. Textile Types (Technical, industrial textiles)
16. Low hanging fruits

OTHER TOPICS:

17. On EPR
18. On EPR for textiles
19. Producer Responsibility Organizations (PROs)*
20. Competition
21. The informal sector*
22. Consumer awareness
23. Changes expected in the industry
24. Development/history of textile as priority sector

*The results from these investigations are not presented separately in the results chapter of this thesis.

3. State of the Art

In this part, a literature review provides an overview on the following topics: European legislation on recycling and textiles (3.1), Fiber production volumes and types (3.2), Textile consumption and lifetime (3.3), Environmental and social impact of textiles (3.4), Textile wastes and textile recycling (3.5) and Extended Producer Responsibility (EPR) (3.6).

3.1 European legislation on recycling and textiles

Waste management and resource circularity of textiles are dealt with by the Waste Framework Directive (2008) and its amendments (2018) and two strategic pieces on circular Economy; the Circular Economy Package (2015) and the Circular Economy Action Plan (2019).

The Waste Framework Directive (2008). The Waste Framework Directive (WFD) is the legal basis for recycling and resource circularity in the European Union. Its objective is the "protection of human health and the environment against harmful effects caused by the collection, transport, treatment, storage and tipping of waste". The provisions aim at the "protection of human health and the environment" including safeguarding the natural compartments water, air, soil, plants or animals. The WFD covers the whole life cycle of products and materials and encourages the conservation of natural resources. Overall, the WFD presents the general framework of waste management requirements and definitions for member states of the European Union (Directive 2008/98/EC, 2008).

Article 4 of the directive deals with the concept of the waste hierarchy. This hierarchy depicts the "priority order in waste prevention and legislation and policy". Paragraph 1 outlines the prioritization in the following order: (a) waste prevention, followed by (b) preparing for re-use, (c) recycling, (d) other recovery, e.g. energy recovery; and ending with (e) final disposal. The concept is illustrated by Figure 1. Paragraph 2 reminds the member states that deviations from this order for specific waste streams are acceptable to achieve the "best overall environmental outcome" (Directive 2008/98/EC, 2008). The directive also includes targets on resource conservation by 2020, in particular, with regards to final disposal into landfills. The aim here is to recover more than 50% from landfilling of municipal waste by preparing for re-use and recycling. As an extension and

partial substitution to this, the circular economy package emerged in 2016. This piece covers new targets replacing former ones and increasing this recovery target to 70% and limiting municipal waste intended for landfilling to 10% by 2030 (EC, 2019b).

In 2018, amendments to the European Waste Framework Directive (2008) occurred. With the aim to enable separate collection and facilitated recycling of textiles, the following articles were amended: In Article 3, textiles are categorized as mixed solid waste and Article 9 addresses the re-use and repair of textile products in the scope of waste prevention. Article 11 sets out obligations for member states for separate textile collection systems by January 2025 and targets for preparing re-use and recycling for textile waste by December 2024 (EC, 2018b).

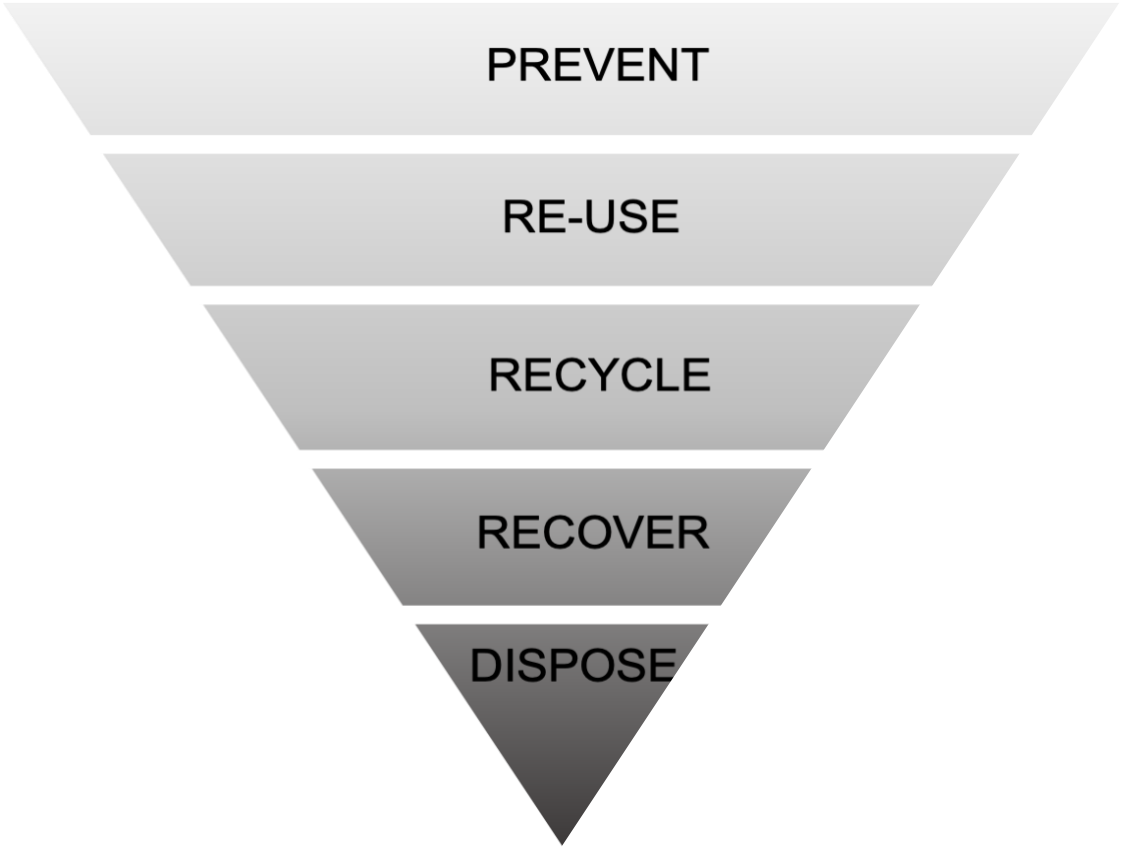

Figure 1: The waste hierarchy concept, as depicted in Article 4 of the Waste Framework Directive (2008): uppermost priority should be given to waste prevention, followed by re-use, recycling and recovery. Disposal should be the last option of waste management, if no other "best overall environmental outcome" can be achieved otherwise

Strategies of the new Commission on textiles. More recently, as announced by the EC under Ursula von der Leyen in December 2019 and approved by the European Parliament

in January 2020, the "European Green Deal" emerged as the strategic roadmap for the EU until 2050. It presents a compilation of policy plans aimed at making the EU climate-neutral by this time (EC, 2020a). In the scope of "mobilizing industry for a clean and circular economy", the textile industry is not only specifically addressed, but also defined as a priority sector with high environmental impact (European Parliament, 2020).

Circular Economy and the EU. The strategy to transition to a circular economy in the EU comprises the following main events: In 2015, the European Commission officially launched the transition into a circular economy with the aim to foster European competitiveness and innovation, economic growth and job creation. This launch consisted of a package with 54 actions for the transition into a circular economy. In March 2019, the EC issued a report stating the completion of the respective tasks of having been delivered or being in the process of implementation (European Commission, 2020). A new focus among researchers, policy makers and practitioners has become the formation of a circular material usage in contrast to preceding linear processes. This linear process is characterized by the sequence "take-make-dispose" and has been increasingly questioned in the recent past. The new "circular economy", as visualized in Figure 2:

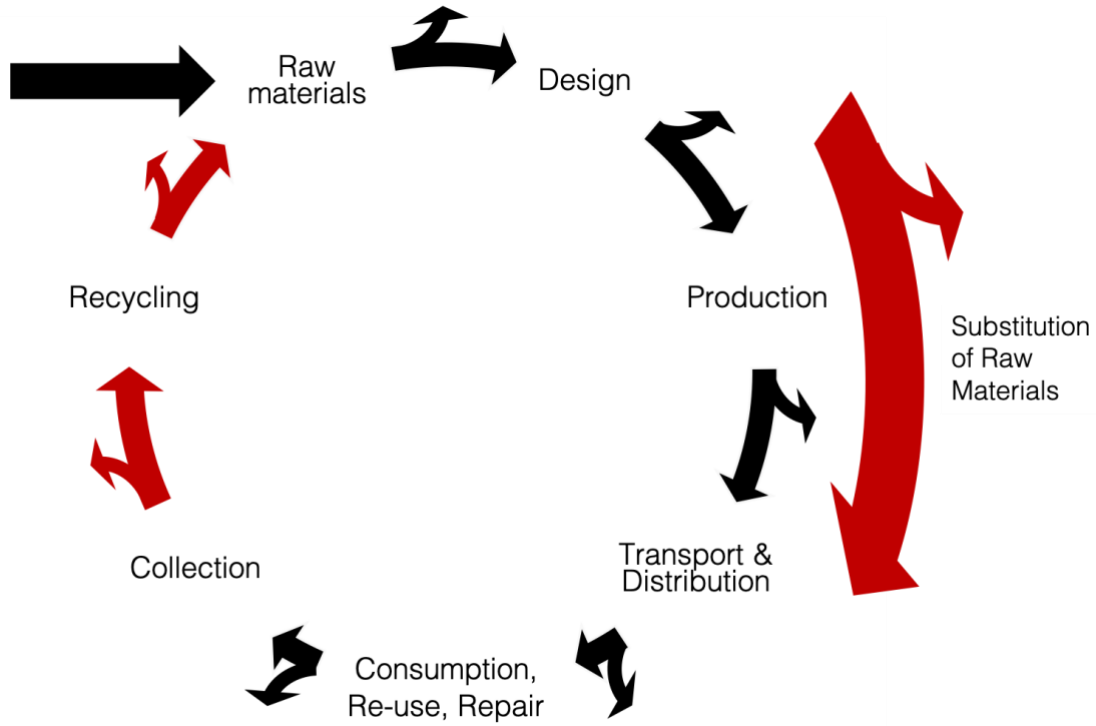

Figure 2: Schematic representation of the circular economy concept. In contrast to a linear "make-use-dispose" system, the circular economy concept aims at closing the resource loop by integrating recycling aspects. In the textile context, increasing emphasis on collection and recycling is necessary. Besides substituting primary materials by high-quality secondary materials, losses in forms of waste and stocks need to be minimized throughout the value chain to enhance resource efficiency and autonomy (Redrawn after EIT Raw Materials (2020)).

Schematic representation of the circular economy concept. In contrast to a linear "make-use-dispose" system, the circular economy concept aims at closing the resource loop by integrating recycling aspects. In the textile context, increasing emphasis on collection and recycling is necessary. Besides substituting primary materials by high-quality secondary materials, losses in forms of waste and stocks need to be minimized throughout the value chain to enhance resource efficiency and autonomy (Redrawn after EIT Raw Materials (2020)). , shall be restorative and regenerative by making use of improved product design and optimum use and reuse of resources (efficiency) and prevent waste in the first place (Bukhari et al., 2018). However, this shift from *linear* to *circular* induces two additional considerations: material losses and the factor time. The minimization of materials losses along a product's life cycle are key since losses (often in form of waste) occur along all stages of a product's life cycle (EIT RawMaterials, 2020). Second, the factor time plays an important role as anthropogenic resource stocks will eventually become waste in the future. It is also unknown whether demand exists for these wastes as a secondary resource. Therefore, it is suggested to include the factor time into circular economy models and move from a static to a dynamic circular economy concept (Scharff, 2018).

Regarding the circularity of textiles, the Circular Economy Action Plan from March 2020 depicts textiles as the "fourth-highest pressure category" in terms of resource usage. The document furthermore announces a comprehensive set of measures including eco-design of products, use of circular materials, separate collection and specifically Extended Producer Responsibility (EPR) with regards to textiles (EC, 2020b). Textiles present a central theme in the current work of the EC, specifically in the "comprehensive EU strategy for textiles" by 2021 and also in the Staff Working Document "Sustainable Products in a Circular Economy" on product policy (DG ENV Officials, personal communication, April 15, 2020). Having discussed the legal aspects of textile circularity in the EU, the next section will now elaborate on the definition of textiles, their production volumes and types.

3.2 Fiber production volumes and types

The basic element of fabrics or other textile structures is a fiber. A textile fiber is a "unit of matter, either natural or manufactured" and usually varies in chemical structure, cross-sectional form, external relief, color and length and width (Houck, 2009). A fiber is also

characterized by a relatively large surface area and a small mass (Fiber Expert TU Wien, personal communication, April 29, 2020).

One can distinguish textile fibers into natural fibers and man-made fibers (Morton & Hearle, 2008). While a natural fiber "is any fiber that exists as such in the natural state", such as cotton, wool or silk, a synthetic fiber, in contrast, does not occur in nature and results from chemical manufacturing processes that convert polymers into fibers. Examples of such synthetic fibers include acryl, nylon, polyester, polyamide and polypropylene (Houck, 2009).

Production volumes. Worldwide, fiber production has increased 3-fold since 1975 and accounts currently to approximately 100 million tons per year (CIRFS, 2020; Ellen MacArthur Foundation, 2017). Cotton accounts to 25% and man-made fibers account to about 75% of the total global fiber production–the latter yielding a volume of 74,7 million tons (CIRFS, 2020). Figure 3 visualizes these fractions. The main fiber producing countries are China, India and the US (CIRFS, 2020; Qin, 2014). The EU's main textile imports stem from China (37%), Turkey (11%), Bangladesh (10%) and India (9%) (Manshoven et al., 2019). Usages of synthetic fibers are manifold and vary from clothing, carpets and household textiles to fire-resistant materials and various other technical products (CIRFS, 2020). Globally, apparel covers about 75% of the total world textile

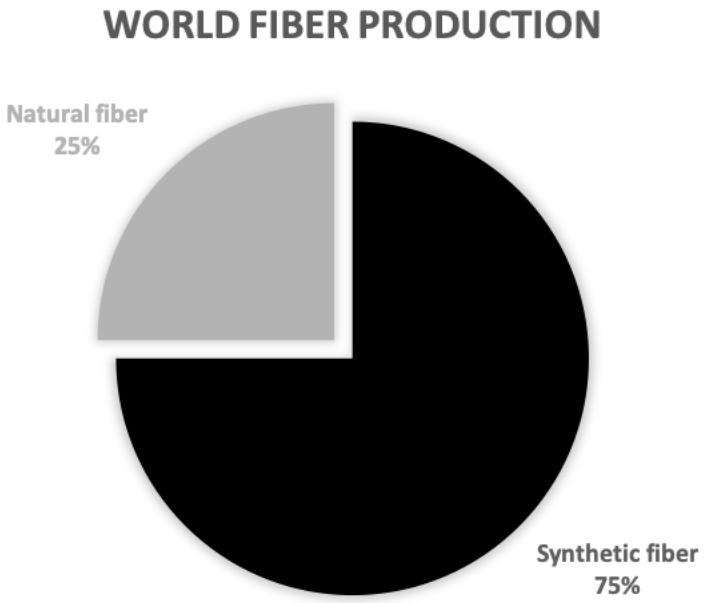

Figure 3: The total global fiber production volume accounts annually to about 100 million tons, 75% (74,4 million tons) present synthetic fiber types and 25% to (about 25 million tons) natural fibers (Data: CIRFS 2020).

production, the remaining 25% can be assigned to technical and industrial textiles (EURATEX, 2018).

Fiber types. While in the traditional textile industry, six polymers commonly make up textile fibers –namely cellulose (wool, cotton), proteins (silk) as well as polyamide, polyester, polyolefin and vinyl (synthetic products)– the composition of fibers reflects nowadays increasing complexity. This includes multi-material fibers and special fibers for high-performance, medical applications (e.g. to assist in wound healing) or so-called smart fibers (Morton & Hearle, 2008; Piribauer & Bartl, 2019).

The Austrian textile industry. On the Austrian level, the textile industry distinguishes between (i) yarns, fabrics and refined products, (ii) home textiles and (iii) technical textiles. Technical textiles have special importance in the domestic textile production and cover almost 50% of the annual turnover, while clothing and home textiles account to the remaining 50%. The total annual turnover of the Austrian textile sector can be estimated to 24 billion € in 2019, employing 11 000 people in 224 companies. Exports account to approximately 80% of the production volume (Fachverband der Textil-, Bekleidungs-, Schuh- und Lederindustrie, 2020). Exports occur majorly to the EU (75%; Germany 29%) and to Africa (10%; 5,6% Mali). Austrian textile imports stem mainly from the EU (52%) and from Asia (35%; 12% China) (Statistik Austria in Fachverband der Textil-, Bekleidungs-, Schuh- und Lederindustrie et al., 2019). Having elaborated on the production side of textiles, the following section will cover textile demand and lifetime.

3.3 Textile consumption and lifetime

In contrast to circular economy, modern fashion industry is characterized by considerable production volumes, short product lifetimes, low recycling and high incineration and disposal rates (e.g. Piribauer & Bartl, 2019).

Textile consumption. Strongly related to economic growth, the consumption of textile fibers per capita increased from 3,7 kg per person in 1950 to 10,4 kilogram per person in 2008. In the last decade, the per capita consumption continued to increase, but in particular in developing countries. While in developed countries the increase in per capita consumption in the three years between 2004 and 2007 accounted to 8%, the demand in the same period in developing countries increased by 20%. Regionally, far Eastern

countries (27%) show the highest rate, closely linked to the emerging economy of China, where fiber consumption amplified by 50% between 2004 and 2007 (FAO/ICAC, 2013). In European countries, a person consumes on average 26 kg of textile products including clothing, footwear and household textiles (carpets, curtains, bedlinen, towels, etc.) per year, while merely 7 kg of these textiles stem from within the EU. Between 1960 and 2016, the global consumption of synthetic and cotton fibers increased from marginal amounts to more than 60 million tons and from 10 million to 25 million tons, respectively (Manshoven et al., 2019).

Apparel lifetime. The duration of textile utilization becomes generally shorter. In Ellen MacArthur Foundation (2017), durability is defined as "the number of times, a garment is worn before it ceases to be used". This number shows a decrease of 36% between 2002 and 2016– a trend that is likely to continue with emerging economies assimilating towards the low utilization rates of industrialized countries. Some clothing groups are particularly effected, for example night ware utilization declined by almost 50% within the fifteen years between 2002 and 2016 in the EU (Ellen MacArthur Foundation, 2017). In Germany, apparel lifetime decreased by 35% from 1998 to 2005. For example, sweaters and pullovers showed a decrease in lifetime from 4 years in 1998 to 2,5 years in 2005 (Korolkow, 2016). The same author reported a decreasing quality in textile products arriving at recycling centers –a trend potentially linked to the expansion of apparel discounters in the same time period. However, it is important to note that not only lower physical durability of clothing items or lowered usage of items may cause this decrease. The development may also reflect cultural variations in style or may be based on the number of people following a trend. However, also products that are not easily prone to style changes, exhibit this decrease, with hosery, for example, that shows a drop in utilization by almost 40% (Ellen MacArthur Foundation, 2017). A further discussion on the lifetime of textile products can be found on page 28 in the results chapter, in the section on waste prevention (4.4.1), while the next section will review environmental and social impacts of textiles.

3.4 Environmental and social impact of textiles

Environmental impact. The textile industry contributes to the exhaustion and degradation of resources and ecosystems, competes for water and land use and emits considerable amounts of greenhouse gas. According to estimates, the textile sector is responsible for

approximately 1,2 billion tons of CO2 equivalents, which exceeds the combined emissions from international flights and shipping. Regarding water resources, the dying and treatment of clothes is held responsible for 20% of water pollution world-wide (Ellen MacArthur Foundation, 2017). Moreover, textiles rely significantly on input of virgin materials which is resource intensive. The cultivation of cotton –often in mono-cultures– effects land use and can contribute to soil and water pollution through the application of pesticides and fertilizers. The production of synthetic fiber is resource-intensive as well and requires significant input from fossil resources and energy (Beton et al., 2014). In addition, fabric production and international shipment of textile products also yields significant emissions (Manshoven et al., 2019). A depiction of the environmental impacts from incineration and landfilling, that may release toxic substances to air, soil and water compartments, is also discussed in (4.4.4).

Microplastic release. A special environmental concern linked to synthetic fibers is their potential to release microplastics or microfibers that can eventually enter the broader environment. Microfiber pollutants emerge particularly from oil-derived synthetic fibers, such as polyester, nylon or acrylic fibers. The total amount of microplastics released from this kind of laundry to the world oceans is estimated to account approximately half a million tons per year (Ellen MacArthur Foundation, 2017). According to estimates, microplastics abrasion by laundry of synthetic fiber products presents the largest share (35%) of primary microplastics released to the world oceans (Boucher & Friot, 2017). Another study was able to detect and identify synthetic-fiber derived microplastics as remote as in snow in the Austrian Alps (Materić et al., 2020).

Social impact. The textile industry also shows a considerable social impact. Besides providing important employment and development opportunities, social deficits in the sector have been regularly exposed. The social disbenefits include precarious working conditions with dangerous production processes and the handling of hazardous chemicals. In addition, pressures related to costs and time generally affect all parts of the textile supply chain. As a consequence, workers in the textile industry often face long working days and low wages. Some reports even show evidence for modern slavery and child labor. Beyond production however, the sector also affects the local environment. Thus, despite benefiting from employment opportunities, local residents often face environmental deterioration from unsound industrial practices, like toxic factory

effluents, as one example, exposing the population to pollutants via drinking water, consumption fish or leisure activities related to water usage (Ellen MacArthur Foundation, 2017).

3.5 Textile wastes and textile recycling

Material recycling is defined as "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes", according to the EU WFD (Directive 2008/98/EC, 2008). Worldwide, volumes of textile wastes can be coined enormous, while recycling rates appear comparably marginal. Citizens of the EU produce altogether around 5,8 million tons of textile waste each year (Beasly, J. & Georgeson, R., 2014). However, recycling of textiles still presents a minor waste management practice: In the EU, recycling accounts to 26% (Bukhari et al., 2018), while worldwide, it is estimated that only 1% of textiles are recycled (EC, 2020b). In Austria, separate collection of end-of-life textiles from households amounted to 36 000 tons in 2017. This presents approximately 25 % of the overall textile waste within the country. The remaining fraction of household textile waste (approximately 140 000 tons) is disposed of in the formed of mixed solid waste and eventually incinerated–despite the existence of a separate collection scheme (UBA, 2020).

Recycling of textile products is also limited by technical restraints. Textiles are often made of multi-material fibers that are unfeasible or even impossible to separate with the current technologies. The established recycling options are based on textiles made from a single fiber material and range from pure material reprocessing, to mechanical fiber recovery and re-spinning to chemical processing such as dissolution of thermoplastic fibers and feedstock recycling. Thus, design improvement with regards to recycling as well as research and development are needed to achieve textile recycling at a larger scale (Piribauer & Bartl, 2019). Another more general restraint to recycling concerns the energy input required for recycling processes. From an environmental perspective, material cycles should not be fully closed due to thermodynamics, i.e. entropy and associated energy needs (Stumm & Davis, 1991). Having mentioned these technical and theoretical fundamentals in recycling, the literature review will now move on to present the policy tool of Extended Producer Responsibility (EPR).

3.6 Extended Producer Responsibility (EPR)

This section describes the EPR concept (3.6.1), presents EPR policy instruments (3.6.1) and finally illustrates the case study of France (3.6.3), where an EPR scheme for textiles is in place since 2007.

3.6.1 The Extended Producer Responsibility (EPR) concept

First introduced by Thomas Lindhqvist in 1990, the concept of Extended Producer Responsibility (EPR) is defined as "environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" by the OECD (2016). The concept deals with life-cycle-related matters of products and presents a "target-oriented" regulation with a set objective in contrast to former "command-and-control" type of approaches. EPR policy aims at involving the producer in the collection of end-of-life products for their final treatment, which is in the ideal case recycling. Thereby, the policy shifts the physical responsibility as well as the financial resources involved in end-of-life management of products from the municipality and the taxpayer to the producer. EPR is therefore in line with the "polluter-pays-principle". This redefinition of responsibility can be achieved by providing incentives to the producer to adapt the design and packaging to optimum recycling conditions. This has the potential to increase recycling rates as well as to reduce the overall waste going to final disposal (OECD, 2016).

On the European Union level, Extended Producer Responsibility is also explicitly outlined in the European Waste Framework Directive (2008). Article 8 encompasses in paragraph 1, a definition for the producer; i.e. "any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products" presents the "producer of the product" who has "extended producer responsibility". Explicitly mentioned instruments include the acceptance of returned products, or their remaining waste, the management of the waste and the financial responsibility involved as well as measures potentially including the provision of publicly available information "as to the extent to which the product is re-useable and recyclable" (Directive 2008/98/EC, 2008). In order to comply with this EU regulations, member states were obliged to introduce EPR policies for specific products, i.e. batteries, end-of-life vehicles and electrical and electronic devices (EC 2015 in Bukhari). Further EPR strategies on

textiles –including eco-design and the usage of circular materials– are now also envisaged on the EU level, as outlined by the Circular Economy Action Plan of 2020 (EC, 2020b).

From a historical perspective, EPR found its introduction as a principle of policies on products into legislation in the 1980s and early 1990s (Deloitte, 2014). In 2016, the OECD published an update on their "Guidance Manual" from 2001 that reviews world-wide EPR schemes (OECD, 2016). According to this report, not only OECD countries, but also emerging economies nowadays embrace EPR policies increasingly. From 2001 to 2016, the OECD observed an increase in EPR policy adaption of 70% to a total of 384 EPR policies. The implementation of EPR policies does not only reduce the volumes of waste for final disposal, it also allows the creation of recycling industries (OECD, 2016).

3.6.2 EPR instruments

Turning now to the specific instruments covered by EPR, a distinction can be made into the following four categories, based on OECD (2016): (i) Product Take Back, (ii) Economic and market-based instruments that include Deposit-Refund systems, so-called Advanced Disposal Fees (ADF), material taxes and a combined system of tax and subsidy, (iii) Regulations and performance standards (iv) information-based instruments. Figure 4 presents a schematic overview of a product life cycle and where specific EPR interventions address it.

(i) *Product Take back* is one of the most commonly used EPR schemes covering about 75% of the almost 400 systems analyzed in the OECD study. Examples for this instrument includes the "responsibility of a producer or retailer for the end-of-life management of products" by defined recycling or collection targets, for example. User incentives, such as to return products to a "selling point", may also be involved. Product examples for this approach include batteries or packaging products.

(ii) *Economic and market-based instruments* comprise four main approaches: First, *Deposit-Refund systems* in which a deposit is refunded upon product return. Second, *Advanced Disposal Fees (ADF)* that present fees to cover the waste treatment of a product. Third, *material taxes* on virgin materials may incentivize the usage of recycled materials as an alternative resource or, fourth, a *combined system of tax and subsidy* in which taxes paid by the

producer are allocated to recycling and treatment to incentivize alterations of material input.

(iii) *Regulations and performance standards* include obligations for a minimum content of recycled material, for example, which may foster the take-back of end-of-life products as demand rises.

(iv) *Information-based instruments* focus on public awareness and involve reporting requirements, product or component labels and enhanced communication with the public and recyclers.

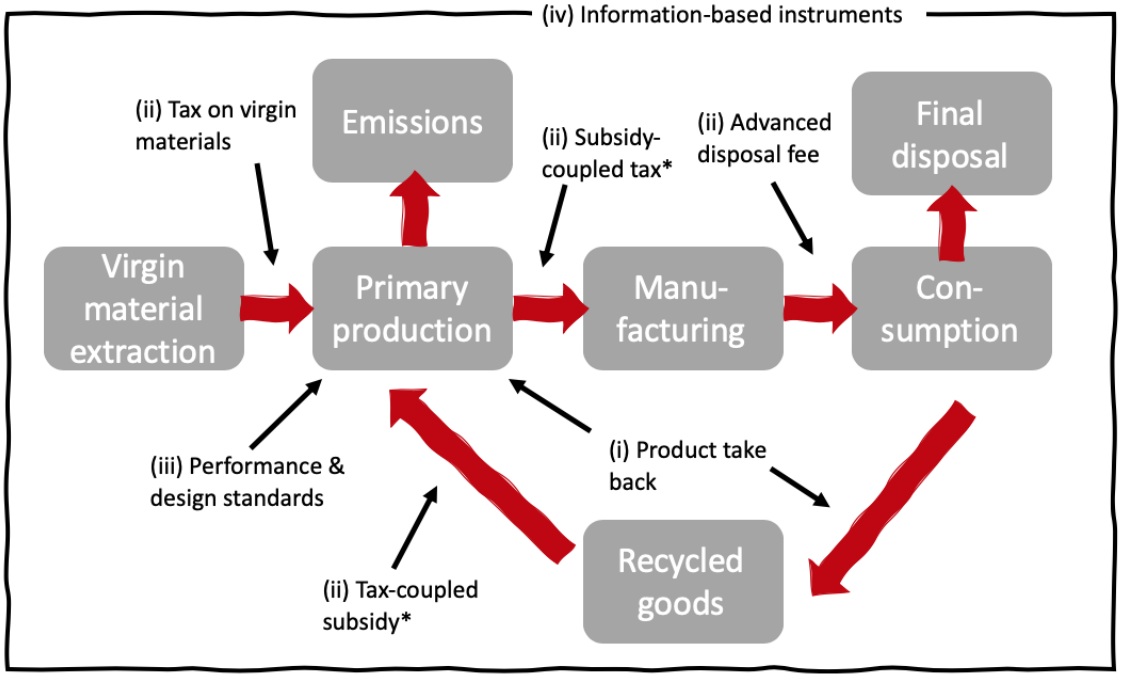

Figure 4: Schematic overview of a product's life cycle and possible EPR instrument intervention points. Taxes on raw materials apply prior to the primary production while design standards, such as a minimum content of recycled material or other composition standards, apply during production. A coupled system of taxes on products and subsidies for recyclers is indicated by an Asterix. Advanced Disposal Fees apply prior to consumption and product take-back options occur before recycling and affect primary production. The illustration was modified after OECD (2016).*

EPR models and Producer Responsibility Organizations (PROs). One can distinguish EPR models into the following four categories: Systems with multiple PROs, systems with single PROs, systems that are government-run systems and systems with tradeable credits (e.g. United Kingdom). However, all approaches need government involvement to oversee activities. Most countries decided to set up central organizations that manage financial and organizational responsibilities for a number of producers in a collective approach. This has several advantages, mainly related to cost savings from economy of scale. However, individual companies established their own individual systems which

requires them to manage responsibilities independently, but also allows them to avoid collective action problems, such as free riding. PROs can differ in their business model: for profit or non-profit. Profit PROs resulted from an environment with several PROs that face competitions, for example in WEEE and packaging. Occasionally in some countries, there are legal requirements for PROs to be non-profit. Examples of products that are presently covered by EPR include batteries, electronics, packaging and tires (OECD, 2016).

The informal sector. Especially developing countries exhibit informal sectors with significant activities and that can play an important role in EPRs. The impacts can be both positive and negative. Positive ones include the collection and sorting (positive for economy and the environment) and may even be more efficient in collecting higher material amounts in some cases. Negative aspects can relate to "unsound practices" with adverse effects on health, working conditions or the environment, clan-like structures, and illegal activities. In addition, a lack of data is often inherent to these mostly undocumented practices. Thus, solutions to the negative characteristics generally include increased inclusion, documentation and formalizations of the sector. Examples, in which the informal sector was aimed to be included and formalized occurred in Colombia, Brazil, or South Africa for example (OECD, 2016; OECD Officials, personal communication, May 5, 2020).

EPR and the EU. Having introduced the concept, its operation and special issues related to the informal sector, EPR in the EU is now briefly presented. In the EU, the circular economy package emerged in 2016 with new targets. These targets replaced former ones and increased the recovery target to 70% and limiting landfilling to 10% of collected municipal waste (EU Parliament 2017 in Bukhari 2017). In order to comply with these EU regulations, member states were obliged to introduce EPR policies for specific product waste streams, i.e. batteries, end-of-life vehicles and electrical and electronic devices. In practice, this means that producers of a certain product are responsible for financing the collection, treatment and recycling their products in the post-consumer phase. In order to augment overall waste collection and recovery, member states have the option to extend their EPR systems beyond the before-mentioned waste streams (EC, 2014, 2014). Moving on now to consider EPR in the textile context, the example of France will be presented.

3.6.3 EPR for textiles in France

In 2007, France was the first country in the world to introduce an EPR system for textiles (Bukhari et al., 2018). In force since 1 January 2007, the law *Code de l'Environnement, Article L-541-10-3* (version may 2019), deals with the French EPR obliging "all legal persons […] that place clothing, shoes or linen on the French market to contribute or conduct recycling or treatment of the wastes that arise from these products". With 1 January 2020, this law was extended to home textiles. Producers either pay financial contributions (fees) to the French accredited textile PRO or arrange for an individual management system that requires approval by the French authorities (Code de l'environnement - Article L541-10-3, 2020). The producers concerned comprise textile and clothing manufactures, importers and distributors. According to the French Waste Prevention Fact sheet, France has a collection target of 50% of clothing, linen and footwear which corresponds to 300 000 tons or 4,6 kg per person per year. A material recovery target was set to 95% for the collected textile items (European Environment Agency, 2016). To accomplish EPR liabilities, apparel manufactures, importers and distributers can become registered members of the *éco-organisme du textile, du linge et de la chaussure* (Eco TCL). This PRO was established in December 2008, is not-for-profit and the only accredited organization in the sector. The contributing fees are used for sorting organizations fulfilling the EcoTCL requirements, Research and Development projects and communication campaigns to promote separate collection (EcoTLC, 2020). Covering the textile value chain comprehensively, the producers of the French EPR can be divided into the following five groups: "(a) General large retailers (e.g. Carrefour, Monoprix), (b) fashion retailers (C&A, Galeries LaFayette), (c) direct sales and mail/online retailers, (d) manufacturers and wholesalers, (e) apparel industry associations" (Bukhari et al., 2018) In 2018, a total sum of 21,8 million € was contributed by 4 237 registered members to the French EPR system for textiles. The support for research and development projects accounted to 3,9 million € in the same year (EcoTLC, 2018).

4. Results & Discussion

4.1 Policy background and development

As outlined in the previous chapter, the foundation of an EU-wide textile strategy, was laid in the Circular Economy Action Plan from 2015. Following the completion of the 54 actions included in this framework in 2019– among which the policy document on the Plastic Strategy received considerable attention– the New Action Plan emerged in early 2020 with a distinct focus on textiles. This focus aims at a comprehensive integration of international trade, EU competitiveness and environmental issues, according to EC officials. They furthermore describe this step as a policy response to two kinds of developments: First, increasing evidence was collected on the harmful impacts of the textile sector on the environmental and resource preservation. Second, incidents like the Rana Plaza accident in 2013 in Bangladesh that killed more than 1 100 people and injured 2 500 (International Labor Organization (ILO), 2018) ultimately exposed the inherent lack of social and safety standards in the industry. According to the officials, these developments lead to the recognition of textiles as a "high priority sector", also in terms of resource circularity. By now, textiles constitute an important subject in the EC's work, such as on product policy in the Staff Working Document "Sustainable Products in a Circular Economy". Legislation that exists on textiles to this end includes the obligation by member states to set up separate collection schemes by 2025 and the obligation to conduct waste prevention programs including re-use and repair activities with a specific reference to textiles. These measures will be extended under the new textile strategy that is currently under development (DG ENV Officials, personal communication, April 15, 2020). The work on the textile sector on the EU level, transposed also the member states level.

In Austria, this rather recent focus on textiles became especially clear under the Waste Framework Directive when textiles became categorized as municipal waste, the separate collection obligation by 2025 was set out and most recently under the New Circular Economy Action Plan. This plan indicates a textile strategy similar to the plastics strategy to achieve high quotas of separate collection. The development on EU level is one reason why Austria started to pay increasing attention to the sector on a country level. In this scope, a survey on domestic textile waste streams is currently conducted by the Environment Agency Austria. This baseline survey is intended to allow the future design

and potential implementation of measures to achieve EU targets (Austrian National Experts, personal communication, April 28, 2020). In Austria, about 25% of domestic textile waste is currently collected separately by either charity or social organizations, private companies or municipalities (Matthias Neitsch (REPANET), 2020; Umweltbundesamt, 2020). Mixed municipal waste contains approximately 8% textiles and shoes, making this category the second largest fraction in mixed solid waste after plastics (packaging and non-packaging) with 17,6% (Bundesministerium für Nachhaltigkeit und Tourismus, 2017). The national experts highlight the additional growth of private textile stocks in Austrian households. Besides these private textiles, the Austrian baseline survey will also explore industrial and technical textile waste streams, although the highly fragmented and specialized sector does not fall under municipal waste as defined by the European Waste Framework Directive. Examples for such technical textiles include Personal Protection Equipment (PPE), geotextiles or industrial filters. Aspects not covered by the survey at this point include informal textile waste flows, like those occurring at flea markets or online platforms outside the regular waste regime. These material streams are difficult to depict due to the inherent lack of data on these undocumented activities. However, in comparison with the informal activities in the WEEE sector, those related to textiles can be assumed relatively modest in Austria (Austrian National Experts, personal communication, April 28, 2020). This estimation conforms with Wagner (2017) who estimates, based on Material Flow Analysis, that merely 1% of total apparel is sold illegally in Austria. Having outlined the policy development and the domestic situation in Austria, the following section will elaborate on the international textile value chain and its implications.

4.2 The international textile value chain and Fast Fashion

Textile production is very international. All steps of the textile value chain are characterized by significant internationalization, according to an international business expert at WU Wien. A piece of clothing, for example, produced in a single country is the great exception. Until 2005, the international "Multi-Fiber-Agreement" regulated what fiber quantities a developing country could export to developed countries. Once these trade restrictions were loosened, exports from Asian countries increased steadily. Nowadays, the main textile exporting country is China covering more than 30% of the total production (International Business Expert, personal communication, April 7, 2020). On an EU level, it is also acknowledged that many clothing items are made outside the

EU, particularly in Asia, and also the re-use of our clothes occurs mainly outside the EU, for example in Africa. This fact comes with advantages and disadvantages: "Textile production outside the EU provides significant income for developing countries, which helps combat poverty. But the conditions in which the clothes are made are not under our control, and we hear of environmental damage, bad work conditions like child labor or forced labor are severe problems" the EC Officials (2020) confirm. According to them, it is a "challenging task to maintain the positive aspects and to eliminate the negative ones." Possible ways forward may lie in due diligence concepts to enhance control throughout the supply chain. "Substantial work on this is ongoing across the Commission services. There are also the OECD guidelines that were developed to help companies and brands perform this checking. This is a policy direction observed by the EC experts which can potentially be taken further in the textile strategy as well" (DG ENV Officials, personal communication, April 15, 2020)

Another important aspect is the Fast Fashion Business model which has brought major changes to the textile industry. According to the business scholar, the model emerged about 20 years ago and there is general consensus that the Benetton company initiated the business model, before other companies developed it further. Fast Fashion can be defined as a "business model characterized by very short throughput periods from design to sales". Based on these short time frames, the model allows companies to react quickly, to sales figures for example, and stir production according to trends. While in the traditional business model, two seasons were brought onto the markets each year, one for summer one for winter, this rhythm has increased dramatically with the new business model. The major players in the field, such as Inditex, for example, have lead times of two to four weeks by now. However, it is important to note that Fast Fashion concerns clothing only, which constitutes about 60 % of the total textile industry (International Business Expert, personal communication, April 7, 2020).

4.3 International and national stakeholders

According to the OECD officials (2020), EPR schemes have the potential to effect existing value chains, the actors there-in and their business models. Thus, stakeholders at the international and at the national scale in Austria will be outlined in this section.

The Producer. In the context of Extended Producer Responsibility (EPR), a producer can be defined as an entity placing products on the market. In the case of Zara, for example, the responsible producer would be Inditex which presents the company acting in the background (International Business Expert, 2020). The EC officials (2020) define the producer in an EPR scheme as "any operator that places products on the EU market". By doing so, this operator needs to contribute to the relevant EPR scheme, independent from their "physical presence" in the EU. If the operator is not physically present in the EU, a legal entity needs to be assigned with carrying out the respective responsibilities. This seeks to avoid the discrimination between EU and non-EU companies under EPR schemes and to ensure compliance by both. The challenges potentially arising if an operator is physically not tangible in the EU, concern mainly enforcement, according to the EC officials (DG ENV Officials, personal communication, April 15, 2020).

Other stakeholders. On the EU level, stakeholders in the field of textiles and clothing can be grouped into three groups conforming to the three main compartments of the textile value chain: (i) textile production, (ii) textile retailers and brands and (iii) entities related to textile recycling and waste. In (i) textile production, one of the major players is the European Apparel and Textile Confederation EURATEX that represents the voice of the European textile industry with approximately 171 000 companies EU-wide (EURATEX, 2018). (ii) Textile retailers and brands are represented by the Sustainable Apparel Coalition (SAC) or the Global Fashion Agenda as examples for groups that aim at increased sustainability and (iii) recycling and waste organizations, such as EURIC for example are related to the post-consumer phase of textile products (EURIC, 2020). In addition, several NGOs are active in the field, such as the European Environmental Bureau as one example. These stakeholders cover mostly apparel, a textile fraction that is estimated to account to approximately 75% of the total textile quantities (EURATEX, 2018). The remaining 25% of textiles are related to industrial and technical products that have received less attention at this stage of the policy development (DG ENV Officials, personal communication, April 15, 2020).

A special stakeholder: charity organizations. Another group of stakeholders in the textile branch are related to textile re-use. In Europe, charity organizations play an important role in collecting and sorting end-of-life textiles and apparel in particular. The introduction of EPR systems has the potential to cause disorder in the textile value chain

and in the business models of the charity organizations. These organizations do not only have established infrastructure, but also significant experience in many EU countries (EXPRA Expert, personal communication, April 14, 2020; OECD Officials, personal communication, May 5, 2020). Evidence for this potential business hazard is the criticism and concern pronounced by French charity organization in the light of the French EPR system for end-of-life clothing and shoes. This resulted in intensified collaboration between these charitable groups and the French PRO for textiles. While partially new structures were created in France, an emphasis was also put on including pre-existing ones. Including established systems has two main advantages, according to the OECD Officials: First, the introduction and operation of the new system can be accelerated and second, the re-use sector also presents the part of the value chain, where the highest values occur, i.e. the sale of high-quality second hand clothing (OECD Officials, personal communication, May 5, 2020). There was general consensus among the interview partners that this high-quality fraction presents approximately 5-10% of collected used apparel in the EU and in Austria. These so-called "crème" products are a point of contention between charity organizations, online platforms and potential future EPR PROs as they can achieve the highest profit in the value chain. However, the OECD officials emphasize that despite this fact, the main focus of a textile EPR system should remain with the outstanding 90-95% of used apparel. These post-consumer products present the considerable textile fraction that needs prevention from incineration or landfilling (OECD Officials, 2020).

On the Austrian level, the collection of used clothes and shoes occurs mainly in two ways: to minor extent by municipalities and to a larger extent by either private companies (> 50%) or by charity and social organizations (< 50%)(Matthias Neitsch (REPANET), 2020). The charity-run collection has developed through history based on the ideology of donating items that are still in good shape to those in need. The system grew to a business model in which revenues from used apparel and shoe sales fund charitable or humanitarian projects. The upcoming EU targets will raise the question how separate collection of textiles can be increased in Austria and which networks will need to be established or developed to achieve these targets. Consequently, this may lead to changes or adaptations of the current ways used textile wastes are managed domestically (Austrian National Experts, personal communication, April 28, 2020).

In Vienna, post-consumer textiles are managed by more than one organizational form. However, textile collection in containers requires a permit by the city authority for traffic (MA 46) and the respective city district and is prone to taxation, the so-called air tax. This system regulates the *location* of the containers (currently restricted to public waste collection points) and whether it conforms with the city planning, while another provision regulates *who* can conduct used textile collection. End-of-life textiles are considered as waste, thus, end-of-life textile collectors need a waste collection permit in order to legally pursue their activities. The city of Vienna is aware of about eight companies that currently conduct collection of used apparel in Vienna. One of them is ÖPULA that collects used clothing in cooperation with charities such as the red cross. The MA48 is the department of the City of Vienna in charge of waste management. As municipality, they also collect textile waste by themselves since 2015. In this time, one of the main observations were the surprisingly high quantities. Collection takes place at central waste collection points, so-called Mistplätze. The collected textiles are then sorted, and either traded to a local recycler or sold in the MA48-owned secondhand store called "48-er Tandler". In contrast to these private textile streams, C&I waste (commercial and industrial waste) concerns a different kind of legislation. The respective wastes do not fall within the responsibility of municipalities but are dealt with by specialized companies. The City of Vienna Expert assumes that this also applies for textiles from technical and industrial appliances. Other textiles the MA48 deals with is in the form of bulky waste, i.e. furniture and carpets. The expert is aware that for certain facilities with large quantities of low-quality textile waste, such as in health care for example, recycling may present a challenge since the demand for this end-of-life textile waste is generally low. Usually, the waste is therefore "downcycled" to insulation material or has to be incinerated. The expert highlights the important role of charity organizations in the sector. It should not be the aim of the textile strategy "to destroy the business models of charity organizations–they must be included in the development" (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

The previous section has shown that stakeholders that are involved in the discussion around strategic approaches to textiles and textile waste legislation can be grouped into production, sales, and end-of-life management interest groups. A graphic illustration of these results is depicted in Figure 5. One group of special relevance are charity organizations that provide infrastructure and long-time expertise in the collection used

apparel in many EU countries, including Austria. The integration of these existing structures into EPR schemes has the potential to accelerate and facilitate the transition process and the actual operation of new systems. However, little focus is currently put on industrial or technical textiles and their representatives that cover about a fourth of the textile sector. The section that follows will move on to consider textile waste streams along the waste hierarchy order.

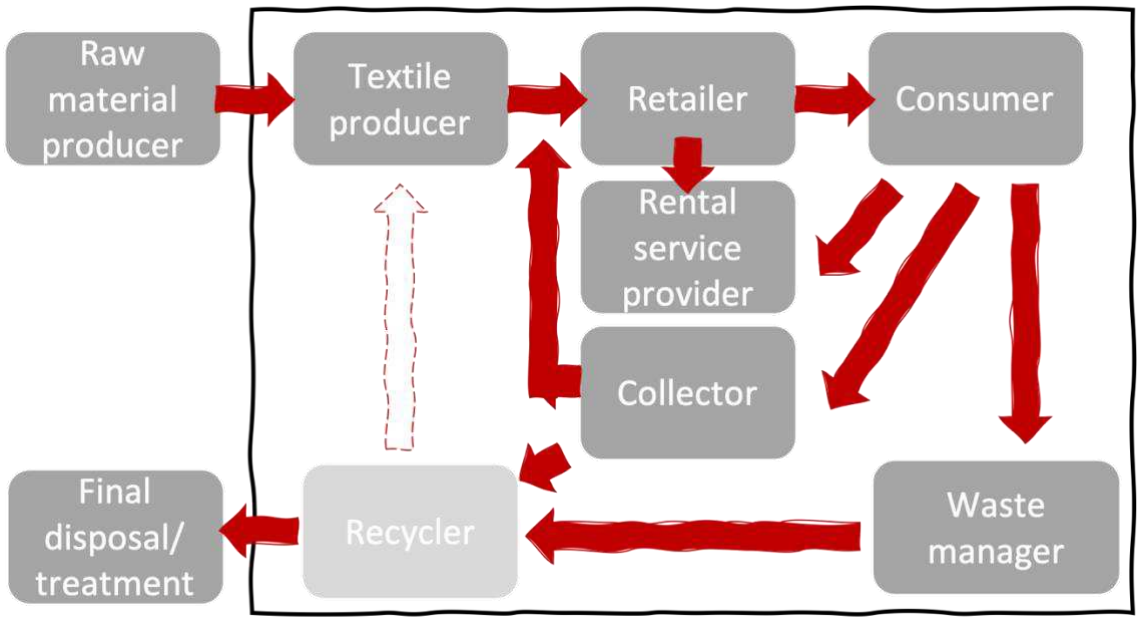

Figure 5: Results of the stakeholder analysis (excluding government) along a simplified textile (clothing) value chain, as applicable in the Austrian system (black frame). Linear economy would stretch from raw material extraction over the producers and retailers to the consumer. Once in the post-consumer phase, textile products pass the waste management system to final disposal. In a circular economy, textile would be kept in loops until they either present a leakage from the loop (not illustrated) or reach eventually final disposal or thermal treatment. These loops may occur between (i) the consumer and rental service providers,(ii) between consumers, collectors and secondhand vendors and (iii) from consumers over recyclers to textile producers and consumers. The dashed line indicates that this is only minorly practiced yet. The added value of the textile product decreases along these cycles: The highest-value items circulate in the form of secondhand products; lower value occurs in recycling and the lowest value (with yet significant energy requirement) at the chemical recycling processes.

4.4 Textile wastes along the waste hierarchy

The following sections discusses current practices, opportunities and restraints of textile waste streams along the waste hierarchy: Prevention (4.4.1), Reuse (4.4.2), Recycling and fiber recovery (4.4.3) and Disposal (4.4.4).

4.4.1 Prevention

This section gives an outline on textile waste prevention and includes a special discussion on rental textile practices.

Waste prevention. As previously discussed, the duration of textiles clothes –describing the number a textile item can be used or worn– is key in waste prevention (Ellen MacArthur Foundation, 2017; Korolkow, 2016). This was confirmed and emphasized by all interviewees in this research (Austrian National Experts, personal communication, April 28, 2020; DG ENV Officials, personal communication, April 15, 2020; EXPRA Expert, personal communication, April 14, 2020; Fiber Expert TU Wien, personal communication, April 29, 2020; International Business Expert, 2020; OECD Officials, 2020; Textile Expert Industry, personal communication, April 30, 2020; Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020). Nevertheless, current practices stand in sharp contrast to the actual quality many fabrics and textile products exhibit and that would be required for enhanced durability. Highlighted by the increasing production numbers of polyester and other synthetic fibers, as presented in the introductory part of this thesis, an increasing part of textiles are composed of these components and especially their blends. Another issue are *material* mixtures (in contrast to *fiber* mixtures) that are often used for decorative or practical purposes and may wear off quickly, be unsuitable for regular laundry and difficult to separate and recycle (International Business Expert, 2020; Textile Expert Industry, personal communication, April 30, 2020).

However, decreasing product quality is not the only reason why textile items enter the post-consumer stage. The Ellen MacArthur Foundation (2017) cites a study on reasons why UK citizens disposed of or donated clothes: the decrease in quality –damaged, stained, worn out or shape lost– actually accounts to only 19% of the reasons why a person would dispose of or donate a clothing item. In 75% of cases, the quality of the item was still sufficient but either did not “fit any more” (42%), “like any more” (26%)

or did not need any more (7%) (WRAP, SCAP textiles tracker (2016) in Ellen MacArthur Foundation 2017b). The results of the same study are illustrated in Figure 6. The factors mentioned above contribute to the fact that the average number apparel is worn is currently quite low, according to the interview partners. “Studies showed that many consumers wear new pieces of clothing only 10 times or less”, as summarized by one interviewee (International Business Expert, 2020).

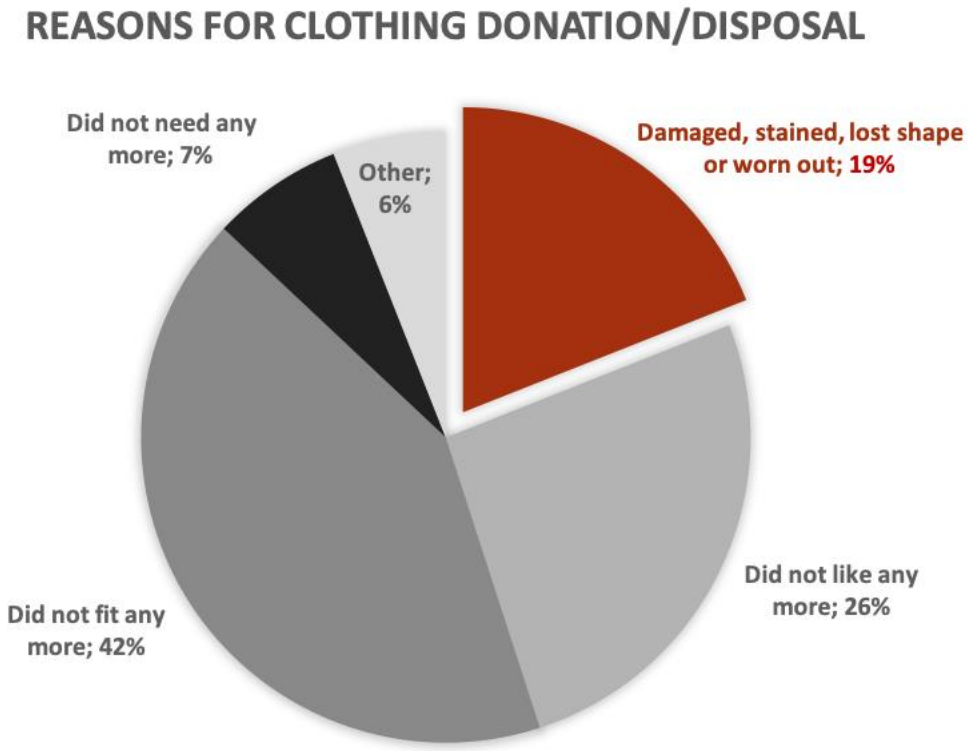

Figure 6: Reasons why UK citizens donate or dispose of clothing items (modified after Ellen MacArthur Foundation 2017; Data source: WRAP, Scap textile tracker survey (2016))

Textile rental. One proposed way to maintain clothing items to a larger extent in the usage phase, are clothing rental services. Rental services are provided both in the clothing sector for private consumers as well as for industry customers that require relatively large textile quantities. Examples for the latter include, but are not limited to, hotel industry and gastronomy, health care facilities or industry or laboratory work wear (Salesianer Miettex GmbH, 2020).

An Austrian textile rental company, for example, reports to treat 550 tons of textiles a day in 9 countries. The company's customers are to the largest extent in health care (37%) and the hotel industry and gastronomy (35%), in industry, commerce and laboratory workwear (23%) and to a minor extent in "mat service and washroom hygiene" (5%) (Salesianer Miettex GmbH, 2020). The interview partner from the company highlights that the business model is based on circular concepts: "Textiles for rental purposes need a particularly long durability with the ability to be cleaned and washed 70 to 80 times. This is important to cover costs". Textile rental is based on the following principle: A customer rents certain textile products, like bed sheets, for example, that are returned to the rental service for laundry after use and exchanged for a freshly reprocessed (i.e. washed and disinfected) set of products (Textile Expert Industry, personal communication, April 30, 2020).

The earliest form of textile renting in Vienna is probably the one for private consumers that wished to rent tuxedos, evening gowns or wedding dresses. The textile rental sector apart from clothing emerged in Austria in the 1960s and 1970s. In this time, dry cleaning companies increasingly introduced the system that was in place in the United States. The service was embraced in particular by hotels and hospitals that were exploring means to outsource their own laundry services. This allows to save both physical space and financial resources once the hotel, for example, reached a certain size. The hotel industry is also important in business expansion: the rental service company, that has by 2020 expanded into 9 different countries, usually establishes their first contacts to the local hotel sector (Textile Expert Industry, personal communication, April 30, 2020).

The products offered in this kind of textile rental service include bed linen, towels and a wide range of workwear (shirts, pants, jackets, overcoats). All products are characterized by a long durability and rather modest design. Although uniformity of rental textiles is always preferred, exemptions for special requests may be granted if a contract to a costumer is large enough. Products for the hotel industry, for example, may be adjusted to a customer, but also in this case remain modest in design to ensure a long durability. On the number of clothing items, both customer and service provers need a set. Besides the products that are with the customer, the same number is stored as stock with the rental textile company as well as one spare piece. So, for example considering five textile products for a typical work week of five days, one can infer another five pieces with the

company and one spare item, accounting to eleven pieces in total. Items are often labeled with sizes, departments or occasionally also names, but it is important to note that the official owner of the products remains still the service provider. Constraints and problems the textile rental services face include misuse of products for the wrong purpose (e.g. cleaning windows with a pillowcase) and generally ownership problems, such as stealing or not taking sufficient care of the items. Overall the system relies on a close coordination with the costumer to determine what kind of product they need and to guarantee the items are only used for the intended purpose. Only this maintains the durability and quality needed in textile rental (Textile Expert Industry, personal communication, April 30, 2020).

Although the business model in the rental textile industry is based on circularity, also in this sector, textiles "drain from the loop" when the quality no longer meets the requirements. To avoid the company-owned products are re-used for the same purpose once they are discarded by the company, most end-of-life textiles are prone to cascadic use: They are shredded and turned into lower value products such as cleaning rags (Textile Expert Industry, personal communication, April 30, 2020).

4.4.2 Reuse

This section deals with the second priority option of the waste hierarchy, reuse, which is illustrated by a show-case study of the reuse/repair sector in Vienna: the secondhand store "48er Tandler" which is owned and run by the City of Vienna.

In the EU WFA (2008), "preparing for reuse" is defined as "checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing" (Directive 2008/98/EC, 2008). For now, reuse is the only significant management priority of the waste hierarchy that is realized at a large scale (DG ENV Officials, personal communication, April 15, 2020; Fiber Expert TU Wien, personal communication, April 29, 2020). On an international level, not every country has the same infrastructure. This is particularly true for emerging economies that show increases in textile consumption. As mentioned in the introduction, the FAO reports an increase in per capita textile consumption to have risen by 20 % from 2004 to 2007 (FAO/ICAC, 2013). Thus, emerging economies become important textile consumers besides their traditional role of importers of secondhand apparel from the EU, for example.

The end-of-life value chain. The internationalization of the textile value chain is not limited to the section between production and consumption: it also occurs significantly once a clothing item is disposed of and enters the re-use or waste cycle. Not every EU country has the same waste infrastructure. However, in Austria one can generally deduce the following: Once somebody decides a clothing product is no longer wanted, one option is to place the item in a public collection container. As discussed in 4.3 above, these collection containers are mostly provided by charity organizations in Austria, like the Red Cross, for example. Subsequently, the collected textiles are picked up, washed and sorted according to fractions. These fractions reflect quality and material criteria. The smallest fraction of the donated clothes (5-10%) can be sold in Austria, but the major fraction consists of low-quality products that are exported. Some fractions also reflect specific demands of certain countries. For example, states with tropical climate do not require European winter jackets (International Business Expert, 2020; Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

According to the International Business Expert (2020), the usual business model is the following: Charity organizations place their containers at public spaces and sorting companies then sort textiles according to specific fractions. A study conducted by the

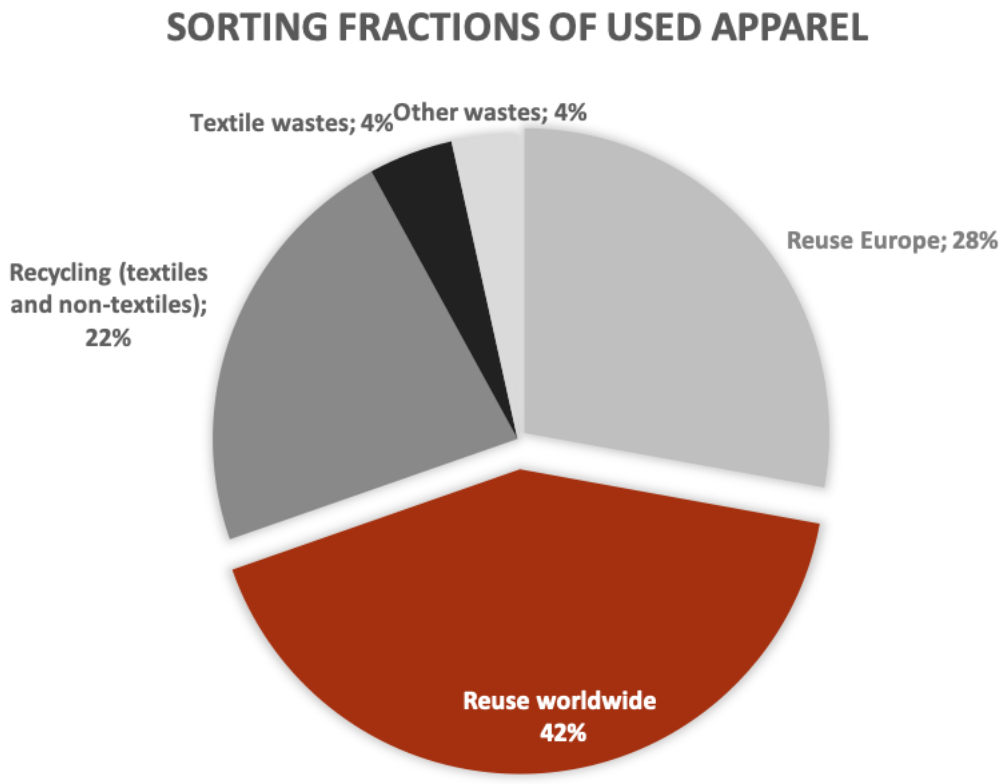

Figure 7: Sorting fractions of a typical container for used clothing collection in Austria. Data: UBA (2019)

Austrian Environment Agency (UBA 2019) on behalf of the collecting company HUMANA People to People Austria reports these used textile fractions from a sampling study. HUMANA collects Austria-wide about 7 000 tons of used clothes annually with approximately 2 200 containers across the country. Once the containers are emptied, the majority of the sorting takes place in a sorting plant in Slovakia relying exclusively on manual sorting means. Sorting aims at the highest possible reusability degree and meeting the current market demand which is inherently changing according to fashion trends. Generally, the study describes two kinds of sorting that were conducted to assess the clothing fractions: (i) main sorting in which 6 062 kg of textile container content were analyzed (Figure 7) and (ii) and fine sorting in which 206 kg of a fraction termed "shop goods" was classified into further re-use categories. Figure 8 visualizes these fractions that resulted from both sorting activities. The main sorting (i) yielded wearable textiles and shoes destined for Europe ("shop goods" Europe) 28%, "wearable" textiles and shoes worldwide (re-use outside Europe) 42%, Recycling goods (knitwear, cotton, paper, plastic bags, metal) 22,5%, textile waste 4,5% and other waste 3,5 %. A group of "shop goods" was further prone to "fine sorting" – manual sorting according to fabric type, and

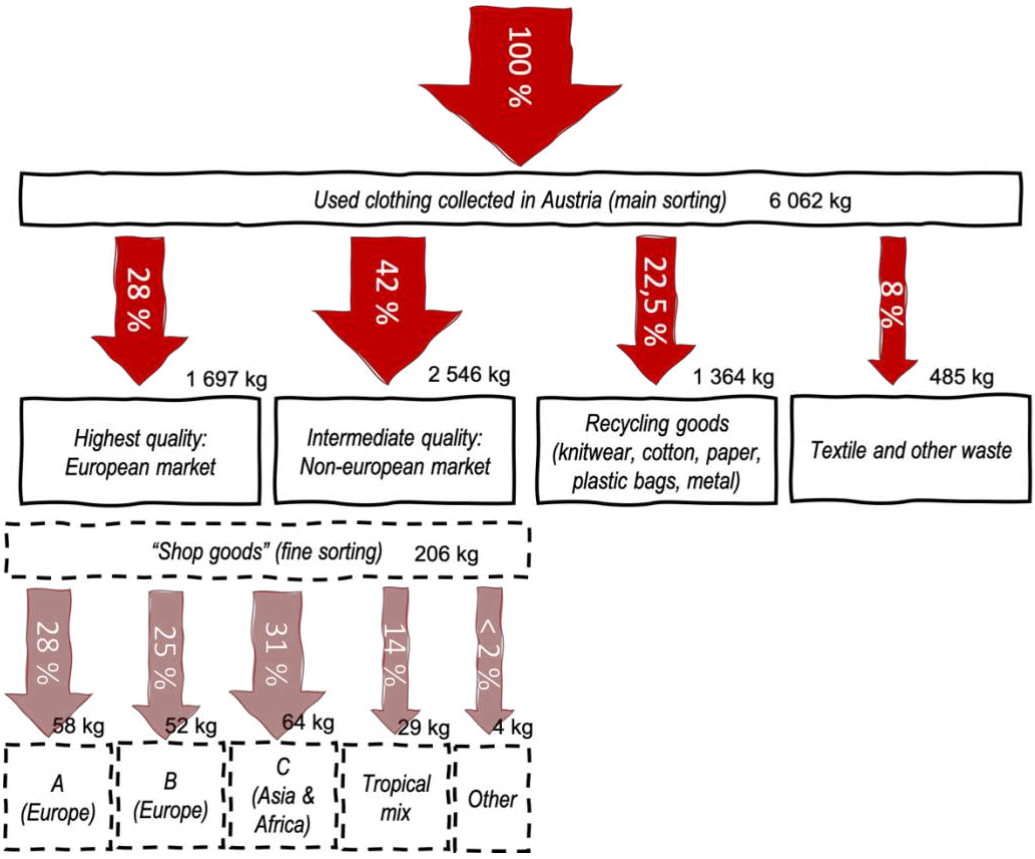

Figure 8: Fractions of used clothing collected by HUMANA in Austria in 2017. Sorting occurred on two levels: main sorting and fine sorting. In both cases, re-use outside Europe presents significant fractions. The figures present rounded values (Data: UBA, 2019).

market requirements. This fine sorting categorizes the materials further into quality classes of A (28%), B (25%), and C (31%). Qualities A and B are sold in secondhand stores in Europe while the goods of the C category are destined for export to Asia and Africa. Within this "shop goods" category, 14% were branded as "tropical mix" kind of clothes for the African market.

In summary, the HUMANA container content was segregated into the following fractions: 67% exhibiting a quality fit for reuse, 23% of the content prone to recycling and about 10% as waste for disposal. Combining the results from main sorting and fine sorting, the authors of the study summarize that the re-use of the clothes collected occurs to about 15% in Europe and to about 52% word wide (UBA, 2019). It is important to add, however, that no specification is made whether this concerns EU member states or non-EU member states with lower income or potentially less stringent environmental standards. According to the technical expert, to date, only large laundry services dispose their wastes locally in Austria while the vast majority (80-90%) of post-consumer clothing is already sorted abroad. Consequently, the waste fraction that remains after sorting (about 10% in the HUMANA study) is then disposed of or treated abroad and "definitely not shipped back to Austria" (Fiber Expert TU Wien, personal communication, April 29, 2020).

After sorting, the fractions destined for further shipment are then sold to exporters in volume fractions. This means no single items, but cubic meters of textiles are sold to wholesalers that export them internationally. Here, the market price comes into play which is crucial and quite volatile in the sector. This fact does not make the trade very profitable, but apparently profitable enough for these organizations, sorters and exporters to operate, according to one expert (International Business Expert, 2020).

The impact of secondhand clothes on local markets. An issue that is often discussed in the global context of secondhand clothing concerns the local market impact of these products in developing countries where they are often exported to. Reports for the UK for example, suggest that 36% of UK used textile exports were destined to Sub-Saharan Africa and 18% to Asia and Oceania (WRAP, 2016). The International Business Expert of this study (2020) concludes that it is a complex question without a simple answer, mostly because there is a lack of recent literature on the topic. Most literature published on the issue stems from the 1990s or around the year 2005. An overall tendency for a

negative impact can be inferred, although the extent of this impact is unclear and despite a range of arguments in favor and against the theory. Import restrictions imposed by a few receiving countries in Eastern Africa highlighted the concern on a negative impact. However, numbers and subsequent extrapolations may not be reliable because of the potential occurrence of informal activities manipulating these numbers. Other models, such as the Five Forces Mode, for example, suggests that substitution between secondhand clothes and imported new goods from Asian countries may appear due to the similar price ranges. This makes a substitution effect plausible. On the other hand, the import also creates new employment opportunities, for example for tailors. To answer the question more reliably, one would need quantify and compare the number of new jobs created with those replaced (International Business Expert, 2020).

From a legislative viewpoint, the EU distinguishes specifically between second-hand products that relate to reuse and textile wastes, also in shipment. What makes the policy attempts special in the textile context includes the high reuse rates that occur in contrast to most other product groups and the fact that textile waste is currently only dealt with by a little number of legal provisions (DG ENV Officials, personal communication, April 15, 2020). Regarding textile export, this distinction applies as well and the EC officials confirm that shipment will find consideration in the upcoming textile strategy. The Circular Economy Action Plan addresses a review of EU rules on waste shipments that aims at "restricting exports of waste with harmful environmental and health impacts in third countries or that can be treated domestically within the EU" (DG ENV Officials, personal communication, April 15, 2020). To guarantee that only intact products for reuse are exported and not waste management duties, the shipment of used apparel requires legal standards and strict guidelines, according to the expert on packaging EPR. Such negative experiences were made in both the WEEE and the packaging sector and lessons-learnt should be integrated in textile approaches, since without thorough regulation, waste of any kind usually finds the "cheapest way" (EXPRA Expert, personal communication, April 14, 2020).

On an Austrian level, the collection of end-of-life textiles is characterized by relatively high amounts of collected clothing yet decreasing marketability thereof. Fast Fashion may contribute to the overall decrease of quality to an extent that inhibits resale and reuse. This results in high quantities of collected goods that can exhaust the storage capacities

of the collecting organizations, as observed by the national experts. Organizations also face difficulties as demand for the low-quality goods declines. According to this oversupply and low demand of end-of-life textiles, the market price is relatively low. The low-price results in many cases in "downcycling" (Austrian National Experts, personal communication, April 28, 2020) which will be discussed in more detail in the recycling section of this study.

Waste prevention and reuse in the city of Vienna–the 48er Tandler case study. The City of Vienna has been involved in reuse and repair activities for more than 25 years. In practice, this has led to the further development of the "48er Tandler" for example, the city-owned second hand store, along with other initiatives and programs (City Of Vienna, 2020a). The MA48 is the city's organizational unit responsible for waste management. Since textiles are defined as municipal waste, municipalities are also responsible for their management. Separate collection of textiles already exists in Austria.

The MA48 collects used goods and textiles in particular at recycling stations, so-called Mistplätze, which are publicly accessible–yet under supervision of personal. According to the Waste Prevention Expert (2020), this is an advantage relative to unattended disposal sites as citizens do not "dare to dispose of all kinds of stuff", but textiles in rather high quality, when compared to the experience of other collectors. The collected clothes are then sorted and processed in the scrap goods logistics. Goods with sufficient quality are sold at the 48er Tandler. Within the MA48, the perception occurs that some people feel better by donating old items to the Tandler than disposing of them completely. This may explain why also the quality of some items is not sufficient for resale in some cases. On the other hand, sometimes also brand-new products appear at the disposal sites of the MA48 (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

Sales at the Tandler are not limited to textiles though since the store generally aims at waste prevention as their central theme. The product range covers furniture, dishes and cutlery, sports equipment, toys, paintings, vinyl disks and CDs, music instruments, and much more (City Of Vienna, 2020b). Initiated by the idea of a section head at MA48, the Tandler was created on the foundations of the pre-existing "48er Bazaar". This was a marketplace for secondhand items at an old factory building that attracted a different kind of customers. In order to take enhanced action in waste prevention, reuse and repair, the

Tandler emerged with the ambition to re-brand itself as “fashionable and modern and to move out of its dusty flea market image it had before”. Thus, the City of Vienna actively aimed at re-branding the secondhand store so that a broader audience would feel welcome and comfortable. “The Tandler should become a place where waste prevention is the central theme and actively lived”, the Waste Prevention Expert explains.

The MA48 enjoys are really positive image in Vienna which is very likely due to its marketing. The Tandler was able to build on this image. However, the popularity of the Tandler is also related to an EU-wide trend: Due to the Circular Economy Package and the Circular Economy Action Plan, the EU has fostered this development all over Europe. An increasing number of EU member states start re-use/repair initiatives and facilities like the one at MA48. Countries with advanced waste management are naturally more active in this than member states that are still developing their management systems. A special pioneer is the Belgian region of Flanders, that was reportedly ahead of this trend. Another good example is Ljubljana that made to the top in waste management within 10 years. According to the Waste Prevention Expert, there is considerable potential in exchanging experiences on waste prevention programs on a European scale: “The whole of Europe can learn from each other” (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

With regards to Fast Fashion, MA48 made the experience that textile volumes are increasing since they have started textile collection about five years ago. This may be linked to the Fast Fashion business model as well as the observation of a substitution effect. Due to labor-intensive sorting, the 48er Tandler cannot offer items below a certain price. Thus, substitution may occur in which customers prefer affordable Fast Fashion products to secondhand items at the Tandler. However, “overall textiles sell very well at the Tandler”, according to the City of Vienna representative. Many customers shop at the Tandler out of financial necessities, but also an increasing number of customers appear to be motivated by the sustainability thought (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

According to the expert, the reuse and repair sector is growing in Austria. This trend can partially be explained by an awareness shift of the population towards sustainability (bottom up) and partially by the effective EU legislation (bottom down). The waste hierarchy does not only make municipalities responsible for waste management, but

above all for prevention and reuse (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020). However, the re-use of textiles is restrained to their state: it can only occur as long as the item is not damaged. This is why also sufficient attention must be paid to protect used clothing from humidity, mold or other negative influences. Only under this prerequisite, minimum leakages of the re-use loop to textile wastes can occur (Austrian National Experts, personal communication, April 28, 2020).

This section has shown how reuse and repair can be effective in waste prevention and that the sector enjoys growing popularity through a combination of policy, marketing and environmental consciousness. The following part of this thesis will explore the stage after reuse, namely recycling.

4.4.3 Recycling and fiber recovery

In this section the following four issues are discussed: first, general challenges and opportunities in textile recycling, second, a description of the technologies that are currently available or under development, third, the question of industrial and technical textiles and fourth and finally, textile groups that are particularly promising in achieving a significant outcome, so-called low hanging fruits of textile recycling.

4.4.3.1 Challenges and opportunities in textile recycling

There was consensus among the experts that textiles are generally difficult to recycle. This is due to their complex composition and the exceptional occurrence of products made from one single material and without additives (i.e. dyes and coatings). Additives are important since some of them can prevent certain fiber recycling processes completely. Both technical experts compared textile recycling with PET recycling: “Recycling of PET bottles is relatively easy, in comparison. Although the lid, the label and the bottle are usually still made from different materials, separating the materials is relatively easy thanks to the methods that are established by now”. Beverage cartons are already more difficult to recycle since they consist of three different layers; paper, aluminum and plastic coating resulting in composite material (Fiber Expert TU Wien, personal communication, April 29, 2020; Textile Expert Industry, personal communication, April 30, 2020).

According to the Fiber Expert from TU Wien, textile recycling would be easier if products had a single fiber type. The recycling of polyester, for example, is technically already possible and currently performed by three companies in Austria that have significant know-how on the process. This is important since technical challenges remain also for a mono-material fiber such as polyester. Hydrolyzation, for example, may damage polymers during the recycling process and thus, requires special precaution. Another example is nylon which can be dissolved in ionic liquids, but also this process is still challenging. The real problem in fiber recycling, however, are fiber mixtures, like the blends of polyester and cotton, for example. In some cases, these materials are blended within one single yarn which makes separation almost impossible. A first approach to achieve this separation occurred in a project at TU Wien. In this study, enzymatic hydrolysis was applied to separate a 50:50 cotton: polyester blend with the aim to dissolve the cotton into glucose and recover the remaining polyester material. The resulting glucose can then be turned into alcohols (e.g. fuel alternatives) or degradable plastics. The other fraction, the polyester material, can be turned into granules that can be used for the production of new fibers. But recycling becomes even more difficult when three fibers or more are interwoven. (Fiber Expert TU Wien, personal communication, April 29, 2020).

Why fiber mixtures developed in the first place can be explained by the specific properties the textiles were intended to exhibit. Textiles with blended fabrics are often easier to treat and are more durable, according to the Textile Expert. He gives the example of a suit made of 100% wool: “It is desirable in some settings, yet it is not very durable in daily office work”. Another example is the ironing of pure cotton textiles which is rather difficult and time-consuming. This is especially the case in large-scale applications, such as laundry services, where costs need to be covered: “Material blends can be simply “finished” with hot air and water vapor to be smoothed out. This also requires less energy than ironing pure cotton.” Also, the comfort of certain items is often enhanced when materials are mixed. A study on textile characteristics and comfort showed that material blends in bed linen often increase sleeping comfort since they tend to dry faster, compared to pure cotton equivalents. The same occurs in sportswear where a current trend is the increased replacement of cotton shirts by microfiber products made of 100% polyester or material mixes. The synthetic products absorb less humidity and distribute moisture better over the whole body which increases the evaporation rate. From a recycling perspective,

however, this is critical since increasing material complexity makes recycling harder (Textile Expert Industry, personal communication, April 30, 2020).

The difficulties in recycling underline that textile products must become simpler. This is illustrated by the cooperation between the Austrian company Lenzing and Inditex, one of the leading global fashion retailers. In their cooperation, wastes from textile production are aimed to be recycled to new fibers. Textile production often occurs in countries with cheap labor costs and less stringent environmental standards. This is the case, for example, in southeast Asia, in countries like Vietnam. Lenzing underholds a cooperation with Inditex to recycle textile residues from such a production–that would be landfilled in Vietnam– to new fibers in Austria (Fiber Expert TU Wien, personal communication, April 29, 2020). Inditex (2019) mentions this technology collaboration specifically as one out of two examples in their recent sustainability report. Their second major endeavor in textile recycling is their ongoing collaboration renowned academic institutions such as the Massachusetts Institute of Technology (MIT). The reports claims an overall investment of 3,5 million € into textile recycling by Inditex (Inditex, 2019). According to the Fiber Expert, the joint endeavor by Inditex is a small step into the right direction, but the cooperation also showed that certain recycling processes only work if dyes and other additives do not interfere. And yet it is a fact that by the end of the production chain, it remains often unclear which dyes and additives were combined exactly. For example, to achieve a certain shade of black, it is not unusual to mix about seven different pigments. According to the Fiber Expert, challenges like these are inherently determined by the product design. Thus, this stresses the importance of implementing design-for-recycle concepts–an approach that can be addressed by EPR. A complementary approach in design adaptation, could be the increased focus on textile durability that supports waste prevention (Fiber Expert TU Wien, personal communication, April 29, 2020).

Having discussed general opportunities and restraints in recycling, the following part presents a more practical section on recycling technology.

4.4.3.2 Textile recycling technologies

Textile recycling technologies can be distinguished into physical/mechanical and chemical methods.

Mechanical/physical processes. An established method that recovers fiber and allows their re-weaving into new products, is based on a mechanical process that uses force to tear textiles apart. The method is probably as old as weaving itself and the Fiber Expert expects thus great potential for innovation. Companies specialized in this method are based in Germany, France and Spain, for example. Driven by resource shortages, the Former GDR deployed this method in Chemnitz for textile recycling. Consequently, the Saxony Textile Research Institute has decades of experience in this. Europe-wide, Laroche in France plays a leading role (Fiber Expert TU Wien, personal communication, April 29, 2020).

The process itself as set-up as a linear sequence of stations that repeat the mechanical ripping process three to five consecutive times. The result is a yarn of relatively low quality since the fiber is damaged and reduced in length to a range of 10 mm. As another disadvantage, the process yields a high dust fraction. An important role accounts to the input material. If the input is pure white cotton, the result is white yarn. A blend of different colored cotton textiles yields a grey yarn. The usage of different materials, like a blend of polyester, nylon or cotton results in a yarn is both low in quality and low in price. The Fiber Expert highlights that this is why this practice is often avoided. In Germany, 95% of these fibers are used in the nonwoven fabric industry. This is fabric that is not woven or knitted but shows as entangled layers. In this application, shorter fiber lengths are acceptable. This low-quality fabric finds applications in linings or carpets for the automotive industry, as sound insulation, and similar applications in which the costumer usually does not have direct physical or visible contact to the textile (Fiber Expert TU Wien, personal communication, April 29, 2020). Since the composition determines the quality of the end-product, legal guidelines could help to avoid problems arising from certain materials. Material separation is crucial in obtaining high-quality end-products (Salesianer Miettex GmbH, 2020). Further applications of the method comprise the recovery of pure wool which can yield a higher price. At TU Wien, the method was applied to aramid fibers, a blended fabric. In this research, viscose was first broken down and dissolved to glucose. By dissolving 50% of the material, the fabric texture was loosened enough to facilitate mechanical ripping of the remaining fibers. From an energy perspective, this recovery method requires far less energy than is needed in the production of new fibers. As a common benchmark for this, the production of 1 ton of synthetic fiber requires 3 tons of oil. Thermal processes generally require more energy

than purely mechanical ones, as specified by the Fiber Expert (Fiber Expert TU Wien, personal communication, April 29, 2020).

Physical material recycling takes place on the polymer level, involves no chemical material changes and is possible for both synthetic and natural fibers. For synthetic fibers, this is possible via heating the fibers, such as polyester, for example and producing granules for the production of new fibers. By exposing the material to elevated temperature, it changes from solid to liquid state. Then, granules are produced from the liquid polyester from which new polyester fibers can be made. However, heating can shorten the polymer lengths. This implies the only potential chemical changes that may occur in the process: the formation of larger macromolecules in re-condensation steps. Re-condensation is applied to compensate for losses in polymer length in the heating process. This is relevant for the parameter "intrinsic viscosity" which is an indicator for polymer length and the material quality. Theoretically, this method can be tuned to fit for bottle production. Material recycling can also be applied to natural fibers such as cotton. Here, the material is cellulose which can dissolved to produce a new cellulose fiber out of the solution (Fiber Expert TU Wien, personal communication, April 29, 2020).

Chemical processes. Besides physical means, also chemical methods allow textile recycling. In contrast to physical methods, the material changes chemically at the monomer level – the units constituting the polymers. Based on this principle, polyester can be hydrolyzed, for example, yielding two monomers. These can then be purified to make new polyester with the same properties as polyester made from the native (raw) material. A variety of methods exists already that can achieve this material break down into monomers. This chemical recycling is particularly effective for polyester, and to a lower degree for polypropylene. Another chemical approach is pyrolysis. Pyrolysis comprises a multitude of unspecified processes yielding different kinds of oils and gases with unspecified applications. However, these unspecified nature makes pyrolysis less suitable for recycling than highly specific products from monomer breakdown (Fiber Expert TU Wien, personal communication, April 29, 2020).

The advantage of the monomer breakdown lies in the versatility of its application. In the TU study in which enzymes turned cellulose into glucose, one of the obtained products was glucose which is very universal in the production of goods. Glucose can be oxidized to lactic acid and further to polylactic acid. The latter is a biodegradable plastic that

degrades at temperatures between 70°C or 80°C. This has clear potential, although it is important to note that most natural environments (e.g. seawater) do not reach these relatively high temperatures. With regards to natural polymers, such cotton or viscose, it is fundamental to note that nature and evolution have adapted to this kind of break-down. A multitude of organisms, like ruminants for example, have specialized over millions of years on metabolizing these natural compounds and breaking them down to monomers. This is not possible for the comparably young man-made compounds such as polyester that stem from the 1930s. Organisms have not adapted to their breakdown yet. However, scientific breakthrough was achieved in this regard with genetically modified fungi that are capable of transforming polyester since it resembles to a natural equivalent, oligo-ester. Yet, this is still at the lab scale (Fiber Expert TU Wien, personal communication, April 29, 2020).

Before moving on to the question of industrial and technical textiles, Table 1 summarizes the characteristics of mechanical, physical and chemical textile recycling as described in this section.

Table 1: Overview on recycling technologies for textiles

Process	*Principle*	*Fiber Type*	*Know-how*	*Innovation potential*
Mechanical	Force to rip textiles apart (for re-weaving fibers into new yarn)	All	E.g. Germany (Chemnitz), France, Spain	Likely as old as weaving itself; high potential for innovation; output quality depends on uniformity of input material
Physical	Physical changes (e.g. solid to liquid) on the polymer level	All, but different approaches for synthetic and natural fibers	E.g. Companies in Austria	Other possible output products (e.g. plastic bottles)
Chemical	Chemical changes on the monomer level	All, especially promising for polyester; nature adapted to monomer breakdown of natural fibers	Not specified; Nature	Recycled polyester with same properties as virgin polyester; Other possible output products (e.g. biodegradable plastics)

4.4.3.3 Industrial and technical textiles

As outlined in the introductory part of the recycling section, textile recycling is considerably constrained by the complexity of textiles. In this regard, technical and industrial textiles that constitute 25% of the textile market (EURATEX, 2018) present a specific challenge. According to the Fiber Expert, these textiles present a very fragmented market in a dozen of branches including personal protection equipment (PPE), geotextiles, composites, industrial filters and others. The textiles are very specific and tailored to their purposes: PPE, for example, requires very different properties, also in terms of recycling, than geotextiles that are eventually stained with soil (Fiber Expert TU Wien, personal communication, April 29, 2020). Generally, the number of industry applications of textiles increases. For example, bicycles were in former days made of steel, then from aluminum and nowadays from carbon fiber, a textile, to make the product lighter in weight which has advantages in performance. Although steel would be the easiest to recycle, it is also heaviest material (Textile Expert Industry, personal communication, April 30, 2020). Another example, often also covered by public media, concerns the recycling and waste management of rotor blades of wind turbines (e.g. GEO, 2010). These blades are made from composite, a fiber-enforced material and, according to the Textile Expert, their recycling still lacks a solution (Textile Expert Industry, personal communication, April 30, 2020). Since technical and industrial textiles are optimized for one certain application, each of these textile products would need their own recycling method. This is one reason why the fiber expert expects these textiles not to fall under EPR. As the second and main reason he confirms that industrial textile waste is not defined as municipal waste by the EU and the circular economy package refers to textiles from private household wastes. Textiles in cars, for example, would also fall under the legislation of end-of-life vehicles (Fiber Expert TU Wien, personal communication, April 29, 2020).

4.4.3.4 "Low-hanging fruits" in textile recycling

One open question that was asked to all experts which concerned their interpretation of "low hanging fruits" in textile recycling, textile fractions that may achieve a large impact in textile circularity with little effort. Answers were two-fold: the first interpretation of "low hanging fruits" was the one of materials that exist in large quantities with relatively simple composition.

The first answer on relatively homogenous textiles in large quantities was brought forward mainly by the technical experts. The Fiber Expert from TU Wien specified that the same rational was used to identify textiles for their study on enzymatic fiber separation that was a joint endeavor between TU Wien and SALESIANER MIETTEX. In this study, the researchers started with bed sheets from industrial laundry services. “Moreover, these textile wastes are clean, sterile and also more pleasant to work with then what is found in the public containers“, the expert explained. “This kind of bed sheets are commonly used in hotels or hospitals, are composed of 50:50 cotton and polyester and endure usually between 70 and 80 washing cycles”. Another benefit is the lack of pigments and dyes as these bedsheets are white in color (Fiber Expert TU Wien, personal communication, April 29, 2020). Dyes can be critical as enzymes that mediate the process may react negatively to them. In summary, the research project showed the separation of polyester and cotton was possible, but still not easy. The more complex a material mix is, the more difficult recycling becomes. This was confirmed by other studies in the EU and on international level that aim at dissolving and separating certain materials (Textile Expert Industry, personal communication, April 30, 2020).

Overall, the researchers identified flat white laundry, such as bedsheets, pillowcases and towels, as the easiest textiles to recycle. Towels, for example, mainly consist of 100% cotton and do not contain foreign material, only fabric and thread. Bed sheets from industrial laundry services have so-called envelope or bag closures and lack additional items such as snap fasteners which is another advantage in recycling. However, another prerequisite for industrial recycling is sufficient quantity that allows an operation to be economic depending on the industrial appliance at stake (Textile Expert Industry, personal communication, April 30, 2020). These factors make flat, white laundry easier to recycle than “already higher hanging fruits” such as professional clothing from workshops, that are relatively homogenous and consist of one fabric layer only. Finally, the probably “highest hanging fruits” from a technical viewpoint, present the content of the common reuse containers: jackets, pants, blouses with buttons, etc. These items are generally very heterogenous and complex. However, also here differences occur. A t-shirt is probably easier to recycle than a multilayered coat with buttons. However, tensions remain between design for recycling and society’s lifestyle that is not matched, in the extreme example that “one simplistic standard suit and dress” would probably not fit customers taste. Alternative ways forward could be the increase of textile durability or

also innovative solutions in which a textile product is composed of one single recyclable material. One example for the latter could be a bathing suit made from polyamide that also has openers and underwires made from polyamide. Such a product would be recyclable in its entity since no more foreign materials such as metal wires or zippers are contained that can damage the shredding knives (Fiber Expert TU Wien, personal communication, April 29, 2020; Textile Expert Industry, personal communication, April 30, 2020).

The second interpretation of "low hanging fruits" addressed the Fast Fashion business model. The model is thought responsible for the dramatic increase in low-quality clothing items that are difficult to recycle and thus has potential for great impact according to two experts (EXPRA Expert, personal communication, April 14, 2020; Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020). This requires quick action by both the legislator and the industry. Prerequisite for any action by the sector is as sound political frame in which industry has no option to avoid compliance, according to a policy expert (EXPRA Expert, personal communication, April 14, 2020).

To summarize this chapter, all experts confirm that in the ideal case, materials are recycled into materials of the same or higher value. From a technical stance, low hanging fruits would constitute products that are composed of either one single or two materials and for which technologies and quantities exist that allow economic recycling (Fiber Expert TU Wien, personal communication, April 29, 2020) In this context, the Austrian National Experts highlight that incentives in the current legal and economic environment are still too low to engage in textile recycling (Austrian National Experts, personal communication, April 28, 2020). In short, a textile product made from a 50:50 mix of polyester and cotton would present such a low-hanging fruit, since cotton covers 25% of the market and polyester 50% of the market. Together they comprise 75% of the market (Fiber Expert TU Wien, personal communication, April 29, 2020)

4.4.4 Thermal treatment and final disposal

When waste prevention, reuse and recycling attempts are exhausted or not applicable, textile wastes are prone to final disposal. The ultimate destination for most textiles is thus still incineration or landfilling. More than 73% of textiles produced worldwide are incinerated or landfilled. This can be illustrated by the content one garbage truck of

clothing incinerated every second, assuming a textile density of 150 kg/m3 and a truck volume of 17,5 m3 (Ellen MacArthur Foundation, 2017).

As a consequence of incineration and landfilling, constituents that were incorporated into the textiles during production or use are released to the environment at differing rates. In 2014, the Swedish Chemicals Agency estimated that the degradation of textiles in landfills releases more than 2 000 tons of hazardous pigments in the EU each year (KEMI, 2014). Regarding incineration plants, pollutants may enter the broader environment through emission stacks, especially when unfiltered (Ellen MacArthur Foundation, 2017). Due to the fact that textiles may release toxic pollutants such as chromium when they are incinerated, some industrial textiles are categorized as hazardous waste (EC, 2018a). This fact can render incineration quite costly in Austria, for example, with disposal costs in the range of 160 € per ton while in other countries, like Lithuania, for example landfilling of the same waste accounts to approximately 20 € per ton. This cost difference may promote textile waste streams from Austria to move abroad where environmental standards are less stringent (Fiber Expert TU Wien, personal communication, April 29, 2020).

After all, there was the continuous call to end the incineration and landfilling of textile wastes in the EU (e.g. Manshoven et al., 2019). Although Article 4 paragraph 2 of the WDF reminds member states to find a different prioritization, if a better environmental outcome for a specific waste stream can be achieved (Directive 2008/98/EC, 2008), incineration and landfilling of textiles is now increasingly under criticism in favor of more circular waste management approaches. The EC stays vague in the ways how to achieve their goals. The EC officials highlighted the general aim of all potential instruments, i.e. that waste has a high potential for re-use or recycling (DG ENV Officials, personal communication, April 15, 2020). The way to achieve this aim, however, is still under debate. The circular economy action plan (March 2020) mentions the application of the new “sustainable product framework” for textiles as the very first products addressed. The idea of the sustainable product initiative is to set design requirements. Hence, with regards to textiles, the EC has committed itself to address design already. In what way is still vague, however. The EC officials confirm that the main aim will be a longer product lifetime (i.e. that the usage of textile products lasts longer) and that once textiles become waste; they are recyclable. The measures that are necessary to accomplish these aims can

encompass the consideration of certain materials or other combinations of materials or their potential environmental impacts, such as microplastic release, for example. Overall, the EC aims at increased product quality with longer lifetime to thereby reduce waste quantitively. One instrument that was generally proposed to achieve more sustainability in the sector is EPR–Extended Producer Responsibility (DG ENV Officials, personal communication, April 15, 2020).

4.5 Extended Producer Responsibility

Regarding this policy approach that may potentially increase textile circularity in the EU in the future, this section will cover the following points: the main lessons learnt on EPR in other sectors, the potential of an EPR for textiles, possible EPR instruments addressing textiles, and important aspects and ways forward.

4.5.1 Main lessons learnt from existing EPR

According to the EPR policy experts at the OECD, EPR has generally proven to be a very effective policy instrument over the recent decades. EPR is very effective in increasing recycling rates and in providing financial flows than can cover the costs of this increased recycling. The policy instrument makes producers responsible for the products they put on the market and for their end-of-life management. The overall aim is to create incentives for manufacturers that can include design for recycling, for example. But in fact, the design incentive was not as strong in practice as it was initially aimed for. This may be caused by the way EPR systems are established. As outlined in 3.6.1, EPR systems can be organized either collectively or individually in a country. The collective system hosts a central organization that takes over responsibilities for a number of producers, in so-called Producer Responsibility Organizations (PRO). However, in his collective case, also classical collective action may problems arise, such as free riding or companies that are reluctant to invest in better design when competitors may profit from it. The idea of collective PROs is based on the economy of scale concept and to exploit respective savings–it allows to reduce costs of end-of-life management and recycling. A drawback in the individual system is diminished cost savings from economies of scale. However, digitalization and other technological developments may nowadays also contribute to cost reduction. Overall, EPR systems yield very good recycling results, but incentives for design are still low with EPR. Another important general finding on EPR by the OECD experts is the dependency of the effectiveness on the broader policy mix.

For example, the effectiveness also depends on the existence of landfill and incineration taxes, on the enforcement and compliance system in place and on the degree of monitoring that occurs. So for establishing an EPR, not only this instrument, but the surrounding policy environment –in which the EPR is implemented– is important (OECD Officials, personal communication, May 5, 2020).

Lessons that can be learnt from other waste fractions that eventually fell under EPR, include packaging waste. In this context, it became clear that Member states implement directives quite differently and that non-EU countries find their own solutions to tackle waste. Although legal situations inherently differ among member states, the challenges often remain the same: similar discussions with authorities and the behavior and acceptance by civil society, for example. This observation underlines the potential that lies in learning from best practices and other EU member states in contrast to developing singular national solutions country by country. One example for missed opportunities in learning from each other is Germany, according to the EPR expert on packaging. When establishing the packaging EPR scheme, Germany missed to learn from the best-practice that Austria exemplified: Austria did not introduce competition to its packaging system instantaneously but undertook a thorough preparation phase of several years. During this time, open discussions were held, and competition was only introduced once all the requirements had been met. This way, Austria avoided problems that Germany had to go through. European umbrella organizations for PROs, such as EXPRA on packaging, see their task in showing member states how they can learn from each other and engage stakeholder to enter dialogues. Regarding industry, the expert made the experience that the cheapest way for waste management is usually explored first which rarely conforms with the most sustainable one. As such, companies may try to avoid extended responsibility, if possible (EXPRA Expert, personal communication, April 14, 2020).

4.5.2 A potential EPR for textiles

In May 2020, France had it in place already, while Sweden and the Netherlands have just confirmed its establishment: an EPR scheme on textiles. The EC is simultaneously developing a textile strategy for the union and following up on the EPR debate. Aware of the effectiveness of the tool for other waste streams, the EC has the potential power to make EPR schemes mandatory for its member states, also for textiles. Although the waste framework directive sets the legal limit for wastes streams in general, EU member states

still remain free in designing their own national approaches to achieve targets. This is because implementation of EU directives takes place on a national level. On the product level, certain products can be covered by a single or several EPR schemes by the EU (DG ENV Officials, personal communication, April 15, 2020).

The OECD is exploring textile EPR in the light of microplastic release. The central question in their research is whether this release can be minimized through EPR and if so, to what extent. The preliminary findings indicate that fiber length is crucial in the release of microfiber during laundry processes. Yet, many other factors in the production process influence how emitting textiles are. Once this information is gathered, the best technological approaches can be determined to minimize microfiber release. This result will then allow to decide on the most favorable political approaches to establish best practices. Generally, on EPR, it is important to note that these policy approaches target municipal waste rather than industrial waste. Since post-consumer clothing waste stems from households, EPR would "make sense" in this situation, according to the OECD experts. Other textile products (furniture, automotive sector, industrial fibers) have often a very different composition, manufacturing processes and supply chains and require different management. In this context it is important to note that many EPR systems give producers flexible options; to opt-in (in order to join an EPR system on a voluntary basis) or to opt-out (of a system) and establish an individual producer responsibility concept. The latter could be useful for large entities with respectively large textile volumes that are potentially more efficient in handling matters on their own, like the military for example. With regards to the automotive and the furniture sectors, the experts highlight that both sectors are already prone to EPR schemes. It could, thus, be beneficial to broaden these existing schemes for textiles instead of establishing a completely new one in the industry context. According to the OECD experts, great benefit can potentially already be made with a textile EPR strategy that covers 60% of the textile industry, namely clothing. From a regulatory viewpoint, there is the need to establish one due to the increasing volumes and decreasing quality, the resource intensity and the environmental impact. Furthermore, textile recycling is technologically difficult, cost-intensive and there are few incentives to develop innovations which makes textile recycling uneconomic. And increasingly so since also the circulation of mixed fibers increases. In order for recycling to work in this kind of market, subsidies are needed. This is the purpose of EPR: to create financial flows that can cover recycling costs that are

otherwise not provided by the market (OECD Officials, personal communication, May 5, 2020) The perception that EPR is needed for textiles and highly likely is also shared by the technical expert at TU Wien (Fiber Expert TU Wien, personal communication, April 29, 2020)

According to the expert on packaging EPR, similarities occur between the two sectors. The textile market has developed in a similar way as the packaging and food market did 20 to 30 years ago. In particular with regards to convenience and speed: fast fashion has replaced the typical winter and summer clothing collections with a business model that is capable of bringing completely new collections into the stores every two weeks. The price of fast fashion does not reflect reality, neither in terms of production, nor in terms of end-of-life management, according to the EPR expert. "Somebody has to pay" for the re-use, treatment or incineration of increasing volumes of low-quality clothes: either the general public or the producer who brings these large volumes to the market at such low prices. To reverse this trend, these low prices would need to be inhibited. For example, if a consumer pays 50 cents for the disposal of each 3€ shirt (advanced disposal fees), a visible effect on the selling price is achieved. The price signal indicates to buy only 5 pieces instead of 10. To achieve this however, it is important that industry feels political pressure, by EPR, for example (EXPRA Expert, personal communication, April 14, 2020).

4.5.3 EPR policy instruments

The following EPR instruments are discussed in this section: product take back and recycling quotas, regulatory instruments (design requirements), material bans, information-based instruments and other economic EPR approaches. Finally, the section provides an instrument ranking in the textile context with a schematic illustration (Figure 9) of the EPR policy instruments at stake.

I. Product take back & recycling quotas

The fact that some companies already have product take-back initiative in place, highlights that such approaches are realistic for individual companies on a country level, from a business perspective (International Business Expert, personal communication, July 4, 2020). This assessment is shared by an EPR experts who adds "as long as this occurs under strict legal conditions" like with specific collection and recycling quotas

that need to be met by all companies equally (EXPRA Expert, personal communication, April 14, 2020). Online trading presents another issue in this context. It is a common market entry strategy before a company becomes physically present in a country. However, it is important to ensure that the same rules apply to all market participants. It needs to be clarified to what extent responsibility concerns Zalando, or other market platforms, or the partner and sellers on these platforms (International Business Expert, personal communication, April 7, 2020).

The main advantage of individual takeback is, that companies need to take the quality back they initially produce. This encourages the producer to focus on high-quality goods. The disadvantage is that the consumer would be the ones to return the items back to the store and these quantities would be missing from the nation-wide collection system (EXPRA Expert, personal communication, April 14, 2020). From a business perspective, the customer return is an advantage. The logistical effort for the company is minimized as long as customers return the textile items to the store themselves (International Business Expert, personal communication, April 7, 2020). As outlined above, a collective system, in contrast, would have the advantage of savings from economies of scale. However, it is compromised by collective action problems such as free riding and companies that fear other companies may profit if they increase the quality of their goods (OECD Officials, personal communication, May 5, 2020).

Countries and also industries need to consider carefully whether to establish a collective or an individual system. The collective system works for packaging, but especially now as requirements aim at adapting fees, for different kinds of plastic for example, the situation becomes more complex (EXPRA Expert, personal communication, April 14, 2020). Another concern that arises with PROs, is the potential harm that could be made to existing collection and secondhand infrastructure, largely run by charity organizations in Austria. This is important since many citizens rely on these stores as the can only afford secondhand clothing. It would be important to integrate these existing structures to ensure that second-hand clothing remains for sale in Austria. It could be quite problematic, if Caritas and Volkshilfe are no longer allowed to collect because a central organization is taking over (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

Take back targets were achieved in the packaging sector. Although the approach could be plausible for textiles too, one of the technical experts expects no significant decrease in textile volumes. However, it can be expected that the consumer would not realize additional product costs that cover recycling fees (Fiber Expert TU Wien, personal communication, April 29, 2020). Overall, it will be crucial to define rules on the management of the textiles once they are collected to avoid mere greenwashing (Textile Expert Industry, personal communication, April 30, 2020). Technological progress must be made first to allow textile recycling, especially with regards to big-scale applications. Recycling occurs already by using old textiles for insulation materials and cleaning rags, so-called downcycling, but a need for technological progress remains to allow similar recycling as PET to PET, a process that is an established practice by now. The aim would be to achieve this kind of textile to textile recycling. If a recycling quota is introduced, it is therefore important to define recycling and whether "downcycling" is included (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020)

In a nutshell. *The fact that companies already started their own product take-back initiatives indicates that this instrument would be a realistic option for the industry. However, in this context two criteria must be met: rules need to apply equally to all market participants (independent from their physical presence in the EU) and that clear guidelines determine the management, transparent traceability and fate of the collected items. In terms of product design, take back options are not very effective unless individual take back systems are at stake. Recycling quotas combined with product take back seem a viable option. However, in order to allow large-scale industrial textile recycling, technological progress is still needed. In France, parts of the revenues from the textile EPR scheme are used to additionally support science and research projects, for example. This could be an option for other countries too but opens the discussion to the allocation of funds, public awareness and communication related to both consumers and the industry.*

II. Regulative instruments on product design

More stringent requirements on product design are realistic from a business perspective. The large retailer Inditex has already committed to it in its financial statement of 2019. Specifically, they plan to make all materials from recyclable fibers until 2025 –A very ambitious goal, according to the expert. Yet, pro-active steps by companies often indicate

if a measure would be realistic (International Business Expert, personal communication, April 7, 2020).

One of the emerging topics in the debate on EPR, the waste framework directive and product design specifically, is fee modulation. According to the OECD experts, this is a response to the lack of individual EPR schemes that could have had more impact on design. However, there is a necessity to assess how fee modulation for different product groups works in practice to avoid drifting into a system that resembles to planned economy. The market is dynamic, and innovation can occur quickly. Thus, a fee modulation would also need quick adjustments. The experts assess the idea of setting price signals to improve design as generally good, but see great challenges in the practical implementation (OECD Officials, personal communication, May 5, 2020). The third EPR expert also highlights fee modulation in the context of product design. Adapting fees increases the complexity of the situation. In the context of plastics, different prices apply to bottles, films, different kinds of films, etc. This could be done for textiles as well to push for more quality, but advantages and disadvantages occur, especially in oversight, that need evaluation (EXPRA Expert, personal communication, April 14, 2020).

According to the technical experts, comparisons can be drawn to packaging EPR. A required minimum content has the potential to create a so-called pull effect. If for example, 40% of recycled polyester are required to constitute a textile product, the demand for recycled polyester rises. In packaging, one could observe this for PET bottles. There was increasing demand by companies. Some companies aimed really high to even use 100% recycled PET for their bottles nowadays. Together with a low crude oil price and the costs of separate collection and sorting, this led to the surprising development that, at some stage, recycled PET became more expensive than virgin PET–despite its lower quality. For polyester, this might be more difficult mostly due to technological challenges and the international character of the textile value chain. From a technical perspective, it can be added that some department stores already claim to have recycled materials contained in their products. Research shows that is also takes to “produce” the recycled material first before you can incorporate it into a new product. As a first step, it takes promotion of companies and institutions that conduct research in the field of textile recycling to allow the future production of recycled fiber in industry scale (Textile Expert Industry, personal communication, April 30, 2020).

However due to the internationalization of its value chain. In contrast to PET bottles that are collected and produced locally in Austria, polyester fibers stem to a large extent from China. But moreover, the value chain from fiber over yarn to fabric and textile production is characterized by in transparency and large shipment distances. Often, the polyester type, for example whether it constitutes recycled materials, is already difficult to determine at the production site, and this difficulty increases along the value chain to the end-of-life textile in the collection containers. This pull effect can be assessed as more effective than push. If nobody wants a certain material or good this rather leads to exports or illegal activities. The pull effect has also potential for re-industrialization and increased production capacities in EU, for example in yarn recycling. Especially when it is requested by law. The automatization of many industrial processes also blurred the difference in labor costs, for example whether items are produced in China or in Turkey. This has advantages in the fast fashion business model as production can be brought to the market quicker. Fast fashion can react quickly to the market. EPR –depending on how it is designed–can have massive effects. In the worst-case scenario, big textile volumes are collected. In the best-case scenario, these big volumes are recycled with the highest possible value (Fiber Expert TU Wien, personal communication, April 29, 2020).

In a nutshell. *Besides being mentioned in the Circular Economy Action Plant from March 2020, the design requirements appear highly likely in the textile context. This appears true from several perspectives: (i) Industry has already shown willingness and pro-activity, (ii) Fee modulations are being discussed as means to address the variety of textile products and (iii) minimum content of recycled material for example can create the fundamental demand for recycled textile. Restraints occur with collective action problems and traceability that would be needed to guarantee international fiber producers comply with the regulation. This would be facilitated if re-industrialization occurred within and nearby Europe, e.g. through increased automatization that avoids high labor costs. Moreover, design-related research is needed to identify disruptors (e.g. certain pigments) in textile recycling and their potential substitutes for maintaining the desired properties without compromising environmental and human health.*

III. Material bans

From a regulatory perspective, material bans are possible which is demonstrated by several examples: The Regulation on Harmful Substances (RoHS) from 2003, for

example, restricts hazardous substances in the electronics sector (EC, 2020c) and other examples stem from the chemicals side, e.g. the REACH regulation banning specific chemicals or the Stockholm convention regulating Persistent Organic Pollutants (POPs). In the context of the Eco-Design Directive, it is currently discussed how an extension could possibly cover circular economy aspects. The considerable volumes and the negative effects on the environment would already justify a material ban, according to the OECD experts. This applies to single compounds or materials. With regards to material mixes, however, sector knowledge is required to depict precise measures to reach the political target of increasing fiber recyclability. Other factors contributing to the selection of measures include technological feasibility, the need for economic incentives and specific material properties (OECD Officials, personal communication, May 5, 2020). Another expert shares this view and highlights the necessity for quick action by the authorities in the context of microplastics–especially when alternative solutions arise. In packaging, for example, the idea of oxo-degradable plastics as eco-friendlier alternative emerged. The idea soon turned out more hazardous than the initial situation since these products break up into smaller plastic pieces –without dissolving or degrading– and contribute to microplastic formation. Quick action by the EU managed to ban the material despite the relentless pushes by industry. It is the task of the legislator and the authorities to act and enforce when items become too dangerous (EXPRA Expert, personal communication, April 14, 2020).

With regards to the recyclability of textile products, demand for action is articulated, while complete material bans or not specified. However, according to the technical expert, no best-practice example for circular fashion exists at the moment, but plenty for worst-practices. One example that is still far from being recyclable is sportswear: A sports sock may consist of four fiber types or more and a sport shoe of sixteen different components. Potential solutions will more likely concern the consumer as big companies may have the incentive to circumvent EU legislation on design but would follow what the customer wants, citing an industry representative (Fiber Expert TU Wien, personal communication, April 29, 2020).

From an economic viewpoint, it would be important to define the specific areas of a material ban–whether legal requirements are limited to Fast Fashion clothing or also include protective clothing, for example. Here, limiting individual industries/products

could be an option. With regards to the fiber mix, the question arises how many changes a company can endure and if an intervention risks a standstill of the entire industry (International Business Expert, personal communication, April 7, 2020). Some products also require a complex composition. Surgical drapes and gowns, for example, also constitute a material mix of membrane and textile. Another example are rain jackets. A total ban of material mixes would not make sense since it would concern this kind of specialized product too. There is also the risk to overlook a certain group which could decrease the number of manufacturers and raise prices (Textile Expert Industry, personal communication, April 30, 2020).

In a nutshell. *Material bans seem plausible for individual materials or specific components, such as hazardous chemicals. These may cause adverse effects throughout textile production, textile usage and possible migration through the environment after final treatment or disposal. Another topic of concern is microplastic release linked to the increasing application of synthetic fibers. Solutions to this problem need to inhibit this release during laundry: either front-end by changing product design or back-end at water treatment. The practical implementation of a material bans for textiles –and especially a ban on fiber and material mixes that are problematic in recycling– may be restrained by the complexity of the textile market and the need for specialized products.*

IV. Information-based instruments

Detailed information throughout the international value chain of textile products and their post-consumer life is scarce. The challenges in providing more information and transparency appear very similar to those of the electronics sector: the supply and value chains are long and very international. In most cases, product origin and chemical usage are unclear to both the salespersons and the customers in Europe. The main leverage in demanding more profound information, are the large textile companies that present the main buyers of textiles stemming from countries such as China. Another comparison can be drawn to experiences in the chemical industry. REACH was established under the assumption that chemicals were produced in Europe and that by regulating the producer, also the market is controlled. However, production has shifted from Europe to other countries by now and Europe is “only” the main importer. This results in a lack of influence and knowledge on the production methods and impact. Although, big retailers

and brands have become active by now, there is "room for more" (OECD Officials, personal communication, May 5, 2020).

Information is an integral part of EPR, yet still problematic in two aspects, according to the packaging EPR expert's assessment: "First, the information provided by many businesses often serves promotion or advertising purposes and second, only a small fraction of customers, around 10%, are actually interested in this information. The majority of people shopping in the Fast Fashion Price segment are usually indifferent to information." On the other hand, the expert highlights that the 10% interested people have difficulties finding reliable information since also clothes from expensive brands are no guarantee for good practices. This statement can be related to social and target group typologies highlighting that not *one* consumer, but *several types* exist. Moreover, information is important since prices in the fashion industry still lack cost internalization in most cases (EXPRA Expert, personal communication, April 14, 2020). One means to enable transparency are eco-labels. One example is the Ökotex label–an ecological certificate that displays information throughout the production and supply chain for a broad range of textile products, ranging from infant clothing to decorative fabrics (Textile Expert Industry, personal communication, April 30, 2020).

From an economic perspective, information-based instruments are both plausible and enforceable to a certain extent. The limitations concern how much information can be obtained, how to sanction insufficient information and the assessment criteria. Transparency should be guaranteed with regards to environmental pollution, greenhouse gas emissions and social responsibility, such as working conditions and the treatment of employees. The ease of realization will depend on product groups. In the case of pesticides, for example, producers have no reporting obligations yet and thus, information is still scarce. However, Zara, for example provides an outline of its sustainability measures in its annual report, including a monitoring on compliance at single steps of the value chain. Although compliance is not fulfilled to 100% at each step, the program already presents a step into the right direction. Legal initiatives are yet needed to ensure companies become significantly active beyond publicity. However, also new technology can help tracking the origin of products across borders in the future (International Business Expert, personal communication, April 7, 2020).

In a nutshell. *Information-based instruments are an integral part of all EPR systems. Currently, the provision of information and transparency is on a voluntary basis and complicated by the long and international textile value chain. Prices often do not reflect social and environmental costs. Although ecological certificates exist that provide information to the costumer, it is unlikely they will reach the vast majority of consumers as different social and target groups react differently to displayed information. All experts assume significant room for improvement. Especially, when a legal frame animates big brands to active their leverages in the international value chain.*

Instrument ranking. As shown by the illustration on EPR instruments (Figure 9), one of the most promising EPR instruments identified in this study, is "regulations on product design and performance". This positive assessment is due to the fact that the instrument (addressing the primary producer) can contribute to three important aspects in the textile value chain: waste prevention, recyclability and increased demand for recycled textiles. First, waste prevention, the uppermost waste management priority in the EU, would be increased by requirements on increased clothing durability. Second, the recyclability of products depends mainly on clothing design. Triggering the design of mono-material products (e.g. fabric and zippers made from the same material) or products made of one or maximum two fiber types (e.g. like bed linen or towels) could rule out important technical recycling constraints and open the door to innovation in the European textile industry. An alignment of product design with technical recycling requirements appears as one of the most promising synergies in the textile context. Third, requiring a minimum content of recycled material would substitute the demand for primary raw materials. Thus, less virgin material input would be needed, and a positive pull effect created for recycled textiles driving up its demand. One fiber type that seems promising in this regard is polyester: it can be reprocessed to the monomer level thereby allowing the same properties as primary polyester. However, in this context it should be noted, that going back the entire value chain from a product to its raw material basis entails implications on the resources at stake (value-added, energy consumption, etc.). The most fundamental challenge will lie in the creation of design incentives however, since collective action problems can severely impede them.

Another important instrument concerns the creation of financial flows. It is evident that financial flows are required to enable the responsible management of end-of-life textiles

and allow recycling in this market. This includes (but is not limited to) labor intensive sorting for re-use, marketing that promotes re-use, the funding of research and development to allow large-scale textile recycling and design improvements in the future and the environmentally sound disposal of ultimate textile wastes. Although the precise provision of these financial flows (taxes or fees) was not a topic that was explicitly covered in-depth by the experts, it became clear from the French EPR that a system based of fees is competent at creating these flows in an EU member state. Fees have the important advantage as they can be dedicated to specific purposes, in contrast to taxes. For example, the flows can be directed research and development or awareness raising campaigns, as described in the section on the EPR system in France in 3.6.3. Eventually, however, it is a political decision in what way financial resources are tapped (fee or tax) and additional economic research would be needed to allow a more distinct statement.

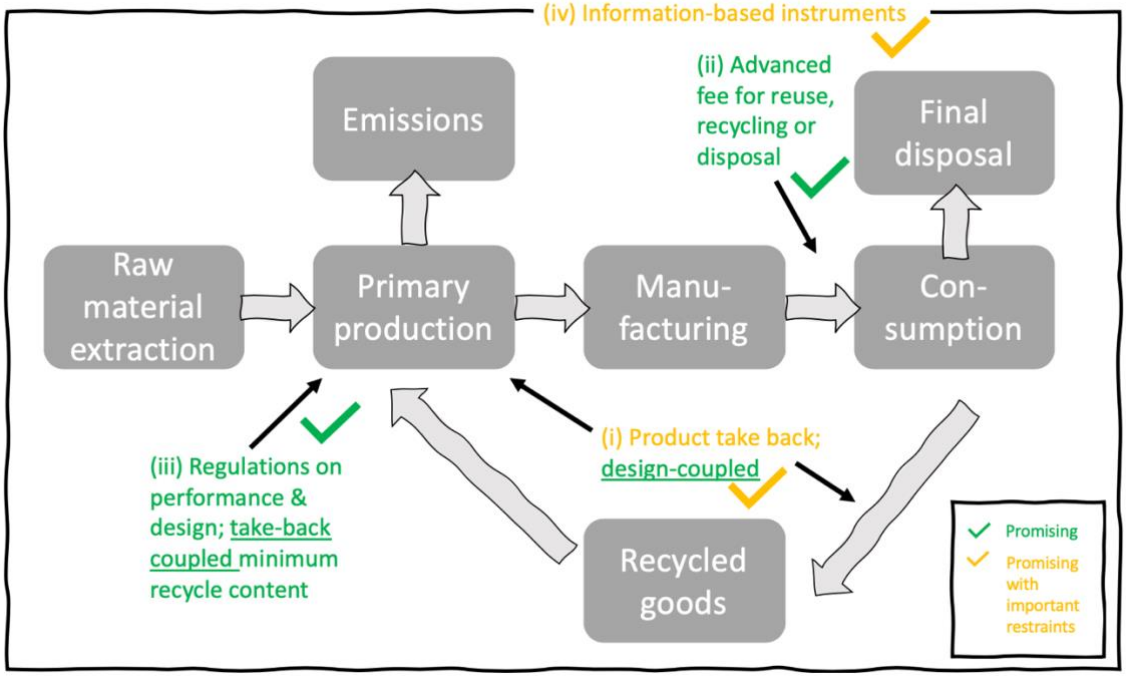

Figure 9: Results of the EPR policy instruments analysis along the textile life cycle: (iii) Performance and design standards (green) are the most promising solution towards a circular textile use. Advanced Fees (green) are plausible with regards to the French system where fees are in place that cross finance sorting, research and development, awareness raising campaigns and research and development. In contrast to taxes, fees are dedicated to specific purposes. Product take back systems (orange) are likely and plausible, yet still require defined quotas and fundamental technological progress in recycling. Product take back has the potential to shift towards a more positive assessment (green) when coupled with a design requirement for a minimum recycling content. Finally, information-based instruments (orange) are crucial for monitoring/oversight and allowing informed consumer decisions, but still face important constraints by the complexity and missing transparency of the textile value chain (Scheme modified after OECD 2016).

Although product take back is another promising EPR instrument for textiles, progress needs to be made to allow the treatment (i.e. recycling) of the collected textiles quantities. Especially, since these quantities can be expected to increase significantly with the upcoming EU obligations for separate collection, despite the fact that precise quotas still need to be defined. Product take-back concerns both, the post-consumption phase and the production phase of the textile value chain. As the most important point, technological progress is required to enable substitution of primary materials with recycled textiles, to meet for example, a minimum quota of recycled material in a product. A system in which take-back is coupled with design via a minimum recycling content appears very potent in enhancing textile recycling. Whether the organizational and operational responsibility remains with existing infrastructures (such as charity organizations in Austria, for example) will depend on the individual member states of the EU. In the Austrian case, the integration of existing structures seems favorable in the light of the social benefits charity and social organizations create (employment, collection rates, affordable secondhand clothing) and the speedy implementation and operation of a new textile system they could allow with their experience and know-how.

Lastly, information-based instruments are a central theme of any EPR system. Yet, the complexity and often missing transparency inhibit its potential at this stage. Important progress needs to be made with regards to the provision of information to allow both government oversight as well as informed consumer decisions.

4.5.4 Additional aspects

Competition. A common concern in the establishment of new policies is the impact on business. However, not every change in legislation is necessarily a disadvantage: EPR strategies can be both advantage and disadvantage for a company. This depends on the company's positioning and whether they have anticipated certain changes or not. If a company sells products that already meet certain requirements, this company has an advantage. Due to the fast nature of the Fast Fashion business models, respective companies might also be faster in adapting to new EPR requirements. If demand additionally shifts into the same direction (i.e. sustainability becomes a decisive criterion for consumers), EPR does not cause a problem for business. Beyond the actions that are visible to the average costumers, companies also conduct risk assessments and prepare for trends which also equips them with advantages in the light of upcoming policies. The

same is true for investments in research and innovation. However, companies will only obey, if the rules apply to everyone (International Business Expert, personal communication, April 7, 2020).

Experiences with EPR have shown how to design legislation without creating competition problems. In the worst case, companies will try to pass on higher costs to the consumer, but the European market can be expected to still remain attractive despite common rumors. Packaging companies in the US have used this argument against EPR strategies in the states, despite performing well on the European market under such regulations. However, the most important factor remains fair competition. In the context of clothing online sales in particular, it remains important to include market platforms. As a consequence, campaigns were already launched in Brussels that aimed at increasing awareness on assigning responsibility to marketplaces (Amazon, Ebay, Zalando, etc.) as well. The expert on packaging EPR cites estimates, according to which 300 000 – 400 000 companies deliver products into Germany: "If the government would manage to pose responsibility on the 10 largest marketplaces, the problem would be solved to 80-90%". This aspect may also be included in the Commission's guidelines on EPR online trading– implementation however, remains on the national level (EXPRA Expert, personal communication, April 14, 2020).

From an EU perspective, the EC generally aims at safeguarding a level playing field. Importance is given to the avoidance of discrimination independent from the conditions applied to a certain product. Competition of European companies should not be impeded and quite on the contrary, open the door to innovation, especially for companies that are already in a good position to provide sustainable products. This was the case for other product groups where eco-design was implemented, like washing machines and dish washers. In addition, those who move first have the advantage as they can set the standards. Competitiveness can be perceived as an "integral part" part of sustainability, according to the EC Officials (DG ENV Officials, personal communication, April 15, 2020).

Consumer awareness. Consumer choices are an important factor and most experts underline that they should not be underestimated. Although, different social and target groups are recognized by the experts, in the recent years, an overall growing environmental awareness has been observed: Consumers show increasing interest in the

origin of textiles, their composition, the value chain and to which world they contribute with their purchasing power**.** The OECD experts identify this push as the driver for large companies to establish corporate responsibility and transparency schemes and to provide this transparency also to the consumer level. The same momentum brought green public procurement, the apparel coalition and movements such as slow fashion, an analogy to slow food, on the European level forward. Another example are the achievements by Greenpeace in 2010 in raising costumer awareness on toxic chemicals (NPEs) that were eventually phased out. One specific approach to address the consumer level are ecolabels, such as the EU Ecolabel criteria or the Ökotex label. They emerged along the tragic incidents, such as Rana Plasa and other scandals in the textile industry, and direct costumers to sustainable options. In scientific literature, however, the "intention-behavior" gap is still widely discussed. This concept describes when consumers have the attitude, but a time lag occurs in their purchasing behavior. Differently put, this means that costumers' intentions do not always correspond to their behavior. As another weakness, corporate responsibility also often lacks technical details, such as recyclability or chemical content of a product. However, EPR has the potential to give these slowly developing systems an additional push and when the demand for sustainable products exists, advantages for companies can occur. Finally, the EU or the EPR regulator will determine the criteria of what information must be obtained and provided to the consumers (DG ENV Officials, personal communication, April 15, 2020; Fiber Expert TU Wien, personal communication, April 29, 2020; International Business Expert, personal communication, April 7, 2020; OECD Officials, personal communication, May 5, 2020).

However, changes in the behavior of consumers has also taken place on the local scale in the reuse sector. In Vienna, observations were made that the re-use repair sector has shown a clear upward trend. In Austria, an increasing number of costumers turn to secondhand options or look into repairing broken equipment which is likely linked the sustainability debate and the movement of the young generation, like Fridays for Future. In addition, the repair sector also received more media coverage in the recent years, for example in reports about repair cafés and other civil society initiatives. According to the Viennese waste prevention expert, this development may result from both top-down and bottom-up initiatives: EU legislation and circular economy strategies have increased actions by the member states, but also citizens increasingly wish to be sustainable. "It is

hard to describe the sector with market terminology –it is not necessarily "growing" but the sector is rising" (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

4.6 Expected changes

In a final open question, the experts were asked on changes they expect from their (subjective) viewpoints. The relatively broad answers could be grouped into the following themes: (i) *New legislation and its implications*, (ii) *technological advances and digitalization* and (iii) "*far-shoring", re-industrialization and COVID-19*.

New legislation and its implications. Changes in legislation change the environment in which companies operate and forces them to adapt and post-consumer textiles are a new priority topic of the EU. However, until 2008, textiles were not part of the European waste legislation and only became defined as mixed solid waste in 2018. Then, separate collection and preparation for reuse followed. Thus, textile are a relatively new development and once it is communicated more, also the costumer's awareness may increase on this issue (Fiber Expert TU Wien, personal communication, April 29, 2020). According to the Austrian experts, the introduction of recycling targets will trigger a technological leap in fiber recycling to achieve these targets. The current practice can mostly be described as downcycling to products of lower value, whereas the real goal should be to obtain new fibers to produce items of similar value as the original one. Thus, the Austrian experts expect intensified collaboration between recyclers and producers, as it happened in the plastic sector. (Austrian National Experts, personal communication, April 28, 2020). The technical experts confirm that changes are already taking place in the recycling sector. The main challenge lies in production (due the long and international value chain). This is why the International Solid Waste Association (ISWA) has launched activities to bring together textile producers and recyclers in one conference. Only their dialogue can ensure design for recycling, according to the expert (Fiber Expert TU Wien, personal communication, April 29, 2020).

Technological advances and digitalization. One of the major game-changers is most likely technology. Technology may allow to track the international production and shipment of clothes in the near future. Besides this potential, technological advances are needed to advance recycling technology as well. Today, many practices are still based on

manual labor, like sensing fabric differences in end-of-life textiles, for example. If technology can determine the kind of fabric, many jobs would be affected–but also new opportunities created by the disruption (International Business Expert, personal communication, April 7, 2020). Since most EPR systems created 10-20 years ago and correspond to that state of technology, digital innovation may allow establishing individual EPR in the future. Still at the distant horizon, but EPR systems could potentially become more individual and allocate costs more specifically to certain producers in the future. The option of individual systems was traditionally often ruled out due to the cost benefits of the collective approach. Digital innovation, however, may allow to compensate for the costs too. Examples of technology under debate involve digital tagging and other methods than can "attach" information to a product. Another technological advances may include automatic sorting systems or artificial intelligence (OECD Officials, personal communication, May 5, 2020). From a technical perspective, changes in both recycling and design are expected, but yet primarily design should be oriented towards recycling. Only textiles of decreased complexity can be recycled which stand in sharp contrast to the current trend of increasing textile complexity. This must be reversed. However, research and development is still needed, in particular to transfer methods them from the lab to the industrial scale (Textile Expert Industry, personal communication, April 30, 2020). An EU collection quota for textiles is very likely to multiply the volumes of non-reuse textiles considerably which also increases disposal costs. This highlights the need for proper recycling systems and plants and an EPR system could be very beneficial in covering these additional costs (Fiber Expert TU Wien, personal communication, April 29, 2020).

On a bit more skeptical stance, a technical expert highlights that technological changes are only one dimension in the issue. First, technical restraints and second, positive side-effects of manual labor occur. Restraints to technology exist even in state-of-the-art sorting facilities like the one in Malmö, Sweden. At this stage, no machine can replace the assessment if a clothing item is fit for re-use in Europe, Asia or Africa, if there are holes or missing buttons. Also, if the rest is sorted into fractions, recycling processes need to exist for every fraction. The kind of separation is crucial since sorting according to colors with the use of optical sensors, is pointless when different materials occur in that fraction. Quite contrary, in the sorting process, the expert underscores the potential of manual labor: "A real success story is from Vorarlberg where the sorting is conducted by

long-term unemployed people. A similar system is in place in Carinthia. Sorting takes place in the county and these schemes of small initiatives have very high rates of 70-80% of bringing people back into the job market. This is achieved by simply giving them a daily routine and responsibility. Those are the last full-time sorting plants in Austria and their success is also determined by the social aspect: People know that they will find the pieces they donate in the local shop. And Vorarlberg has also the highest separate collection rate of textiles in Austria" (Fiber Expert TU Wien, personal communication, April 29, 2020). In fact, the last statement is confirmed in Wagner (2017) who reports that 7,75 kg/inhabitant of used clothing are annually collected in Vorarlberg, while 2,05 and 0,59 kg/inhabitant are collected in Vienna and Salzburg, respectively. The technical expert could also envision a uniform container system in Vienna that could potentially lower confusion among the citizens and enable them to better dispose of used textiles– thereby increasing the overall collection rate. However, in this context, close coordination with the charity organization would be necessary (Fiber Expert TU Wien, personal communication, April 29, 2020).

"Far shoring", re-industrialization and COVID-19. According to the business expert, the current corona crises exposed the complex supply chains and the insecurity that result from "far-shoring" or "off-shoring" of industry. Due to the corona crisis, a major slump is expected in the sector which may promote "near shoring" in the near future. This means that production may move closer to Europe again. For Fast Fashion, this is actually already partially the case. Inditex reports that more than 50% of their production occurs in countries in or near Europe, such as Turkey, Portugal or Spain, for example. This relatively short distance, in comparison to Asia, allows faster shipment and makes the Fast Fashion business model even more successful. However, with regards to environmental initiatives, a technological dimension often occurs as well: new technologies may allow new fibers and opportunities for innovative companies or fiber producers. Actually, environmental and economic change may present innovative opportunities for European and Austrian companies (International Business Expert, personal communication, April 7, 2020). COVID-19 made evident that the activation of still existing networks in Austria was possible. Not only Lenzing and Palmers joint forces to produce face masks with their newly founded company, but also small tailors started selling face masks. To the textile expert, this is another proof for the purchasing power of consumers, since the market will provide when demand emerges (Textile Expert

Industry, personal communication, April 30, 2020). But demand also emerged for low-price clothing items. Throughout the corona shut down, the Viennese secondhand store Tandler received many requests when they would re-open again, simply due to the fact that people had lost their jobs. The same experience was made at the charity Volkshilfe. In addition, many employees at charity organizations belong to vulnerable groups in society: long-term unemployed people with pre-existing conditions (Waste Prevention Expert; City of Vienna, personal communication, April 23, 2020).

5. Summary & Conclusion

While the global fiber production is estimated around 100 million tons per year, about 73% percent of all textiles are still incinerated or landfilled. This presents a tremendous resource loss and damage to the environment and could be prevented by circular economy approaches. Triggered by the evidence on the environmental impact and by tragic incidents exposing the poor social standards, the European Commission has been shaping a policy response, a "textile strategy", to the shortcomings of the textile industry. One instrument that is under debate to achieve these political goals is Extended Producer Responsibility–EPR. This policy aims at shifting organizational and financial responsibility from the public, to the producers that put products on the market. This instrument proved especially beneficial in the management of municipal waste; the waste household textile is assigned to. Besides policy makers and authorities, stakeholders in the design of a textile strategy reflect the inherently international value chain of textiles: from raw material extraction, to producers, retailers, consumers, the reuse/repair sector, waste management providers and recyclers. A special stakeholder in European countries, such as Austria, are charity organizations that provide infrastructure and expertise in the collection of used clothing. In order to estimate how textile circularity could potentially increase, an analysis of textile waste streams along the waste hierarchy was conducted, before EPR approaches and instruments were analyzed in detail. A summary of the main findings is depicted in the following part of this chapter, followed by a final conclusion.

Prevention. Waste prevention should be the uttermost priority and respective programs specific to textiles will be extended by the EU in the near future. Current trends describe decreases in both clothing lifetime and quality–thereby compromising waste prevention. One approach to counteract is textile rental. Rental systems exist for private clothing as well as for textile-intensive sectors, such as gastronomy, health care or the hotel industry. In this study, a Viennese industrial textile rental service was analyzed in more detail. Generally, rental services proof beneficial in keeping textile products in the usage phase and prevent them from entering the post-consumer, waste phase. Although new forms of textile rental services exist, in particular online, the concept is not modern. Textile rental services –independent from private or professional purposes– rely generally on high-quality fabric that can endure cyclical cleaning and laundry procedures. Thus, the sector offers expertise and experience on maintaining a high degree of waste prevention.

Reuse. Textile re-use is not a novel concept either, but where the reuse occurs geographically depends on individual market demands. High-quality or design items can achieve the highest prices and still have a market in Europe. Accordingly, this high-quality fraction receives most attention, yet accounts to merely 5-10% of the total used clothing volume. Secondhand products of lower local demand are the majority and mainly sold on African or Asian markets. Here, it is critical not to repeat mistakes made in WEEE or packaging and to ensure and monitor the export of intact products, not waste. Fast Fashion is another important factor in reuse: Not only because it is very likely to contribute to rising number in clothing wastes, from an economic perspective, it also presents a substitute product for relatively cheap second-hand products. In other words, Fast Fashion may compromise the demand for secondhand clothing–thereby depressing textile re-use. In addition, maintaining secondhand fashion for sale in EU member states is important since many people with low financial capabilities still rely on it. To reach a wider audience, reuse requires efforts, such as marketing. Role models for Austria in this regard could be the Belgian region of Flanders that has a pioneering role in reuse.

Recycling. Although textile recycling is still in its infancy, "re-inventing the wheel" is not necessary: promising methods based on mechanical, physical and chemical processes exist that offer innovation potential. In order to meet potential recycling targets by EU legislation, emphasis should be put on the most promising materials with regards to recycling that also occur in high quantities. Products such as bed sheets, towels or other products with simple shapes and composition are promising in this regard. These "low-hanging" fruits will be substantial in meeting ambitious recycling targets. However, further research and methodical development will be crucial in the transition from the lab to the industry scale. Other products with recycling potential include workwear and simple clothing items such as t-shirts. Covering about 60-75% of all textiles produced worldwide, clothing and its waste constitute the group identified most difficult to recycle. A textile group that is often overlooked concerns industrial and technical textiles. These highly specialized products would require specific recycling options, but depending on the respective quantity, this might be economic. More research and data are needed to explore the recycling potential of this product group.

Incineration and final disposal. This lowest part of the waste hierarchy that should be avoided by the before-mentioned means, presents actually the most common management

option for end-of-life textiles. According to estimates, 73% of all textiles produced globally are incinerated or landfilled. Both practices can release pollutant that were incorporated in the textile product during production or usage. This environmental damage and waste of resources could be improved by circular economy approaches and the ban and substitution of hazardous chemicals.

EPR instruments. The results of this study show that EPR has the potential to be an effective tool for the textile waste stream, in particular to end-of life consumer clothes. These fall under municipal waste and EPR is primarily designed for municipal waste. Every EPR instrument comes with advantages and disadvantages in fulfilling a political goal. The EU has to decide which instruments will be applied, but to this end, product quality and design improvements with regards to durability and recyclability are confirmed. The main challenge will lie in overcoming collective action problems in the creation of design incentives. A recycling quota for textiles is also very likely, the precise target, however, unknown. Such a quota can be coupled with obligations on product take-back, similar to packaging, which has a great potential in creating demand for recycled textiles. Member states would determine the exact EPR approaches: monopolistic vs. collective approaches and whether existing infrastructures are incorporated. The effectiveness of each approach will also depend on the remaining policy mix. As highlighted by the OECD experts, an alternative to EPR could be product standards and norms to stop bad practices promptly. This may be applicable if hazardous substances and toxic chemicals are at stake. In this case, economic instruments (such as EPR) are often not effective enough to eliminate these substances from the market completely. Bans would make sense for specific hazardous materials or substances–potentially also in the light of microplastic emissions; a general ban of material mixes that are difficult to recycle is unlikely.

Overall, a combined approach of EPR instruments appears as the most effective option. For example, a system in which take-back is coupled with design via a minimum recycling content appears very potent in enhancing textile recycling: Input of primary virgin material would diminish while the demand for recycled textiles would rise. Moreover, design can be tuned to align with recycling capabilities and higher clothing durability in the light of waste prevention. Information improvements are still needed to inform both industry and consumers sufficiently and to allow oversight and monitoring.

For this transparency in the in the global textile value chain, action by the biggest corporations is key. PROs in a collective system can take over this information responsibility, for example. Regarding organizational responsibility, i.e. collection, coordination with existing infrastructures can enhance implementation and operation of a new EPR system. Here, France could show other EU countries important insights into the inclusion of existing structures into textile EPR scheme.

Expected changes. Changes in the textile industry may appear in the form of adaptation to policy (top down), but also according to the environmental momentum and rising consumer awareness (bottom up). The most significant changes are expected in technology. First, technological advances are needed to meet upcoming recycling targets and second, technology and digitalization have the potential to increase traceability and transparency in the value chain and may allow more specified policy approaches in the future (e.g. fee modulation). However, the need to identify where technological change is most suitable still exists. This is highlighted by positive side effects of manual labor and charity practices. The current COVID-19 pandemic exposed the vulnerability of both our economic and social system in the textile context. Together with local innovation, this awareness may lead to increased "near-shoring" in the future, according to the experts.

In conclusion, this study analyzed and discussed textile waste streams along the waste hierarchy, followed by analysis of EPR schemes for their potential to increase textile circularity in the European Union and in Austria. To meet potential recycling targets under the EU textile strategy, priority products for recycling were identified qualitatively in terms of their recycling potential and possible impact (Flat white textiles made of one or two materials maximum > workwear and other single-layer clothing > other clothing types > highly specialized materials with specific properties). Despite forming 25% of textile market in the EU, little information is available on technical and industrial textiles and their recycling potential. Further studies should explore this sector to reach findings beyond the common "consumer perspective" which deals with clothing primarily. Representing the majority of textile products, the importance of clothing should not be neglected, however. Here, the prime task should address design and aim for synergies between three points: (i) waste prevention (durability), (ii) recyclability and (iii) stimulating demand for recycled textiles. Overall, the findings of this study suggest that

a mix of EPR instruments is very promising in which emphasis is put on design, coupled with product take back. The prerequisites for this combined approach are that producers have incentives to change design, material streams of collected goods are regulated and monitored, recycling technically possible and that financial flows (e.g. fees for dedicated purposes) are created. Besides this, the instrument combination would require transparency as well as research and progress from both ends, product design and recycling technology, but has the clear potential to increase textile circularity in the European Union. France with their existing EPR scheme for textiles as well as the Netherlands or Sweden in the preparatory phase could offer important orientation for other EU member states. Further research is needed to gauge the qualitative outcomes of this study with quantitative data on global and local scales.

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