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critical aspects in design for fiber-to-fiber recycling of textiles

by
Maria Elander and Hanna Ljungkvist

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Author: Maria Elander (IVL Swedish Environmental Research Institute) and Hanna Ljungkvist (IVL Swedish Environmental Research Institute)
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IVL Swedish Environmental Research Institute Ltd.,
P.O Box 210 60, S-100 31 Stockholm, Sweden
Phone: +46-(0)10-7886500 Fax: +46-(0)10-5886590

www.ivl.se

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MISTRA
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foreword

As a part of Mistra Future Fashion Phase 2, IVL Swedish Environment Institute (IVL) has identified and assessed critical aspects for fiber-to-fiber recycling of textiles. Data was collected in expert interviews with textile producers (fashion industry) and waste management companies (textile sorting companies and textile recyclers). On behalf of Mistra Future Fashion IVL would like to thank all companies and organizations that have contributed with input to our work. Thank you for your interest and participation! Without you, our work would not have been possible.

Stockholm, March 31st 2016

Maria Elander

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summary

As a part of Mistra Future Fashion Phase 2 critical aspects for increased fiber-to-fiber recycling of textiles were identified from stakeholders' perspectives. The aspects were identified through in-depth interviews with representatives from fashion companies, textile sorters and textile recyclers. The identified aspects were subsequently categorized, grouped and ranked. Differences in perspectives between different stakeholder groups were highlighted. The critical aspects' impacts on the stakeholder groups were outlined as were the possibilities of the stakeholder groups to influence the critical aspects. The identified aspects were clustered as to their main influence on the value chain regarding textile waste entering the recycling process, the recycling process itself or the recycled textile fibers leaving the recycling process.

The interviewed stakeholders from fashion companies, textile sorters and textile recyclers generally stressed the importance of investigating barriers to fiber-to-fiber recycling. The current situation does in their view not offer possibilities to handle used textiles in an economic and resource efficient manner. In total, the stakeholders identified 43 critical aspects for increased fiber-to-fiber recycling of textiles. These aspects were grouped into 16 subgroups in four main categories of aspects: Material input to recycling, Markets, Technology and Information. The stakeholders were asked to rank the identified aspects as having high, medium, small or no (little) impact on fiber-to-fiber recycling of textiles. Based on all answers, the aspects from the following subgroups were on average rated to have medium to high impact:

- Use of mixed textile fibers in textile products
- Presence of non-textile materials in textile products
- Quality of textile fibers for recycling
- (Lack of) economic viability of textile sorting and recycling
- Market prices for (recycled) textile fibers
- Trade barriers for textile waste
- Availability of textile recycling technology
- (Lack of) information regarding content in textiles for recycling
- (Lack of) guidance on ownership of used textiles / textile wastes

On average, the aspects in the categories Material input, Markets and Technology were ranked as having the same impacts on fiber-to-fiber recycling of textiles by the stakeholders. The aspects in the category Information were ranked to have a slightly higher impact. However, in addition to and independent of the ranking, the stakeholders were asked to mention the most and second most important aspect for increased fiber-to-fiber recycling of textiles. In doing so, the respondents primarily stress aspects related to markets and technology.

The identified aspects for increased fiber-to-fiber recycling of textiles address the textile waste entering the recycling process (input material to recycling), the recycling process itself and the recycled textile fibers leaving the recycling process (output material from recycling). The aspects impact fashion companies, sorters and recyclers differently. The stakeholder groups also have different possibilities of influencing these aspects. Recyclers form the stakeholder group that is affected by

most aspects whereas the fashion companies are the stakeholder group able to influence most aspects.

Stakeholders rank the impacts of the critical aspects for fiber-to-fiber recycling of textiles differently. Sorters rank market related aspects the highest, whereas recyclers rank aspects regarding material input the highest and fashion companies rank technology related aspects the highest. In general the stakeholders rank critical aspects connected to their own core businesses high. However, the differences in the ranking of individual aspects indicate that each stakeholder group sees the responsibility (or ability) to overcome the main obstacles for increased fiber-to-fiber recycling of textiles in other parts of the textile value chain. This, in turn, indicates strong dependencies and interconnections along the value chain, where e.g. fashion companies are depending on high quality recycled materials, recyclers are depending on clean and well sorted input fractions and sorters are depending on existing re-use and recycling markets for their materials. There is a clear need for increased coordination and exchange of information across the textile value chain. This could help stakeholders to focus on their contribution for creating more circular textile value chains, rather than focusing only on their current core business.

Increased fiber-to-fiber textile recycling must not be reduced to a waste problem. The challenge of increasing fiber-to-fiber of textiles cannot be met by a single stakeholder group or on a single place in the textile value chain. On the contrary, a holistic perspective must be used in terms of textile products entering and textile wastes circulating in the value chain. The whole value chain must be included when introducing policy measures with the objective to increase fiber-to-fiber recycling of textiles. When introducing policy measures identified knowledge and communication gaps as well as tradeoffs between design for durability and design for recyclability should be considered.

The identified critical factors for increased fiber-to-fiber recycling will serve as important background information for the subsequent Task 4.3.7 in Mistra Future Fashion Phase 2. Task 4.3.7 includes identification of a selection of policy measures promoting both reuse and fiber-to-fiber recycling of textiles. Two policy measures (or combinations of policy measures) will be selected for impact assessment with regard to Sweden and the Swedish fashion industry.

1 introduction

1.1 background

121 000 tons new clothes and household textiles were put on the Swedish market in 2013. Annually about 30 000 tons of textiles are separately collected in Sweden, of which only 4 000-6 000 tons are recycled after sorting abroad (Elander et al., 2014; Palm et al., 2014). This corresponds to a recycling rate of only 3-5 percent. With current quality of separately collected textiles, on average 5-10 percent of the textiles can be sold for reuse in Europe and additional 40-45 percent on other markets. After separation of textiles for reuse, about 80 percent of the remaining textiles, corresponding to 40 percent of the total collected textiles, are suitable for recycling. The rest, around 10 percent of the collected materials, is discarded due to poor quality or as non-textile waste (Rosinski, 2016b).

Figure 1 indicates the significant potentials in increasing both reuse and recycling of used textiles originating from Swedish consumption. Incineration is currently the most common waste management treatment, reflecting the predominantly linear textile value chains. The creation of more sustainable and circular value chains requires more and better (higher quality) textile recycling options.

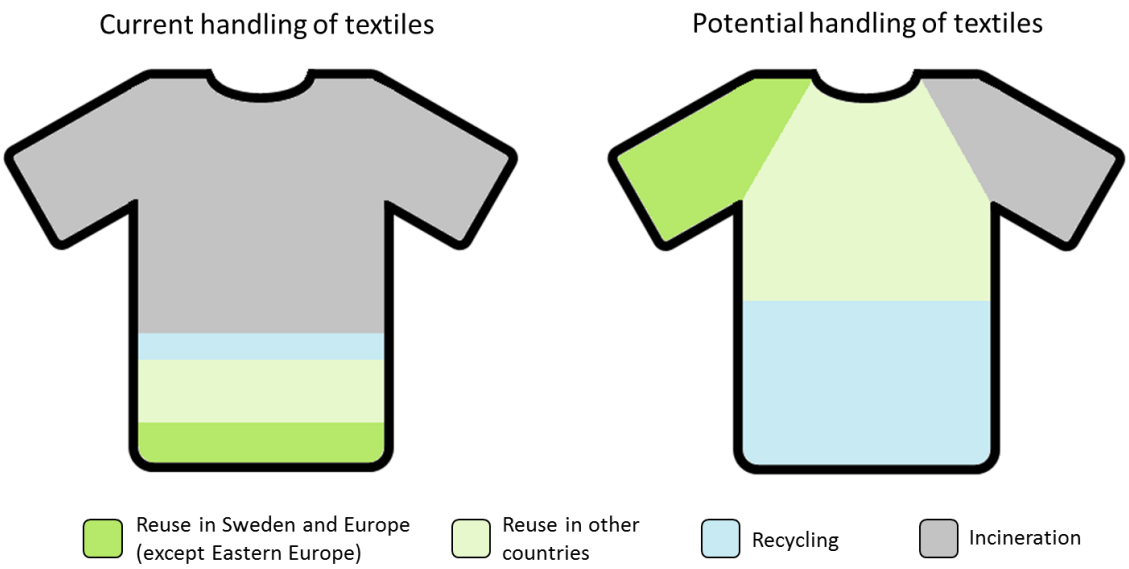

Figure 1
Comparison of current handling of textiles in Sweden compared to potential handling, reflecting current qualities of separately collected textiles (based on Elander et al., 2014; Rosinski, 2016b).

1.2 objective

The quality and recyclability of used textiles depend on a variety of different factors. In turn, this influences the subsequent recycling processes and potential applications of

recycled textile fibers. The objective of this report is to identify critical aspects for fiber-to-fiber recycling from stakeholders' perspectives and assesses them from a policy perspective.

The report documents the work carried out in Task 4.3.6 in Mistra Future Fashion Phase 2. The identified critical factors for increased fiber-to-fiber recycling will serve as important input for the subsequent Task 4.3.7, where two policy measures for increased reuse and recycling of textiles will be selected for impact assessment.

1.3 scope

Critical aspects for fiber-to-fiber recycling of textiles were identified from stakeholders' perspectives. Stakeholders included in the study were fashion companies, companies and organizations engaged in textile sorting (including companies and organizations that are engaged in both collection and sorting) and textile recycling companies. Consumers, located between fashion companies and waste management companies in the textile value chain, were excluded from the scope of the study.

The goals of Mistra Future Fashion Phase 2 relate to Swedish businesses and the Swedish fashion industry. Therefore, regarding stakeholders from the fashion industry, only Swedish fashion companies were included in the study. However, the market for sorting and recycling of textile waste is not limited to Sweden. On the contrary, no large scale textile sorting and recycling exist in Sweden. Separately collected textiles that are not reused in Sweden are generally exported for sorting, reuse and recycling within the EU. Therefore both Swedish and other European companies and organizations engaged in sorting and recycling of textiles were included in the study.

The scope of this study was limited to identification and assessment of critical aspects for fiber-to-fiber recycling of textiles, as opposed to the subsequent Task 4.3.7 that will include policy measures promoting both reuse and fiber-to-fiber recycling of textiles.

The scope of the study did not include description of different techniques and processes for textile recycling.

2 setting the scene: textile recycling of today

This study does not include mapping and description of different techniques and processes for textile recycling. However, as an introduction to the following sections, focusing on critical aspects for fiber-to-fiber recycling of textiles, this section provides a general overview and gives examples of current textile recycling techniques.

2.1 the challenges of linear value chains and quality

Textile recycling today is dominated by the use of textile fibers to produce lower grade products (down-cycling), such as cleaning rags and insulation. Mechanical fiber-to-fiber recycling of e.g. wool, acrylic and cotton, where the recycled textile fibers are used in the fashion industry, also occurs in small scale. The process, however, tends to lower the quality of the fibers (Östlund et al., 2015). Recycled textile wastes are often used for applications with linear value chains unable or unsuitable to recirculate the textile fibers multiple times. In order to achieve more circular use and economy of textiles an increased share of recycling allowing for multiple use of the textile fibers would be necessary.

Textile recycling used to be common in Europe, but has to a large extent moved to countries with lower labor costs like India, China, Pakistan and Bangladesh (Boer Groep, 2014; Östlund et al., 2015). Some mechanical recycling operations are available in Europe today, for example in Italy, England, Germany and Poland (Bes, 2016; Doertenbach, 2016; Rosinski, 2016a).

2.2 existent textile recycling techniques

The following two sections give examples of different mechanical and chemical recycling techniques for textiles that are available today.

2.2.1 mechanical recycling

Table 1 lists examples of existing mechanical recycling methods for different textiles with the main process steps and end products respectively (Boer Groep, 2014; Östlund et al., 2015). E.g. the absence of current mechanical recycling techniques for polyester blends constitutes a large challenge for increased textile recycling (Östlund et al., 2015).

Table 1 Existing mechanical recycling methods for textiles (Boer Group, 2014; Östlund et al., 2015)

Input to recycling (textile type)	Main steps in recycling	Output from recycling (end product)
Weaved textile with wool	Shredding and pressing	Felt for mattresses and carpet underlays
Broken jeans material	Removal of zippers, buttons etc., pressing with resin	Insulation for cars, washing machines etc.
Colored or white textiles, >70 percent cotton	Cutting to the right size, packing	Colored or white wipers for car- and shipping industry
Terry towel textiles	Cutting to the right size, packing	Water absorbing wipers
Production waste* and post-consumer waste of cotton	Shredding, carding, spinning as mix with virgin fibers (~40 percent material loss) (fiber-to-fiber recycling)	Cotton yarn
Knitted pullovers, >70 percent wool or mix of wool/acrylic	Sorting by color, soaking in water, tearing, drying, spinning (fiber-to-fiber recycling)	Wool yarn or wool/acrylic yarn

* Waste from combing, spinning- and knitting processes.

2.2.2 chemical recycling

Chemical fiber-to-fiber recycling of textiles does exist; however in limited scale and generally not for mixes generally not for mixes of natural and synthetic fibers, mainly due to the differences in the fiber the fiber regeneration processes (dissolution versus melting) (Östlund et al., 2015). The Japanese Teijin-Japanese Teijin-process, which is able to handle mixes of 80 percent polyester and 20 percent cotton, 20 percent cotton, forms an exception. This process is however very sensitive, and only uses Teijin uses Teijin products as input. The existing chemical recycling processes are summarized in

Table 2 below. Processes that are not yet commercial (pilot scale) are listed in *italic*.

Table 2 Overview of existing chemical fiber-to-fiber recycling methods. Pilot scale processes are marked in *italic*.

Input to recycling (textile type)	Main steps in recycling	Output from recycling (end product)	Actors
Pure polyester or polyester/cotton blends (max 20 percent cotton)	De-polymerisation to monomer, polymerisation, meltspinning	Polyester fibers	Teijin, Japan
Polyamide 6 from used textiles and fishnets	De-polymerisation to monomer, polymerisation	Polyamide 6 fibers 50 percent recycled/50 percent virgin e.g. for carpets	Hyosung, Korea Aquafil S.p.A, Italy
Cotton, viscose, lyocell (cellulose fibers) ***Pre- and post-consumer***	*Pre-processing, dissolution*	*Dissolving pulp for new cellulosic fibers*	*RE:newcell, Sweden* *Evrnu, USA*
Mainly cotton	*Pre-processing, dissolution, wet spinning*	*Cellulosic fibers*	*Reloopingfashion, Finland*

Due to lower fiber quality than virgin fibers, mechanical fiber-to-fiber recycling of textiles is regarded unlikely to achieve economic viability both in short and long term (Östlund, et al., 2015). Most processes for chemical fiber-to-fiber recycling of cotton are currently only available in lab scale whereas chemical recycling of polyester is carried out in full scale in Asia. Regarding polyester fibers existing chemical recycling processes are expected to increase and new chemical recycling processes are expected to be developed in lab scale by 2030 (Östlund, et al., 2015). Chemical recycling processes of cotton and cellulose based textile fibers are expected to be developed in full scale by 2030 (Östlund, et al., 2015).

3 stakeholders' views on critical aspects for fiber-to-fiber recycling

Fashion companies and textile sorters and recyclers were invited to provide their views on critical aspects in design for fiber-to-fiber recycling of textiles. The results of the interviews carried out are presented and discussed in this section.

3.1 interviewees from three stakeholder groups

In total 12 in-depth telephone interviews with experts were conducted during February and March 2016. This constitutes the majority of the approached organizations and companies, indicating a large interest among stakeholders.

The interviewees were selected from three stakeholder groups, defined by the actors' main role in the textile value chain: design and production of textile products (fashion companies), collection and sorting of textiles (sorters) and recycling of textiles (recyclers). The interviewees were selected both from the Mistra Future Fashion Phase 2 industry partners[1] and others in order to cover all stakeholder groups. An even distribution of interviewees in relation to the stakeholder groups was reached with four interviewees from each group. All interviewees possess expert knowledge in textile collection, sorting and recycling. The interviewed companies and organizations are listed in appendix 1. The questions used as base for the interviews are listed in appendix 2.

The answers to the questions as well as additional information were noted during the interviews and formed the basis for the analysis. Critical aspects for increased fiber-to-fiber recycling of textiles were identified both in the answers given to specific questions as well as in the additional information received. Most aspects were mentioned by several interviewees, i.e. several references were made to most aspects.

3.2 four main categories of aspects regarding textile recycling

In total 43 critical aspects for fiber-to-fiber recycling of textiles were mentioned by the interviewees. In the evaluation a reference to a certain aspect from one interviewee was registered as one reference independently on how many times the interviewee mentioned the particular aspect.

Some of the aspects are closely connected and could have been aggregated to more general aspects. To exemplify, use of mixed fiber types, presence of plastic prints, plastics, metals, spandex and inlays in textile products could have been aggregated to one common critical aspect "complexity of textile products". The objective was, however, to assess how particular aspects impact textile recycling. In the process of identifying different critical aspects for fiber-to-fiber recycling of textiles the higher level of detail was therefore retained.

[1] To learn more about Mistra Future Fashion industry partners, please visit www.mistrafuturefashion.com.

The critical aspects were divided into four main categories depending on their characteristics: Material input (to recycling), Markets, Technology and Information. The aspects identified in the interviews are presented according to these main categories in Sections 3.3-3.6.

An overview of all critical aspects is documented in appendix 3, including a short description of the aspects and indication of the total number of references to each aspect. The total number of references is in this respect equal to the total number of persons that have referred to a particular aspect since multiple references to one aspect from one interviewee was only counted as one reference.

3.3 aspects regarding material input to recycling

The study identified 15 critical aspects for fiber-to-fiber textile recycling relating to different aspects of the input material to recycling, i.e. textile waste that has been sorted out and sold for recycling.

Nine of the 15 aspects refer to design features in textile products that complicate sorting and recycling of textiles, e.g. use of mixed fibers and different fibers for lining and outer materials as well as presence of plastic prints, spandex, inlays, metals and plastics. Three of these are intimately connected to the production process, namely presence of chemicals and hazardous substances, presence of colors/dyes and to the use of threads in different materials than the fabric in the textile products.

Four out of the 15 aspects relate to insufficient volumes of textile waste available for recycling. Too small volumes of used textiles and textile waste are (separately) collected and, from the collected materials, too small volumes are sorted out for recycling. The latter may indicate a conflict of interest between textiles for reuse and textiles for recycling, where textiles that are sorted out for reuse are not available for recycling (reflecting the waste hierarchy). It may also indicate that not all collected textile waste is sorted with the objective to produce both textiles for reuse and recycling. Recyclers also identify lack of long-term contracts with material suppliers and varying quality of input textiles for recycling due to different sources and small volumes as critical factors.

Three critical aspects were mentioned by at least two thirds of the interviewees:

- Lack of textiles available for recycling due to insufficient collection
- Use of mixed fiber types in textile products
- Presence of chemicals and hazardous substances in textile products

Additional three critical aspects were mentioned by at least one third of the interviewees:

- Presence of metals, plastic etc. in textile products (e.g. zippers and buttons)
- Lack of textiles for recycling due to insufficient sorting for recycling
- Presence of dyes (in textiles for recycling and/or in recycled textile fibers)[2]

[2] Dyed textiles both include (to recyclers unknown) chemicals and might impact the color of the output material if not sorted out before entering the recycling process. The identified critical aspect includes both aspects.

In total the 12 interviewees made 55 references to the 15 critical aspects regarding input material to recycling. Figure 2 shows that primarily recyclers and fashion companies mentioned these aspects with 25 and 22 references respectively.

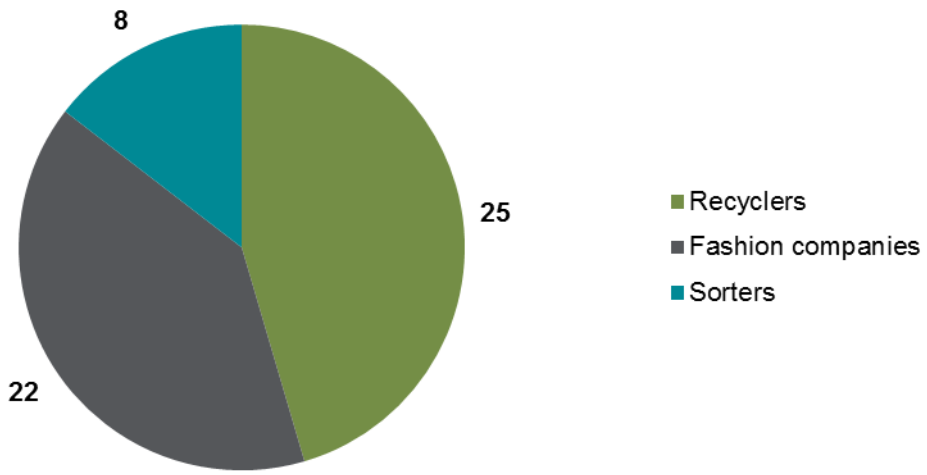

Figure 2 Distribution of references to critical aspects for textile recycling regarding material input to recycling between the stakeholder groups. In total 55 references were made.

The critical aspects mentioned most often by recyclers, sorters and fashion companies respectively reflected the aspects mentioned most often in total. This indicates an overall common understanding among the three stakeholder groups of the critical aspects for textile recycling regarding material input to recycling.

3.4 aspects regarding markets

The study identified 15 critical aspects for fiber-to-fiber textile recycling related to markets. Four of these aspects concern a lack of demand for recycled textiles. This includes both a lack of demand for recycled textile fibers from fashion industry, textile producers and retailers and, a lack of demand for textile products with recycled fibers from end consumers. The low demand is connected to low market prices for virgin textile fibers, which in turn influences market prices for recycled textile fibers.

Four of the 15 critical aspects reflect lacking economic viability of textile recycling, including sorting of textiles for recycling. Costs for the recycling processes are high as well as transport costs for textile waste. The latter is particularly relevant for textile waste collected in Sweden and other Nordic countries since it is exported for sorting and recycling abroad. Incentives for investment in textile recycling are missing.

Three critical aspects reflect limited supply of recycled fibers/ textiles with recycled content. These aspects were exclusively expressed by fashion companies and reflect the small market for recycled textile fibers available for production of new textile products and, for some fiber types, higher market prices for recycled fibers than virgin fibers. On the other hand, minimum order quantities of recycled fibers can be to too large for smaller companies (i.e. textile producers do not sell small quantities).

The definition of used textiles as waste is perceived to work as a trade barrier for recycling of textiles since the textiles then are subject to waste regulation which poses stricter requirements than if they were not classified as waste.

Four critical aspects were mentioned by at least half of the interviewees:

- Lack of demand for recycled textile fibers (from fashion industry, textile producers etc.)
- Lack of economic viability of textile sorting
- Lack of economic viability of textile recycling
- Lack of incentives for investments in textile recycling

In total the 12 interviewees made 55 references to the 15 critical aspects regarding markets.

markets.
Figure 3 shows that primarily sorters and fashion companies mentioned these aspects with 23 and 18 references respectively.

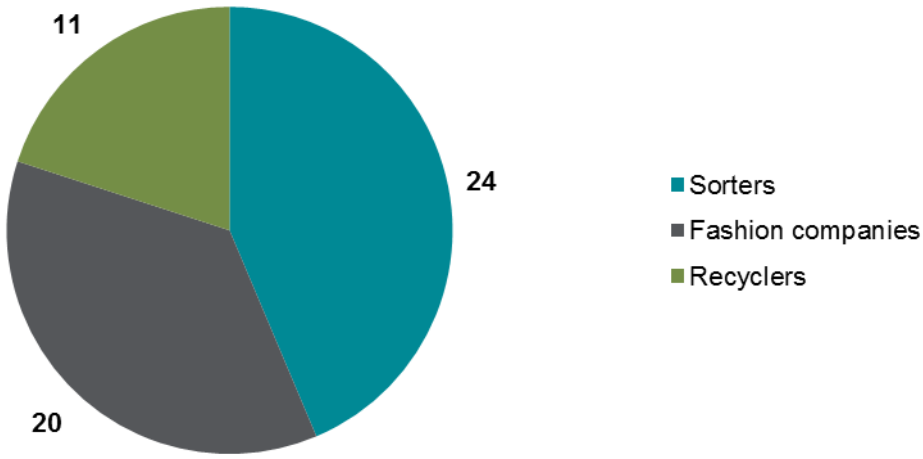

Figure 3 Distribution of references to critical aspects for textile recycling regarding markets between the stakeholder groups. In total 55 references were made.

The critical aspects mentioned most often by waste management companies (sorters and recyclers) reflected to a very high degree the aspects mentioned most often in total. The critical aspects mentioned most often by fashion companies, however, differed to some extent. Fashion companies were the only stakeholder group that mentioned aspects regarding lacking supply of recycled textile fibers. This reflects to a large degree the different roles of stakeholders in the value chain, with waste management companies (suppliers of recycled textile fibers) on one hand and fashion industry (buyers of recycled textile fibers) on the other.

3.5 aspects regarding technology

The study identified ten critical aspects for fiber-to-fiber textile recycling related to technology. Four of these relate to lack of recycling technologies, including chemical textile recycling as well as mechanical textile recycling, recycling technologies for mixed textile fibers and lack of investments in recycling technology.

Three of these ten aspects concern lack of sorting technologies in order to increase volumes sorted for recycling (sorting quantity) as well as fiber-type purity of textile waste sorted for recycling (sorting quality). Lack of investments in (automated) sorting technologies and scale up of such technologies was, as for recycling technologies, identified as one critical aspect.

Three aspects are linked to the quality of the recycled fibers and their use as raw materials in new textile products. They cover the need for blending recycled and virgin fibers to increase quality of the end product, material losses in mechanical fiber-to-fiber recycling and limitations as to what products can be produced from recycled fibers. These aspects were predominantly referenced to by fashion companies.

Five critical aspects were mentioned by at least half of the interviewees:

- Lack of chemical textile recycling technology
- Lack / limitations of mechanical textile recycling technology
- Lack of automated textile sorting to increase volumes of textiles for recycling
- Lack of automated textile sorting to increase purity (fiber type) of textiles for recycling
- Lack of investment in recycling technology

In total the 12 interviewees made 53 references to the 10 critical aspects regarding technology. Figure 4 shows a relatively even distribution of references between the stakeholder groups.

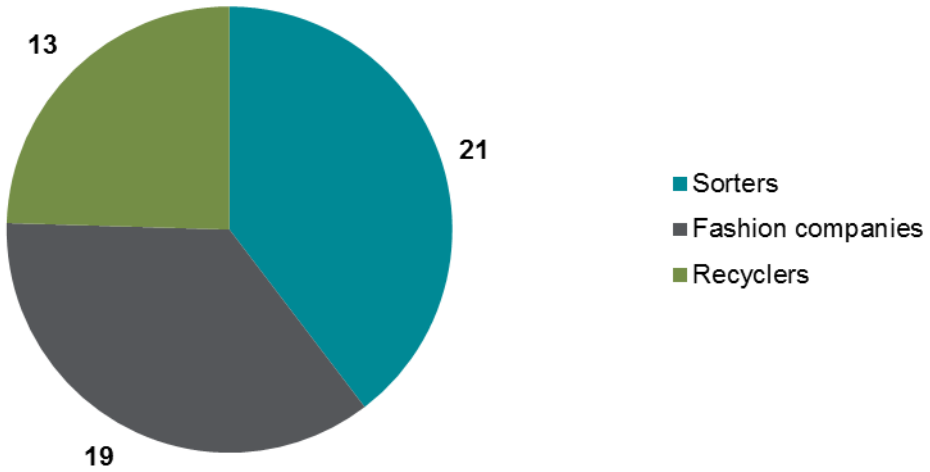

Figure 4 Distribution of references to critical aspects for textile recycling regarding technology between the stakeholder groups. In total 53 references were made.

The critical aspects mentioned most often by waste management companies (sorters, collectors and recyclers) reflected to a very high degree the aspects mentioned most often in total. The critical aspects mentioned most often by fashion companies, however, differed to some extent. Fashion companies made six of seven references to aspects linked to quality of the recycled fibers and their use as raw materials in new textile products. While referencing lack of recycling technologies slightly more often than waste management companies, they made much fewer references to lack of automated sorting technologies (only two of 19 references). This seems to reflect the fact that sorting constitutes pre-treatment of textile waste. Whereas sorting plays a central role for textile sorters and recyclers, fashion companies focus more on the output from final treatment of textile waste, i.e. the recycled textile fibers available for production of new textile products.

3.6 aspects regarding information

Three critical aspects for fiber-to-fiber textile recycling related to information were identified. Two of them concern lacking information regarding textile content, namely lack of information regarding chemicals and hazardous substances in textile products and insufficient (and sometimes false) labelling of textile products. The third aspect relates to the unclear ownership of used textiles / textile wastes.

Figure 5 shows that the references to aspects regarding information were dominated by textile sorters.

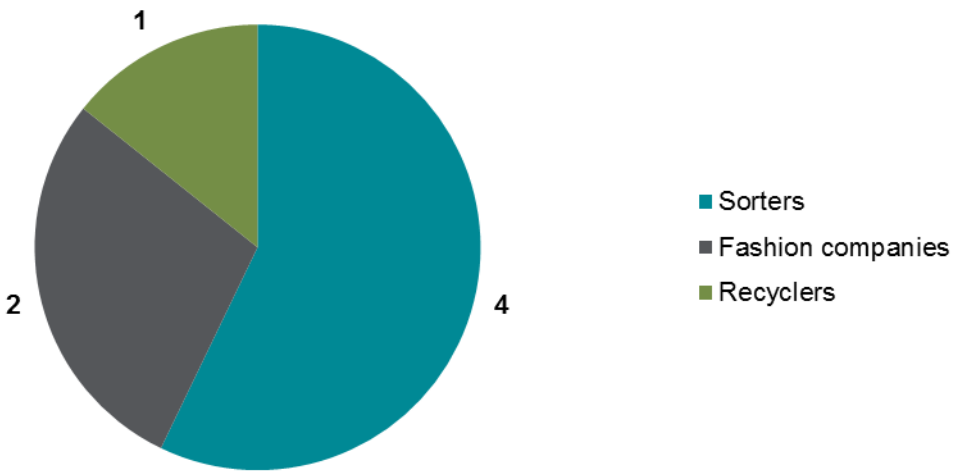

Figure 5 Distribution of references to critical aspects for textile recycling regarding information between the stakeholder groups. In total 7 references were made.

The lack of information regarding chemicals and hazardous substances influences both actors engaged in sorting, recycling and production of new textiles. The sorters lack information regarding which textiles they need to sort out in order to match recyclers' needs and produce textile fractions with homogenous quality and high quality and value. Recyclers lack information of chemicals in input materials to recycling. Potential presence of hazardous chemicals and unwanted substances in output fractions from recycling decrease the value of the recycled fibers and influence their outlet. The lack of

information regarding potential presence of hazardous chemicals and unwanted substances in recycled textiles fibers might deter fashion and textile companies from using recycled fibers in order for them to fulfil their quality standards.

Only three interviewees specifically mentioned lack of information regarding chemicals and hazardous substances in textile products. However, eight interviewees mentioned presence of chemicals and hazardous substances in textile products as a critical aspect for textile recycling regarding material input to recycling. This indicates uncertainties in how the interviewees phrased their answers and how they were interpreted in the evaluation of the interviews.

3.7 discussion

Section 3 primarily documents and presents the critical aspects for fiber-to-fiber recycling of textiles mentioned by the interviewees from fashion industry and waste management companies (sorters and recyclers). The number of references to different aspects and the number of critical aspects within each main category give first indications on stakeholders' views on relevant aspects for increased textile recycling. For a more quantified evaluation of which aspects stakeholders consider having the largest impacts on increased textile recycling a rating of all critical aspects was carried out. This is described in Section 4.

Interviewees have expressed the importance of investigating barriers to fiber-to-fiber recycling. The current situation does in their view not offer possibilities to handle used textiles in an economic and resource efficient manner. Even though textile recycling has received increased attention over the last years and there is a lot of ongoing research, the progress of scaling up solutions and bringing them to the market is perceived as too slow.

Of the total 43 critical aspects for textile recycling identified in the interviews 15 aspects concerned input material to recycling. 15 acritical aspects related to markets. 10 critical aspects were linked to technology. Finally, 3 critical aspects referred to issues of information. The distribution is shown in Figure 6.

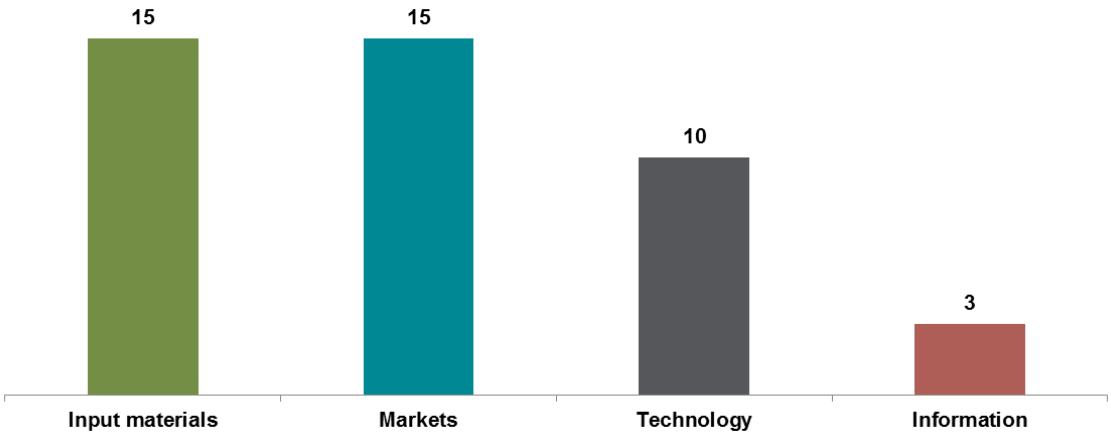

Figure 6 Distribution of the critical aspects for fiber-to-fiber recycling of textiles between the four main categories. In total 43 aspects were identified in the interviews.

In total 170 references were made to the 43 identified critical aspects for textile recycling, i.e. several stakeholders mentioned the same aspects. Figure 7 shows that the distribution of references to critical aspects differs slightly from the distribution of critical aspects for the main categories in Figure 6. In the category Technology, more references were made to each aspect. The average number of references to each aspect in the category Technology was five. This means that every aspect in this category on average was mentioned by five interviewees. On average every aspect in the categories Material input and Markets were mentioned by four interviewees and on average every aspect in the category Information was mentioned by two interviewees.

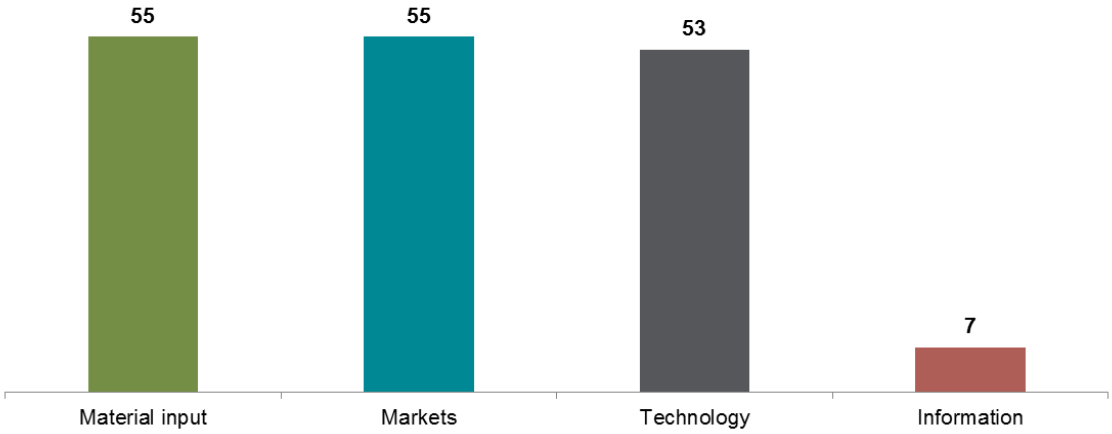

Figure 7 Distribution of references to critical aspects for fiber-to-fiber recycling of textiles between the four main categories. In total 170 references were made.

Figure 8 shows that the number of references was relatively evenly distributed between the three stakeholder groups (fashion companies, sorters and recyclers). No group stands out by making a significantly lower or higher number of references to the aspects. This indicates that all stakeholder groups have a high level of awareness of obstacles for increased recycling, even if they to some extent put different emphasis on what aspects they mention in the interviews.

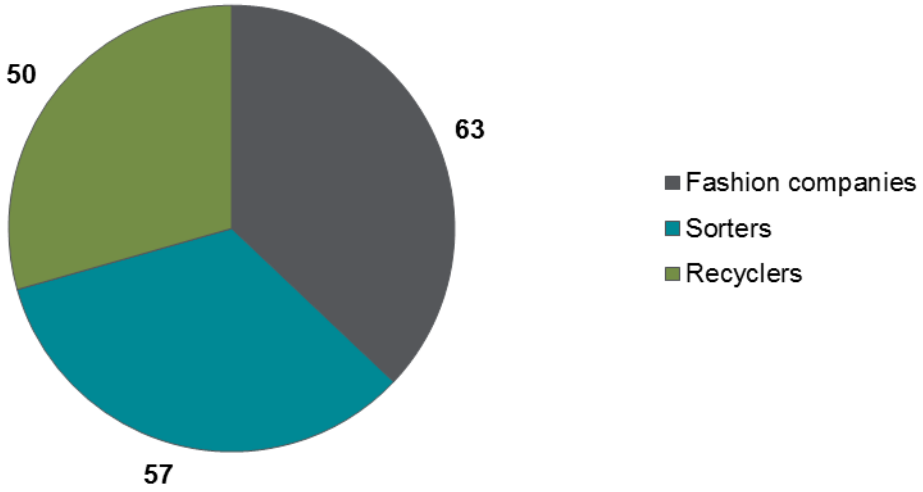

Figure 8 Distribution of references to critical aspects between the three stakeholder groups. In total 170 references were made.

4 the most relevant critical aspects for stakeholders

The interviews generated 43 critical aspects for fiber-to-fiber recycling of textiles (Section 3). The interviews were designed to identify aspects and to generate a wide collection of factors, not to rank them individually. The fact that interviewees mentioned particular aspects more than others often gave some indication of relevance and perceived impact on textile recycling. In order to assess the aspects in more detail, however, a better understanding of the most relevant critical aspects for stakeholders was necessary.

After the interviews, the interviewees were therefore invited to rank the aspects identified in the interviews. This provides insights to what critical aspects stakeholders perceive to have the largest impacts on textile recycling. It also pinpoints the need for action and indicates needs for potential policy measures for increased textile recycling. The results of this ranking is presented and discussed in this section.

4.1 methodology for rating

Respondents for the survey were all 12 stakeholders that had been interviewed. All respondents were asked to rate all identified aspects, i.e. stakeholders were asked to rank both aspects that they had and had not mentioned themselves. Ten of 12 respondents completed the rating.

The rating was carried out as an online survey using the Apsis Pro software (APSIS, 2016). In the survey, the critical aspects were grouped according to the main categories identified in Section 3. The individual order within each category did not reflect the number of references made to the aspects respectively. The respondents were asked to rate the impacts of the critical aspects on fiber-to-fiber recycling of textiles as no (little), small, medium or large respectively, see Figure 9. The respondents were also given the possibility not to specify the impacts of a specific critical aspect. After the rating of all identified aspects, the respondents were asked to state the most and the second most relevant critical aspect for increased fiber-to-fiber recycling of textiles.

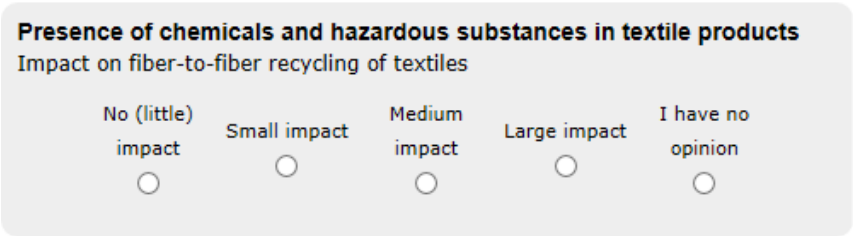

Figure 9 The interviewees were asked to estimate the impacts of the identified critical aspects from their perspectives respectively. This particular example refers to the presence of chemicals and hazardous substances in textile products.

The individual ratings in the survey were used for making a ranking of all critical aspects identified in the interviews. The rating of each aspect by each respondent was given a value according to the following:

- “No (little) impact”: 0
- “Small impact”: 1
- “Medium impact”: 2
- “Large impact”: 3

Answers indicating “I have no opinion” were not given any value, i.e. they were not included in the calculation of average score for the particular aspect.

The sum of all answers for each critical aspect was divided by the number of respondents that had rated that particular aspect (excluding the answer “I have no opinion”). This resulted in separate scores for each of the identified critical aspects for fiber-to-fiber recycling.

4.2 ranking of critical aspects in overview

Figure 10 gives a general overview over the ranking of the 43 aspects identified in the interviews. Maximum score is 3, corresponding to “large impact” on fiber-to-fiber recycling of textiles. For an aspect to get 3 as score, all respondents must have rated that particular aspect to have large impact on textile recycling. Minimum score is 0, corresponding to “no (little) impact” on textile recycling.

A complete overview of the scores and ranking is given in appendix 4.

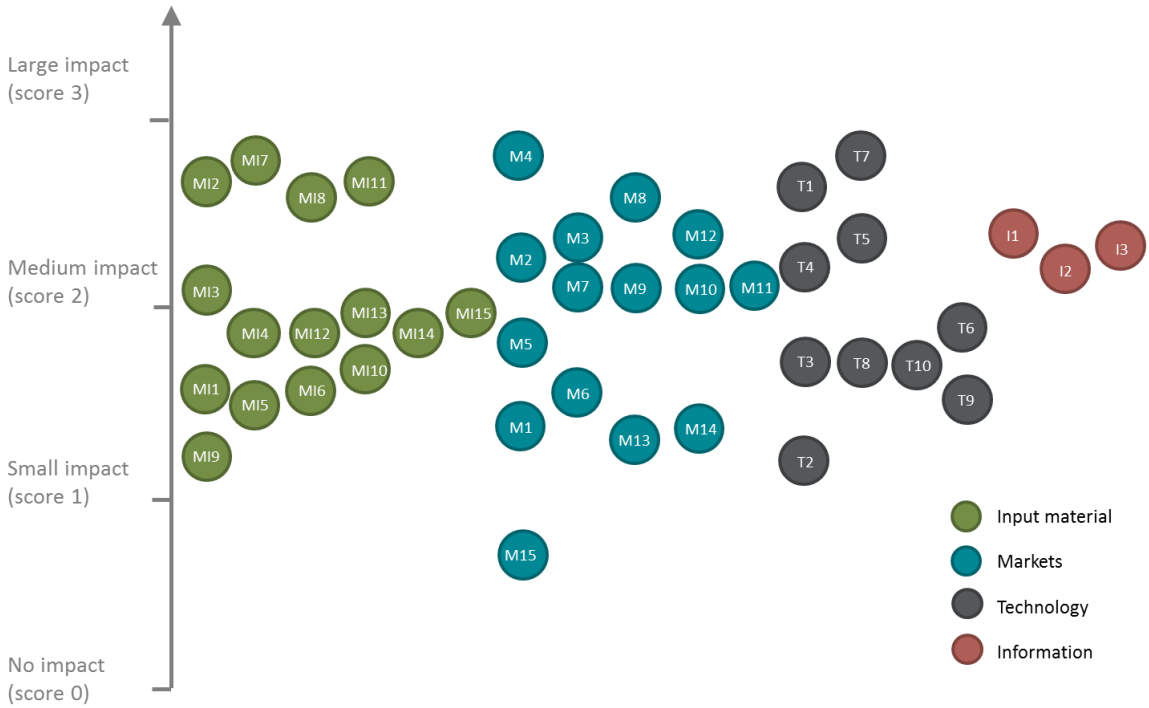

Figure 10 Overview of stakeholders' rating of critical aspects for fiber-to-fiber recycling of textiles. Maximum score is 3, corresponding to large impact on fiber-to-fiber recycling of textiles. The references (e.g. MI2, T2 etc.) indicate specific aspects listed in Table 5 in appendix 3.

Table 3 shows the eight aspects with the overall highest scores (all higher than 2.5).

Table 3 Stakeholders' Top 8 critical aspects for fiber-to-fiber recycling of textiles

Rank	Critical aspect	(Score)
1.	Lack of incentives for investments in textile recycling	(2.8)
2.	Lack of recycling technology for mixed fibers	(2.8)
3.	Presence of plastic prints on textile products	(2.8)
4.	Use of mixed fiber types in textile products	(2.7)
5.	Presence of spandex / lycra / elastane in textile products	(2.7)
6.	Lack of chemical textile recycling technology	(2.7)
7.	Low market prices for recycled textile fibers	(2.6)
8.	Purity of input textiles for recycling in terms of fiber type (e.g. cotton, wool etc.)	(2.6)

The Top 8 aspects reflects high scores for aspects from the category Material input as illustrated in Figure 11.

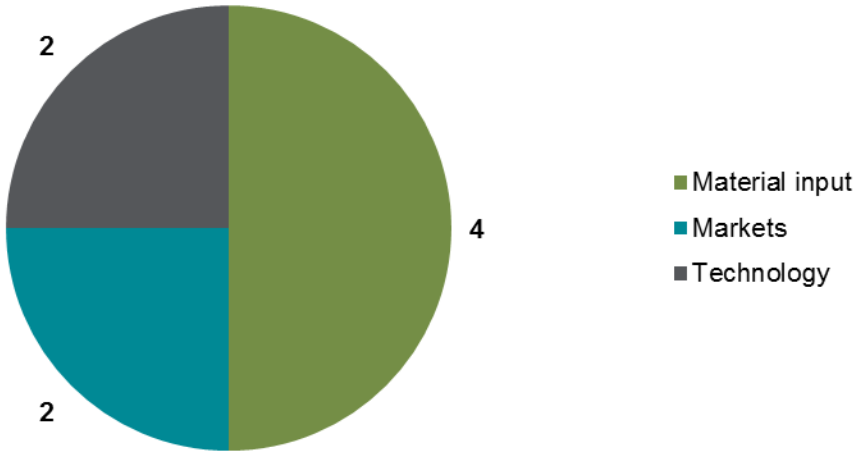

Figure 11 The Top 8 aspects with highest scores were dominated by aspects from the category Material input.

23 aspects were given average scores 2.0 or higher, representing medium to high impacts on fiber-to-fiber recycling of textiles, see appendix 4. A more detailed evaluation of the ranking according to main categories and stakeholder groups is presented in Sections 4.3-4.4

4.3 rating according to main category of critical aspects

Figure 12 shows the average scores (from all stakeholder groups) of the critical aspects within each of the main categories defined in Section 3. The figure shows a slightly higher average score for aspects from the category Information than for aspects from the other categories.

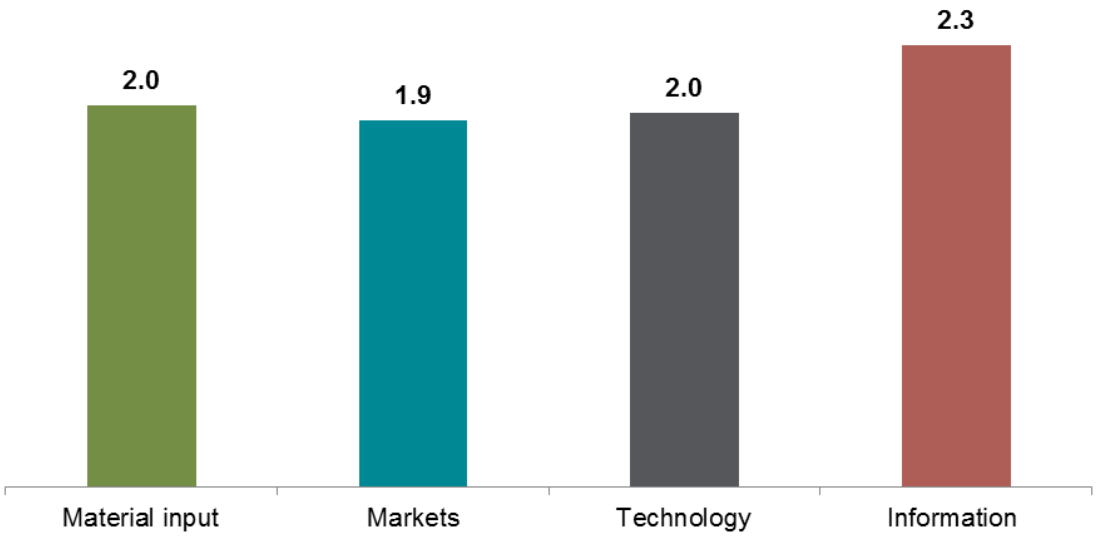

Figure 12 Overall average score of critical aspects for textile recycling within each main category.

Sections 4.3.1-4.3.4 present the overall average scores of the critical aspects within each category in more detail.

4.3.1 aspects regarding material input

The aspects with the highest scores in the category Material input were dominated by aspects regarding design of textile products. Five of seven aspects with average scores above 2.0, corresponding to medium to large impact, related to different design issues influencing the ability to recycle the textile products.

Of the 15 aspects in the category Material input seven aspects (47 percent) were rated as having medium to large impact (scores higher than two). Eight aspects (53 percent) were rated as having small to medium impact (scores between one and two).

The following aspects were rated as having medium to large impact on fiber-to-fiber recycling of textiles:

- Presence of plastic prints on textile products
- Presence of spandex / lycra / elastane in textile products
- Use of mixed fiber types in textile products
- Purity of input textiles for recycling in terms of fiber type (e.g. cotton, wool etc.)
- Presence of chemicals and hazardous substances in textile products
- Use of different lining and outer materials in textile products
- Varying quality of input textiles for recycling (e.g. due to different sources)

4.3.2 aspects regarding markets

The aspects with the highest scores in the category Markets were dominated by aspects concerning lacking economic viability for sorting and recycling of textiles and lacking demand for recycled textile fibers. Four of nine aspects with average scores above 2.0, corresponding to medium to large impact, related to economic viability.

Of the 15 aspects in the category Markets 9 aspects (60 percent) were rated as having medium to large impact (scores higher than two). Five aspects (33 percent) were rated as having small to medium impact (scores between one and two).

The following aspects were rated as having medium to large impact on fiber-to-fiber recycling of textiles:

- Lack of incentives for investments in textile recycling
- Low market prices for recycled textile fibers
- Import regulations for waste (trade barrier)
- Lack of economic viability of textile recycling
- Lack of economic viability of textile sorting
- Higher market prices for recycled fibers than virgin fibers (for certain fiber types and volumes)
- Low market prices for virgin textile fibers (primary raw materials)
- Lack of infrastructure for circular textile value chain (currently only small material flows)
- High transport costs (e.g. for Nordic textiles currently exported for sorting and recycling)

4.3.3 aspects regarding technology

The aspects with the highest scores in the category Technology were dominated by lack of recycling technology. Three of four aspects with average scores above 2.0, corresponding to medium to large impact, related to recycling technology.

Of the ten aspects in the category Technology four aspects (40 percent) were rated as having medium to large impact (scores higher than two). Six aspects (60 percent) were rated as having small to medium impact (scores between one and two).

The following aspects were rated as having medium to large impact on fiber-to-fiber recycling of textiles:

- Lack of recycling technology for mixed fibers
- Lack of chemical textile recycling technology
- Lack of investment in recycling technology
- Lack of automated textile sorting to increase purity (fiber type) of textiles for recycling

4.3.4 aspects regarding information

The aspects with the highest scores in the category Information were dominated by lacking information regarding content in the textiles for recycling. Two of three aspects concerned information regarding content.

All aspects in the category Information (100 percent) were rated as having medium to large impact (scores higher than two). These aspects were:

- Lack of information regarding chemicals and hazardous substances in textile products
- Insufficient (and sometimes false) labelling of textile products
- Unclear ownership of used textiles / textile wastes

4.4 rating according to stakeholder groups

Sections 4.4.1-4.4.3 present the average scores of the critical aspects from the perspectives of the three stakeholder groups defined in Section 3 respectively.

4.4.1 sorters

Figure 13 illustrates the average scores resulting from sorters' rating of critical aspects for textile recycling. In general sorters ranked aspects in the categories Material input and Technology lower than average and aspects in the category Markets higher than average.

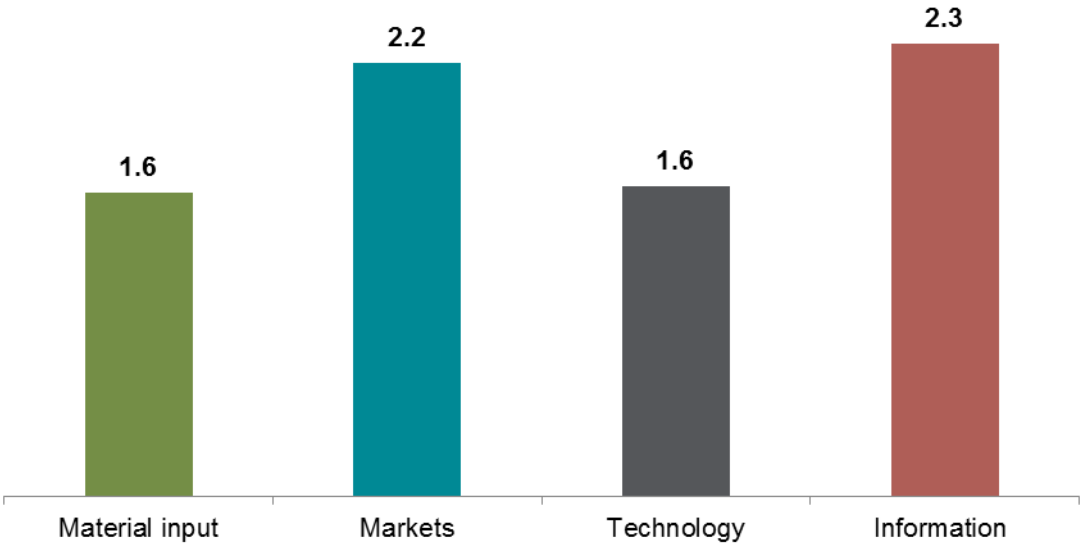

Figure 13 Average score of critical aspects for textile recycling within each main category from the sorters' perspective

The sorters ranked in total 15 aspects with maximum score 3.0, corresponding to high impact on fiber-to-fiber recycling of textiles. Aspects concerning lacking demand for recycled fibers, design features limiting the recyclability of textiles and lacking recycling technologies dominated these 15 aspects.

The sorters ranked 11 aspects with scores less than 1.0, corresponding to no (little) to small impact on textile recycling. Four of these aspects related to lack of volumes of textiles for recycling, i.e. sorters do not perceive lack of textiles available for recycling as a problem. The sorters did not regard presence of chemicals and hazardous substances in

textile products or varying quality of input textiles for recycling as a problem (both aspects with average scores 2.0 or higher, see section 4.3.1).

4.4.2 recyclers

Figure 14 illustrates the average scores resulting from recyclers' rating of critical aspects for textile recycling. In general recyclers ranked aspects concerning lacking technology lower than average.

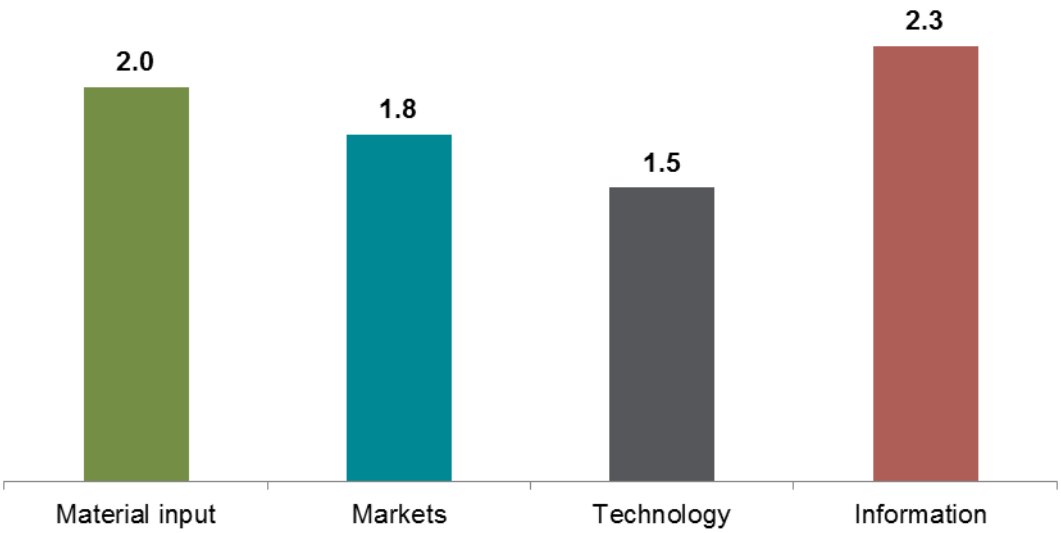

Figure 14 Average score of critical aspects for textile recycling within each main category from the recyclers' perspective

The recyclers ranked 20 aspects with the score 2.0 or higher, corresponding to medium to large impact on textile recycling. Of these aspects only two concerned lacking technology, namely lack of recycling technology for mixed fibers and lack of chemical textile recycling technology. Recyclers Top 20 included all aspects in the category Information and all aspects regarding economic viability of textile sorting and recycling in the category Markets.

The recyclers ranked only four aspects with scores 1.0 or lower, corresponding to no (little) to small impact on textile recycling. In their view, limitations to mechanical recycling do not impact overall textile recycling to a larger extent. Neither do they regard lack of available volumes of recycled textile fibers for production of new textile products as a problem.

4.4.3 fashion companies

Figure 15 illustrates the average scores resulting from fashion companies' rating of critical aspects for textile recycling. In general fashion companies ranked aspects in the category technology higher than average.

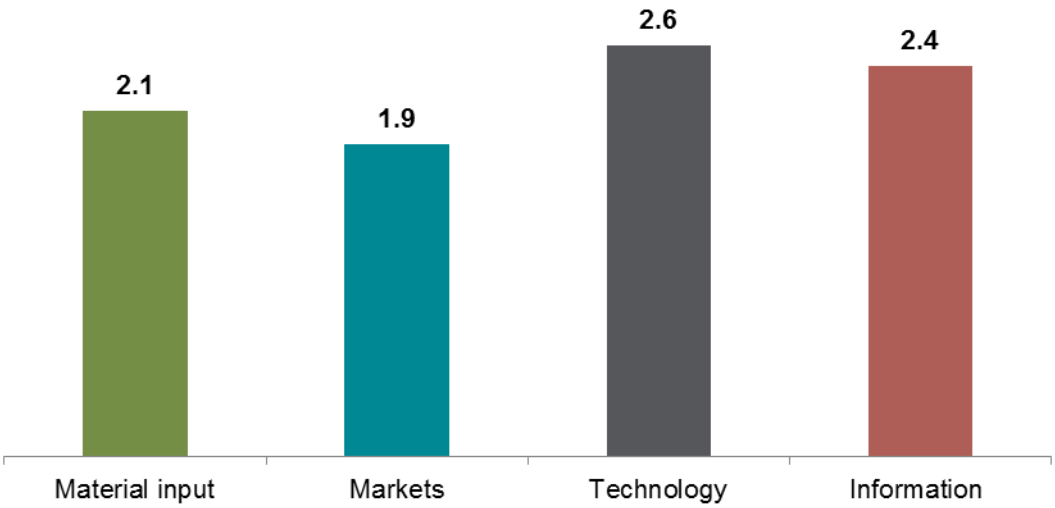

Figure 15 Average score of critical aspects for textile recycling within each main category from the fashion companies' perspective

The fashion companies ranked in total four aspects with maximum score 3.0, corresponding to high impact on fiber-to-fiber recycling of textiles. All of these aspects concerned lack of technology for recycling and automated sorting of textiles.

In total the fashion companies ranked 32 of the 43 aspects as having scores of 2.0 or higher, corresponding to medium to high impact on textile recycling. 15 aspects were given scores above 2.5. None of the fashion companies' Top 15 aspects referred to aspects in the category Information. The fashion companies ranked mechanical degrading of textile fibers (in use and recycling) as well as lack of textiles available for recycling due to insufficient collection considerably higher than sorters and recyclers. They also ranked lack of automated textile sorting and lack of investments to scale up such technologies considerably higher than sorters and recyclers.

The fashion companies only ranked one aspect with a score below 1.0, corresponding to small impact on textile recycling: they did not perceive lack of demand for recycled textile fibers as a problem.

4.5 respondents' views on most critical aspects

After having rated all 43 critical aspects for fiber-to-fiber recycling of textiles identified in the interviews the respondents of the survey were asked to state the most and second most important critical aspect for fiber-to-fiber recycling (open questions).

Of the total 20 answers, ten related to aspects in the category Markets. The respondents see an urgent need to create the right conditions for a new infrastructure for recycling of textiles and more circular textile value chains. Furthermore, they pointed out that there has to be a positive economic value in order to make collection, sorting and recycling of textiles fiber-to-fiber interesting. A business case for this is still missing. Market demand for recycled fibers is lacking, particularly for the production of new textiles. This is partly due to the low prices of virgin fibers compared to recycled fibers. One respondent argued

that if market demand for recycled fibers can be created, the rest of the textile chain will follow. Textile products made with recycled fibers are often considered having secondary quality instead of being valued for using secondary raw materials while meeting quality standards. One respondent called for increased awareness of the advantages of recycling. One respondent stressed the importance of creating Nordic or European value chains in order to secure transparent and profitable value chains for used textiles.

Five answers related to aspects in the category Technology. Primarily representatives from the fashion companies highlighted both the importance of more efficient (automated) sorting of textiles and more sophisticated recycling processes for textiles. Recycling technologies should be able to recycle both natural and synthetic fibers including fiber blends, e.g. cotton-polyester blends. They should also be able to remove hazardous chemicals, e.g. dye stuffs, from the textiles for recycling. In order to use recycled fibers in larger scale, fashion companies and textile producers need access to large volumes of recycled textile fibers with homogenous high quality. This is interpreted as the reason why primarily representatives from the fashion companies stressed the aspects in the category Technology.

Three of the answers concerned aspects in the category Information. All of them reflected the lack of information regarding chemical content and contaminations in textile products.

Two of the answers reflected aspects in the category Material input and primarily addressed the issue of mixed fibers and fiber compositions of textile products reducing the recyclability.

4.6 discussion

The answers from the respondents regarding the most and second most important critical aspect for fiber-to-fiber recycling were all included in the critical factors identified in the interviews. However, the answers reflect a slightly different focus compared to the results of the ranking. Whereas the rating of aspects in the categories Material input, Markets and Technology were similar in the ranking, the respondents' answers on the open questions were primarily stressing aspects related to markets and technology.

Apart from aspects in the category Information, the different stakeholder groups, i.e. fashion companies, sorters and recyclers, rank the impacts of the critical aspects for fiber-to-fiber recycling of textiles somewhat differently. Sorters rank aspects regarding markets the highest, whereas recyclers rank aspects regarding material input and fashion companies rank aspects regarding technology the highest.

In a way, all stakeholder groups are pointing towards other stakeholder groups when identifying the main obstacles for increased fiber-to-fiber recycling of textiles and more circular textile value chains. Fashion companies do not see a lacking demand for recycled fibers as a problem whereas this aspect was ranked considerably higher by sorters and recyclers. Recyclers rank lack of technology for sorting and recycling of textiles considerably lower than fashion companies. Sorters have no problem with presence of chemicals in used textiles whereas recyclers and fashion companies rank this aspect considerably higher.

This reflects the different roles of the stakeholder groups in the textile value chain. Sorters are highly dependent on available and functioning markets for the sorted textiles for recycling and in existing markets, mixed and complex materials have limited value. Sorters also see large challenges in increasing collection volumes (for sorting), decreasing sorting costs and increasing market demand for sorted textile waste. Recyclers are dependent on the quality and properties of the textiles entering their recycling processes in order to be able to handle them. This is true both for existing and future recycling processes. Fashion companies are dependent on large volumes of recycled fibers of homogenous quality in order to be to increase the use of secondary raw materials in their textile products. They are to a large extent governed by current business models and customer demands, and hope for recycling technology that can handle the complex materials they generate.

There is an obvious need for a common strategy, coordination and increased information exchange between the different actors in the textile value chain.

5 role of critical factors for increased textile recycling

After the identification and ranking of critical aspects for fiber-to-fiber recycling, the aspects were grouped into subcategories and assessed regarding their respective position in the textile value chain. The aspects were also assessed regarding their influence on quality and quantity of fiber-to-fiber recycling of textiles. The aim was to get information about what kind of aspects that impact certain stakeholder groups, and which aspects each group can influence. Understanding of these dependencies, causes and effects in the value chain is vital to avoid sub-optimization when designing policy measures aiming to promote circular textile value chains.

5.1 bundling critical aspects for textile recycling

The 43 critical aspects for fiber-to-fiber recycling of textiles were bundled into 16 subgroups under the main categories of aspects (defined in Section 3). The objective was to reduce the number of aspects in each category so that each subgroup characterized one type of aspects. The subgroups are presented in Sections 5.1.1-5.1.4. An overview of all subgroups is documented in Table 7 in appendix 5.

Average scores were calculated for each subgroup based on the individual scores of the included critical aspects. These average scores are illustrated in Figure 16.

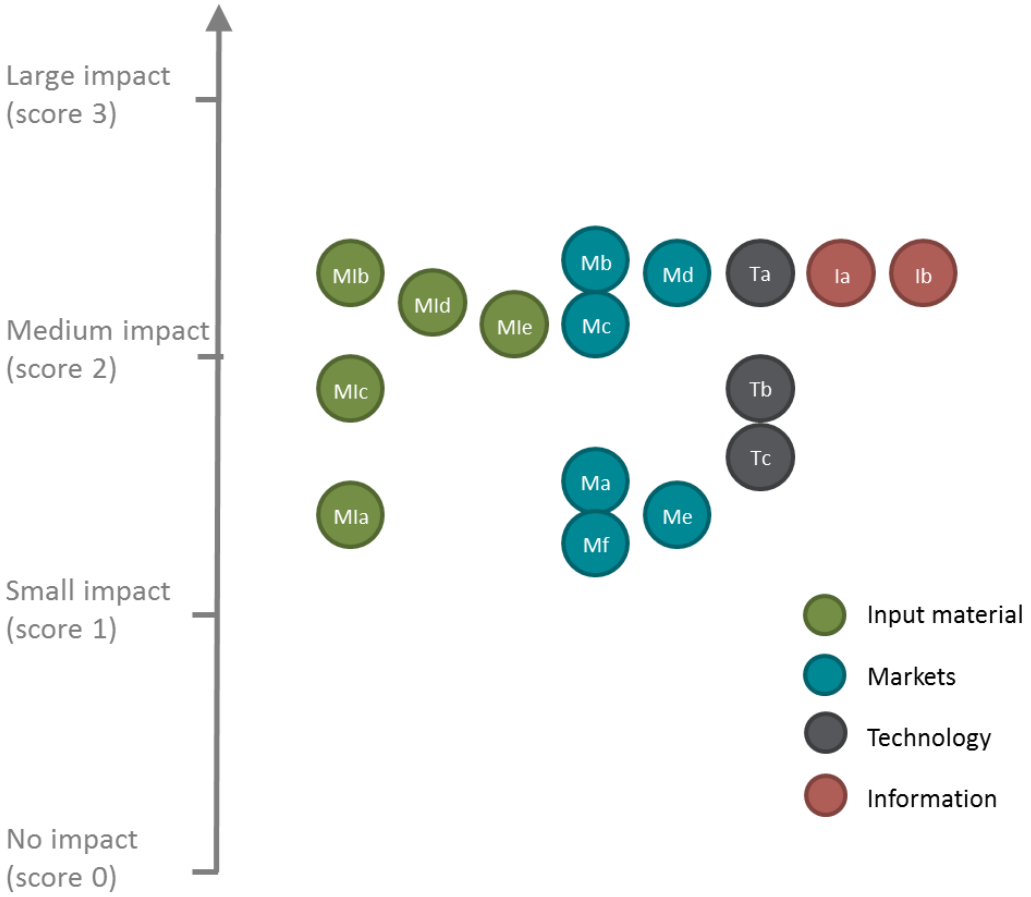

Figure 16 Average scores for each subgroup of critical aspects for increased fiber-to-fiber recycling of textiles. The references (e.g. MIa, Mf etc.) indicate specific subgroups listed in Table 7 in appendix 5. Maximum score is 3, indicating large impact on fiber-to-fiber recycling of textiles.

5.1.1 material input

The 15 aspects regarding material input to recycling identified in the interviews were bundled into five subgroups. Three of them (60 percent) were ranked with scores higher than 2.0, corresponding to medium to high impact on textile recycling.

- **MIb:** Use of mixed textile fibers in textile products (average score: 2.3)
- **MId:** Presence of non-textile materials in textile products (average score: 2.2)
- **MIe:** Quality of textile fibers for recycling (average score: 2.1)
- **MIc:** Presence of chemicals in textile products (average score: 1.9)
- **MIa:** Supply of textiles available for recycling (average score: 1.4)

Primarily the two aspects supply of textiles available for recycling and presence of chemicals in textile products were ranked differently by different stakeholder groups. Fashion companies ranked sufficient supply of recyclable textiles as having medium impact, whereas sorters ranked it as having no (little) impact. Fashion companies ranked the presence of chemicals in textile products as an aspect having medium to high

impact, whereas sorters ranked this aspect as having only small impact on textile recycling. This probably reflects the fact that the presence of chemicals in textiles do not directly influence the sorting process (even if it indirectly influence the value of the sorted output materials), whereas the presence of chemicals in recycled textile fibers directly influences the quality of produced new textiles from recycled fibers.

5.1.2 markets

The 15 aspects regarding markets identified in the interviews were bundled into six subgroups. Three of them (50 percent) were ranked with scores higher than 2.0, corresponding to medium to high impact on textile recycling.

- **Mb:** Economic viability of textile sorting and recycling (average score: 2.4)
- **Md:** Market prices for textile fibers (average score: 2.3)
- **Mc:** Trade barriers for textile waste (average score: 2.1)
- **Ma:** Demand for recycled textiles (average score: 1.5)
- **Me:** Supply of recycled textile fibers available for production of new textiles (average score: 1.4)
- **Mf:** Conflict of interest regarding textiles for reuse and recycling (average score: 1.3)

Predominantly one aspect was ranked differently by different stakeholder groups: demand for recycled textiles (Ma). Whereas sorters ranked this aspect as having high impacts on recycling, fashion companies ranked it as having only no (little) to small impact. The aspect of lacking demand for recycled textile fibers might reflect a causality dilemma of creating supply and demand for recycled textile fibers at the same time (chicken or the egg dilemma). Fashion companies and textile producers need large volumes of recycled textiles with high and homogenous quality in order to use recycled fibers to a larger degree. From this angle there is a large demand for recycled textile fibers. On the other hand, sorters face some difficulties in finding markets and achieving high value for their sorted textiles for recycling. From this point of view there is a lack of demand for recycled textile fibers. The process of creating an industry and an infrastructure that can supply large volumes of recycled textile fibers of constant high quality is not something that can be switched on. Rather, it must develop and go hand in hand with increasing demand starting on a lower level.

5.1.3 technology

The ten aspects regarding technology identified in the interviews were bundled into three subgroups. One of them (33 percent) was ranked with score higher than 2.0, corresponding to medium to high impact on textile recycling.

- **Ta:** Availability of textile recycling technology (average score: 2.3)
- **Tb:** Availability of textile sorting technology (average score: 1.9)
- **Tc:** Limitations of available textile recycling (fibers and technology) (average score: 1.6)

Recyclers ranked the aspect availability of textile recycling technology lower (small to medium impact) than sorters and fashion companies (medium to high impact). Fashion companies ranked both availability of textile sorting technology and limitations of

available textile recycling higher (medium to large impact) than sorters and recyclers (no (little) to medium impact).

5.1.4 information

The three aspects regarding information identified in the interviews were bundled into two subgroups. Both subgroups (100 percent) were ranked with score higher than 2.0, corresponding to medium to high impact on textile recycling.

- **Ia:** Information regarding content in textiles for recycling (average score: 2.3)
- **Ib:** Guidance on ownership of used textiles / textile wastes (average score: 2.3)

The stakeholder groups ranked the aspects in the category Information similarly.

5.2 stakeholder impacts and influences in the textile value chain

The critical aspects for recycling identified in the stakeholder interviews impact different stakeholders in the textile value chain to varying extent. Likewise, stakeholders in the textile value chain can influence the aspects to a varying degree. Figure 17 and Figure 18 give schematic overviews of what stakeholders are affected by the critical aspects and what stakeholders might influence them. For the sake of clarity and simplicity the figures only include one reference to each aspect even if several actors might be affected by or might be able to influence a particular aspect. In these cases, generally the most relevant stakeholder group has been chosen. Where two adjoined stakeholder groups are affected or might influence a particular aspect, the aspect has been placed between those stakeholder groups in the figures.

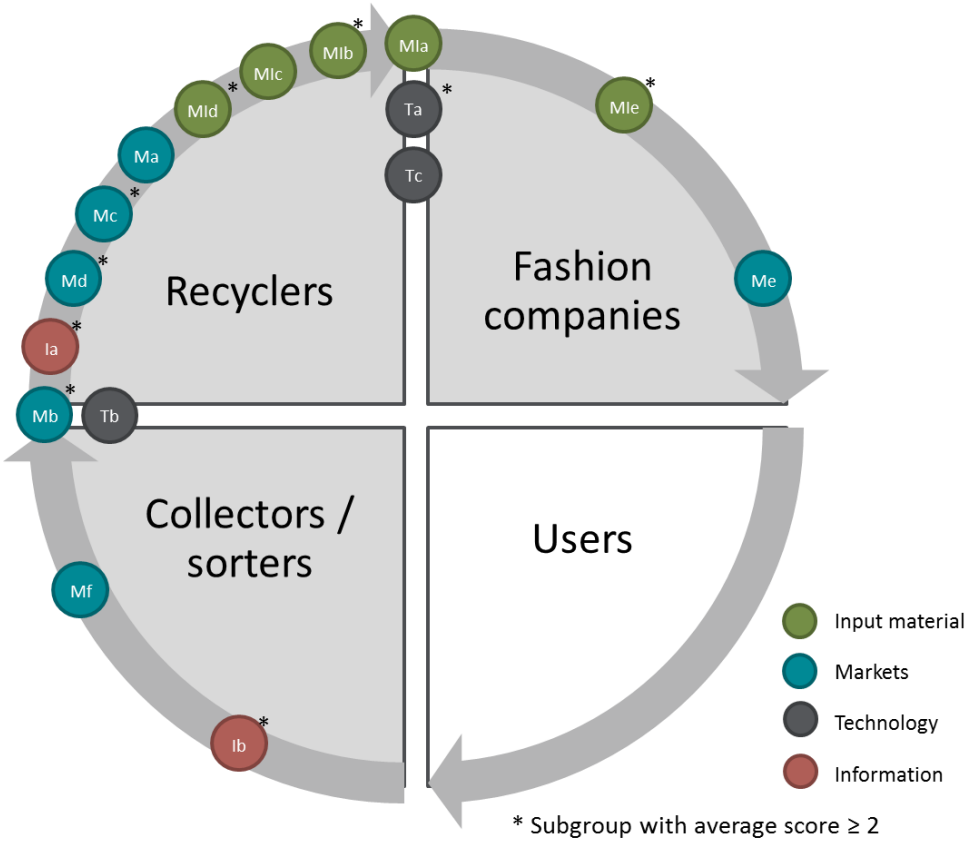

Figure 17 Stakeholder groups primarily affected by the critical aspects identified by stakeholders. Grey sectors indicate stakeholder groups included in the study. The references (e.g. MIa, Mf etc.) indicate the specific subgroups listed in Table 7 in appendix 5.

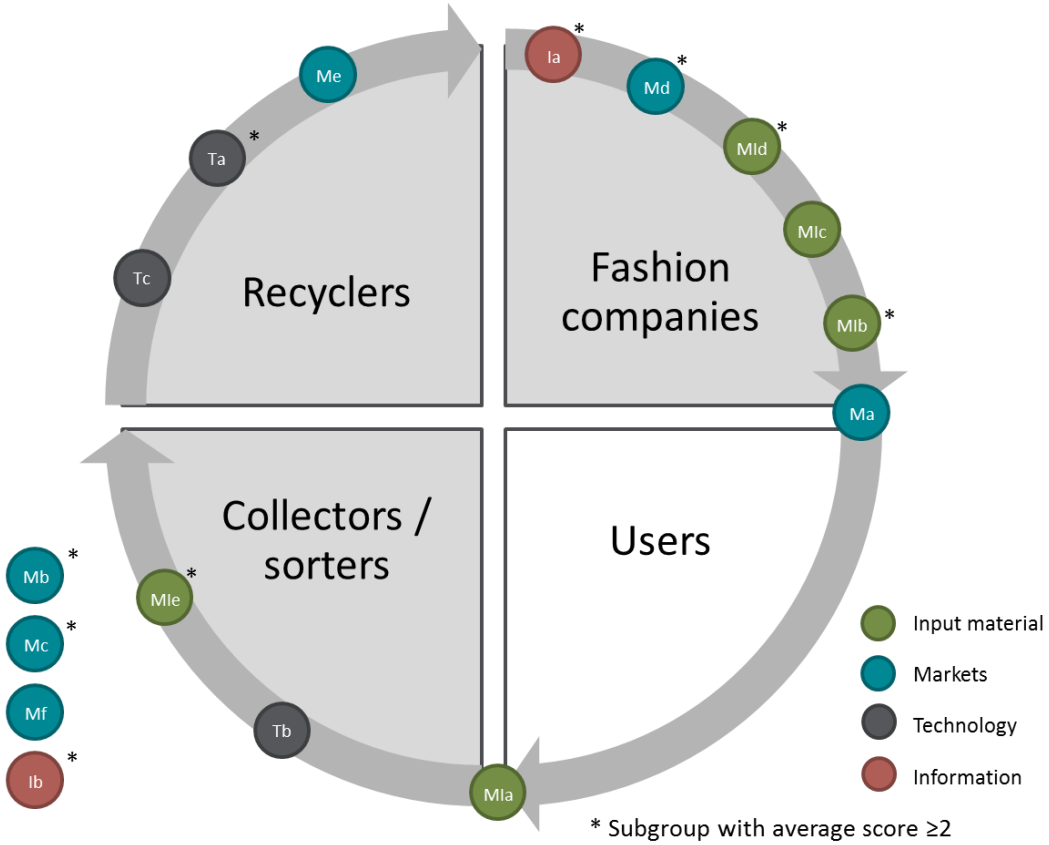

Figure 18 Stakeholder groups primarily able to influence the critical aspects identified by stakeholders. Grey sectors indicate stakeholder groups included in the study. Four aspects could not be assigned to one or two of the defined stakeholder groups. The references (e.g. MIa, Mf etc.) indicate the specific subgroups listed in Table 7 in appendix 5.

In spite of the simplifications made, Figure 17 and Figure 18 indicate that recyclers are the stakeholder group affected by most aspects (12 of 16 aspects) whereas the fashion companies are the stakeholder group able to influence most aspects (six of 16 aspects). Critical aspects regarding technology influences all stakeholder groups included in this study. Recyclers are affected by aspects from all categories. Fashion companies have the possibility to influence critical factors regarding input material, markets and information whereas recyclers primarily can influence aspects regarding technology and markets and sorters primarily aspects regarding technology and input material to recycling.

The aspects rated to have medium to high impact on textile recycling (score 2.0 or higher and marked with * in Figure 17 and Figure 18) largely coincide with the above, i.e. recyclers are affected by most of aspects with medium to high impact and fashion companies are the stakeholder group able to influence most aspects with medium to high impact on textile recycling.

5.3 recycling policy challenges; quality, quantity and markets

An increased fiber-to-fiber recycling of textiles requires both increased volumes of textile waste for recycling and increased quality of this textile waste. It seems unlikely that a majority of future textiles will be made from single fiber materials. Instead, the fiber-to-fiber recycling process must be adapted to the available textile waste, i.e. must be able to handle complex post-consumer textile waste. At the same time, the output need to match customers' demands, i.e. be able to fulfill fashion companies' requirements on recycled textile fibers both regarding quality and volumes. The recycled materials have to be produced in cost efficient processes to be able to compete with virgin materials on the market. These are big challenges that call for increased collaboration and information exchange in the value chain, but also for policy measures that aid the development towards sustainable textile flows.

Subsequent work in Mistra Future Fashion Phase 2 (Task 4.3.7) will consider bot pull and push strategies when selecting and assessing policy measures (or combination of policy measures) promoting reuse and fiber-to-fiber recycling of textiles. A push strategy has the objective of securing sufficient recyclable textile waste entering recycling, e.g. setting of binding collection targets. A pull strategy has the objective of securing sufficient demand for recycled textile fibers from recycling, e.g. economic incentives, removal of trade barriers and information to consumers. Both strategies contribute to economic viability of textile recycling. Strategies for the development and scale-up of new recycling technologies are also needed, especially for complex materials.

Figure 19 illustrates which of the identified critical aspects that influences quality and quantity of textiles for recycling as well as the aspects that influence markets for the recycled fibers (use). The quality is mainly influenced by factors related to material input such as fiber mixes and chemical content, and also by factors related to information about material content. Quality is influenced by all the different types of aspects, e.g. supply, trade-offs between reuse and recycling, sorting technology and guidance on ownership. Markets are influenced by aspects related to demand, trade barriers and prices.

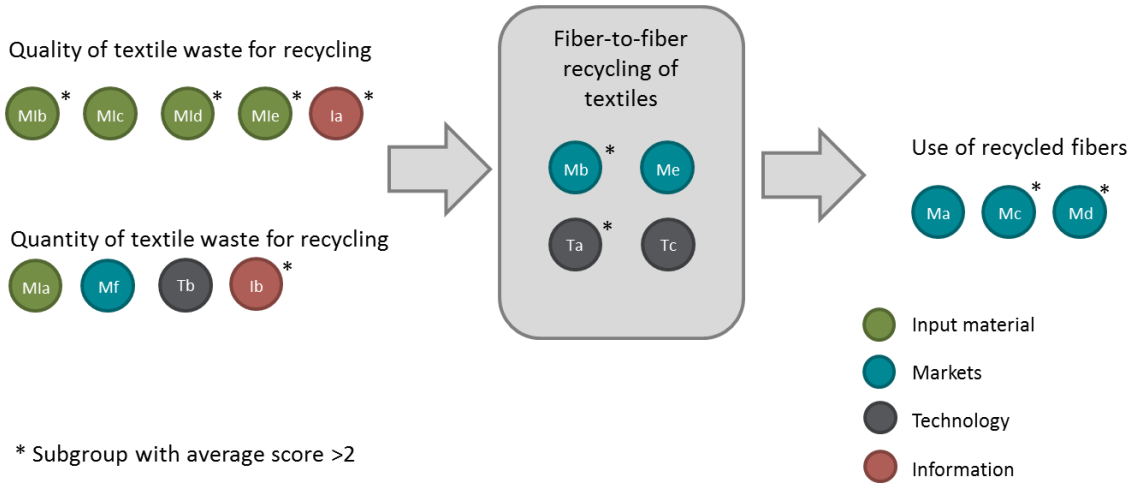

Figure 19 Critical aspects' main influence on quantity and quality of textiles for recycling and their impact on markets for recycled fibers. The references (e.g. MIa, Mf etc.) indicate the specific subgroups listed in Table 7 in appendix 5.

5.4 discussion

Of the 16 subgroups of critical aspects 9 were ranked as having medium to large impact for increased fiber-to-fiber recycling of textiles. The aspects represent all identified categories: Material input to recycling, Markets, Technology and Information (see section 5.1). They address both materials entering and leaving the recycling process as well as the recycling process itself (see section 5.3). Furthermore, the stakeholder groups are affected by the aspects to different degrees and also have different possibilities to influence them (see section 5.2). This indicates that increased fiber-to-fiber textile recycling should not be reduced to a waste problem. On the contrary, the whole value chain must be considered when introducing policy measures with the objective to increase fiber-to-fiber recycling of textiles.

Different policy measures could be targeted towards certain actors of parts of the textile value chain, but not without understanding the dependencies and connections to the rest of the value chain. This poses a challenge due to the global nature of the textile sector, which may make local or regional policy measures ineffective. In addition, policy measures targeting increased recycling may come at the expense of reuse. While developing policy measures for increased recycling of textiles, it is important to keep this trade-off in mind and have clear policy targets and objectives.

6 identified knowledge and communication gaps

Textile value chains are complex and global, which makes communication a key aspect for the realization of more circular value chains and closed textile loops. Knowledge that exists in one part of the value chain, e.g. at upstream suppliers, is not automatically transferred to downstream partners in the chain and vice versa. This section highlights knowledge and communication gaps identified in the interviews with stakeholders.

6.1 geographical distances

One main factor that influences the transfer of knowledge is the geographical distance between raw material and fabric producers and European fashion companies. The majority of textile production has moved from Europe to Asia, making communication more challenging. This is especially the case for the development of innovative solutions for closed loop recycling. The distance to innovation is perceived as problematic. It would be easier for European based companies to gain competitive advantages if value suppliers and fashion companies were closer to each other geographically (Klarén, 2016; Lennarth, 2016). This could be seen as an opportunity for the "re-industrialization" of Sweden and Europe.

Another obstacle is the difficulty to find sorted textiles for recycling (secondary raw material) of the right quality within Europe (Recycler, 2016). This refers primarily to pre-consumer textiles, but also to post-consumer textiles. The relatively large Turkish market for secondary textiles for recycling is perceived to be closed for European actors due to the fact that all available material is used within Turkey (Recycler, 2016).

6.2 designer knowledge

The interviews revealed a lack of knowledge about recycling aspects when designing textiles. Alternatively, they might indicate a lack of priority for designing recyclable textile products, i.e. that the knowledge is available but not always put into practice (Klarén, 2016; Brännsten, 2016). The interviewees stressed that this is driven by customers' demand for complex textile products, and that it is difficult to design clothes matching customers' demands using a limited number of materials, mono fiber fabrics and considering separability of the materials (Brännsten, 2016; Norlin, 2016; Harlin, 2016; Vernooy, 2016). All interviewed fashion companies state that they are working on to increase the recycled content in their products. Some also work with improving the recyclability of their products, e.g. by educating their designers (Klarén, 2016). The process of changing routines in large companies is, however, slow. The learning could be sped up by increased sharing of best practices between companies (Larsson, 2016).

6.3 chemical contents

The chemical content of textile products poses a major knowledge gap according to a majority of the interviewed stakeholders as well as available literature (Lexén et al., 2016). Fashion companies work with restricted substance lists but have limited ability to

know the complete chemical content of their products. This is mainly due to the long and complex supply chains, the discrepancy in national and regional legislation (REACH) and very limited transparency of the chemical industry supplying the chemicals (Klarén, 2016; Larsson, 2016).

The lack of knowledge of chemical content in textile waste is considered to be a large obstacle for both pre- and post-consumer recycling of textiles. Recyclers mention that they generally avoid certain markets, due to their bad experiences of chemical content, or that they even avoid all post-consumer material for that reason (Recycler, 2016; Norlin, 2016). Tests have e.g. shown content of prohibited substances in dyestuffs. Suppliers may not have enough knowledge about what chemicals are prohibited by European legislation, when the same chemicals are not restricted in other markets. It may also be difficult for producers to obtain the information on chemical content from chemical suppliers. In this way, legislation becomes a trade barrier that can only be solved by more transparency and global harmonization. Not only chemicals added on purpose, like colors, are problematic. Chemicals from production processes can also stay in textiles and are more difficult for fashion companies to regulate (Klarén, 2016). Existing certification schemes that consider chemical content, like the Ökotex standard, are not sufficient for follow up, since they make very few audits (Recycler, 2016).

6.4 consumer awareness

Several interviewees mentioned a lack of customer and consumer knowledge of recycling issues and the benefits of recycled textiles. They argued that increased knowledge about the environmental impacts of textile production and the benefits of reuse and recycling could help change consumer mindset, both in the public and private sector (Lennarth, 2016; Brännsten, 2016; Enebog, 2016). This could potentially create a larger market for reuse and textile products with recycled content. Public textile procurement customers have a large potential to make a difference, depending on the requirements they set up for their products regarding material type, quality and durability (Lennarth, 2016). As an example, some county purchasers of hospital textiles are moving away from using cotton due to the large environmental impacts (Lennarth, 2016).

Increased consumer awareness may also increase the collection volumes of used textiles from consumers, which was mentioned as important by many stakeholders (Brännsten, 2016; Enebog, 2016; Klarén, 2016; Larsson, 2016). Some consumers may be skeptical about leaving more of their used textiles to recycling (Rosinski, 2016a). New business models should be developed that makes increased collection easy for the consumers (Norlin, 2016).

Both recyclers and fashion companies mentioned that fashion companies have a large possibility to impact customers' awareness through e.g. marketing (Klarén, 2016; Norlin, 2016; Recycler, 2016; Vernooy, 2016).

6.5 knowledge of market conditions

Many actors, including e.g. researchers, fashion companies and policy makers, have limited knowledge in and understanding of sufficient volumes and qualities of used textiles needed to make recycling economically viable (Rosinski, 2016a). Deeper

knowledge of market conditions such as current market segments, available volumes, transport costs, sorting costs, prices of used textiles versus incineration costs etc. is needed to make informed decisions about the feasibility of different initiatives towards increased recycling. Policy makers must understand and accept that the textile value chains are global (Klarén, 2016).

6.6implementation of research

Many stakeholders emphasize that ongoing research in textile recycling and circular value chains needs to be implemented in the market (Enebog, 2016; Klarén, 2016; Lennarth, 2016). The results from research projects, e.g. Mistra Future Fashion and textile projects funded by the Nordic Council of Ministers play an important role in this knowledge transfer. Public procurement of textiles, e.g. in the health sector, has a promising potential for testing implementation of new solutions (Lennarth, 2016). It is important to increase the knowledge of textile producers, since fashion companies feel that the knowledge of their suppliers is limited when it comes to recycling issues (Klarén, 2016).

7 trade-offs between design for durability and recyclability

Design aspects that prolong the lifetime of textile products may in some cases cause reduced recyclability. Generally, the type and quality of materials are mentioned by all interviewed fashion companies as the most important aspects that enhance durability and long life of garments (Brännsten, 2016; Klarén, 2016; Larsson, 2016). Another important aspect is to design garments in classic style that will survive over many fashion cycles. This section summarizes the trade-offs between durability and recyclability from a design perspective mentioned by stakeholders in the interviews.

7.1 mixed materials

One reason for mixing natural fibers with synthetics is to increase durability. This is particularly evident in the production of staff uniforms for health care and other sectors, where high requirements are set for durability. The mix of polyester and cotton is very common in uniforms because it can survive the 60-80 washes without losing shape or pilling too much (Lennarth, 2016). Another example is the use of lycra and metal threads; which interferes with mechanical recycling machinery (Vernooy, 2016). Using synthetic threads on when making e.g. cotton garments could improve the durability of the seams, but makes recycling more difficult (Norlin, 2016). Mixing of elastane and polyurethane with cotton are also problematic from a recycling perspective (Harlin, 2016). But blending of fibers could also be a means to enable increased content of recycled fibers in garments, e.g. by mixing high quality fibers like spider silk with recycled cotton (Larsson, 2016).

7.2 chemical treatment of textiles

Work uniforms could provide a large potential source of relatively homogenous textiles suited for recycling. However, some work uniforms are treated chemically to improve durability or provide certain properties, e.g. flame resistance. This makes them difficult to use for mechanical recycling purposes (Rosinski, 2016a). Outdoor garments are another type of garments designed for long life that are often chemically treated to withstand water and dirt. Single use uniforms from the health sector can be produced with mono materials (Lennarth, 2016), but may instead have issues with contamination if they are not washed.

7.3 wear and tear of fibers

Textile fibers get shorter over time through wearing and washing. This limits the possibility for mechanical recycling and increases the losses in mechanical recycling processes. The longer the life of the garments, the more worn the fibers are. Chemical recycling processes for synthetic fibers are able to regenerate fiber quality, but long life garments made from natural fibers may not be recyclable due to fiber quality degradation. This trade-off is related to limited supply of the right qualities of input material to recycling, which is mentioned by recyclers. The challenge is greater for post-consumer material than for production waste. (Recycler, 2016; Norlin, 2016)

7.4 washing standards/treatment for uniforms

Current washing and care standards for uniforms are too focused on durability to enable use of most recycled material.[3] Requirements need to be lowered, or the quality of recycled material has to be significantly increased, in order to enable more recycled content in this market sector (Lennarth, 2016).

[3] This aspect might apply for a range of other textile products than uniforms. This section, however, reflects only the input given from the interviewees within the scope of this study.

8 findings and next steps

This study identifies critical aspects for fiber-to-fiber recycling from stakeholders' perspectives. The identified aspects are categorized, grouped and ranked. Differences between stakeholder groups are highlighted. Patterns of how stakeholders are impacted and how they influence the critical aspects are outlined. The main influences of the identified critical aspects on input to and output from recycling are identified. Finally knowledge and communication gaps posing obstacles for increased fiber-to-fiber recycling of textiles are identified.

This section summarizes the main findings of this study and outlines the next steps. The results will feed into the subsequent work in Mistra Future Fashion Phase 2.

8.1 main critical aspects for textile recycling

The interviewed stakeholders from fashion companies, textile sorters and textile recyclers identified 43 critical aspects for increased fiber-to-fiber recycling of textiles. These aspects were grouped into 16 subgroups in four main categories: Material input to recycling, Markets, Technology and Information. The categories Material input and Markets contained most identified aspects, followed by the category Technology. Only three aspects referred to the category Information.

On average, the aspects in the categories Material input, Markets and Technology were ranked as having the same impacts on fiber-to-fiber recycling of textiles by the stakeholders. The aspects in the category Information were ranked to have a slightly higher impact. This indicates a greater variety of critical aspects in the first three categories, even if they are not considered more important or having larger impacts than the aspects regarding information. However, in addition to and independent of the ranking the stakeholders were asked to mention the most and second most important aspect for increased fiber-to-fiber recycling of textiles. In doing so, the respondents' answers primarily stress aspects related to markets and technology.

Regarding the material input to recycling, the use of mixed textile fibers in textile products, the presence of non-textile materials in textile products and the quality of textile fibers for recycling were ranked as having medium to large impact on textile recycling by the interviewed stakeholders. The aspects connected to markets that were rated having medium to large impact on textile recycling were (lack of) economic viability of textile sorting and recycling, market prices for (recycled) textile fibers and trade barriers for textile waste. Availability of textile recycling technology was rated as having medium to large impact on textile recycling in the category Technology. Finally, in the category Information, both (lack of) information regarding content in textiles for recycling and (lack of) guidance on ownership of used textiles / textile wastes were seen as having medium to large impact on textile recycling.

8.2 need for holistic approach

The critical aspects for increased fiber-to-fiber recycling of textiles identified in the interviews impact fashion companies, sorters and recyclers differently. The stakeholders

also have different possibilities of influencing these aspects. Recyclers form the stakeholder group that is affected by most aspects whereas the fashion companies represent the stakeholder group able to influence most aspects. Critical aspects associated with (lack of) technology influence all interviewed stakeholders. Recyclers are affected by aspects regarding material input to recycling, markets, technology and information. Fashion companies have the greatest possibility to influence critical factors regarding input material, markets and information whereas recyclers primarily can influence aspects regarding technology and markets. Sorters can primarily influence aspects regarding technology and input material to recycling.

The identified critical aspects address different positions in the value chain: the textile waste entering the recycling process (input material to recycling), the recycling process itself and the recycled textile fibers leaving the recycling process (output material from recycling). Whereas the aspects regarding input material to recycling reflects all categories (Material input, Markets, Technology and Information), the aspects regarding recycling process only reflects Markets and Technology and the aspects regarding output material from recycling only Markets.

Stakeholders rank the impacts of the critical aspects for fiber-to-fiber recycling of textiles differently. Sorters rank market related aspects the highest, whereas recyclers rank aspects regarding material input the highest and fashion companies rank technology related aspects the highest. The differences in the ranking of individual aspects indicate that each stakeholder group sees the main obstacles for increased fiber-to-fiber recycling of textiles in other parts of the textile value chain than their own. Rather than a simple blame game this seems to be symptomatic for a lack of strategy, coordination and exchange of information in the textile value chain. Each stakeholder group is focusing on its own problems instead of taking a joint strategic approach for creating more circular value chains. This reflects the different roles of the stakeholder groups in the textile value chain and what business relationships they are relying on for their profitability. Despite this, all interviewed stakeholders express a strong interest in joint research and collaboration. However, it takes time to change existing business models, complex global markets and traditional working processes.

The above indicates that increased fiber-to-fiber textile recycling must not be reduced to a waste problem. The challenge of increasing fiber-to-fiber recycling of textiles cannot be met by a single stakeholder group or on a single place in the textile value chain. On the contrary, a holistic perspective must be used in terms of textile products entering and textile wastes circulating in the value chain. Effects on the whole value chain, like connections between stakeholders and market mechanisms must be considered when introducing policy measures with the objective to increase fiber-to-fiber recycling of textiles. The identified knowledge and communication gaps as well as tradeoffs between design for durability and design for recyclability should also be considered.

8.3 need for dialogue between stakeholders

The creation of more circular textile value chains requires active dialogue between different stakeholders in the value chain. More new textiles put on the market must be designed to allow for a long active life time and enable used textiles and textile fibers to re-enter the textile loop in an efficient way. At end-of-life, both garments and other textiles must be collected and fed into recycling processes with minimal negative

influences on the quality of the textile fibers. Sorting of used textiles must match recyclers' demands on textile fibers entering different recycling processes. Recycling of textile fibers must, in turn, match producers' demand on input materials for production of new textiles.

8.4 next steps

The identified critical factors for increased fiber-to-fiber recycling will serve as important background information for the subsequent Task 4.3.7 in Mistra Future Fashion Phase 2. Task 4.3.7 includes identification of a selection of policy measures promoting both reuse and fiber-to-fiber recycling of textiles. Two policy measures (or combinations of policy measures) will be selected for impact assessment with regard to Sweden and the Swedish fashion industry. The two selected policy measures will represent both pull and push strategies. Push strategies promote separate collection of post-consumer textiles in sufficient quantities to make recycling a viable industry for textiles consumed in Sweden. Pull strategies will aim at increasing the demand for recycled fibers in new textile products. Both types of strategies will need to take a wider perspective than the Swedish one in order to be successful.

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appendix 1

List of interviewees

As part of Task 4.3.6 in Mistra Future Fashion Phase 2 12 in-depth interviews with stakeholders were carried out. This constitutes 75 percent of the approached organizations and companies.

Interviews were carried out with the following representatives from textile producers (fashion industry) and waste management companies:

1. **Boer Group**
   Elisa Bes, Sorting and recycling expert
2. **Filippa K**
   Elin Larsson, Corporate Sustainability Manager
3. **H&M**
   Cecilia Brännsten, Sustainability Innovation Responsible
4. **Human Bridge /ReturTex**
   Klaus Rosinski, Manager Textile Markets / Advisor Business and Development
5. **I:CO**
   Paul Doertenbach, Manager Sales and Marketing
6. **Italian textile recycler***
7. **KappAhl**
   Fredrika Klarén, Sustainability Manager
8. **Martinson**
   Ellenor Lennarth, Commercial Manager
9. **Myrorna**
   Emma Enebog, Sustainability Manager
10. **RE:newcell**
    Henrik Norlin, Business Developer
11. **Reloopfashion**
    Ali Harlin, Research Professor VTT
12. **Vernooy recycling**
    Harry Vernooy, CEO

* An interview was carried out with a representative from an Italian textile recycling company. The interviewee also participated in the rating of critical aspects for fiber-to-fiber recycling of textiles (see Section 4). The interviewee has expressed the wish to remain anonymous.

appendix 2

List of questions for the interviews

A list of questions was developed as a base for the interviews carried out in Task 4.3.6 in Mistra Future Fashion Phase 2. Due to the interviewees' different roles in the textile value chain, not all questions were asked in all interviews. Table 4 indicates what questions were asked depending on interviewees'' roles.

Table 4 List of questions for the interviews carried out in Task 4.3.6

	Design / production	Collection / sorting	Recycling
How large proportions of input materials to sorting are currently sorted for reuse and recycling respectively?		x	
What proportion of the textiles sorted out for recycling is currently sorted out/used for fiber-to-fiber recycling?		x	
Which textiles are sorted for recycling / recycled?		x	x
Why are these particular fractions sorted out for recycling?		x	
Which additional fiber types have potential for fiber-to-fiber recycling?			x
Could additional fractions be sorted out for recycling manually? If yes, which? If no, why not and what would make it profitable?		x	
How would automatic sorting for recycling influence volumes, quality and use of textiles for recycling?		x	x
What could/would increase the proportions of textiles sorted out for recycling in general and fiber-to-fiber recycling in particular?		x	
Are textiles sufficiently and correctly labelled?		x	
Does (manual) sorting include looking at labels?		x	
How large volumes of sorted textiles are necessary to provide one fiber-to-fiber recycling facility with enough secondary raw materials?			x
How large volumes of sorted textiles are necessary for creating a recycling market?			x
What are the limits for recycling content in new textiles (fiber-to-fiber recycling) for different fiber types - and what are the main reasons? What would increase the possible recycling contents?	x		x
Are you primarily/only using pre-consumer or post-consumer textile wastes for recycling? The market in general? If post-consumer materials: Are you primarily/only using used textiles from private or corporate customers?			x

What are the specifications on "fiber type purity" for input materials to fiber-to-fiber recycling? Are waste fractions meeting these requirements available today? How would increased fiber-type-purity impact fiber-to-fiber recycling?			x
In the "clean" textile waste fractions today: what are the wrongly sorted textiles?			x
What design-features decrease recyclability of used textiles?	x		x
How is this reflected in the current design of new textiles (design for recyclability)?	x		
What chemical substances pose obstacles for current and future (fiber-to-fiber) recycling processes and why? How much of these chemicals can the recycling process cope with?	x		x
Does interest from textile producers (fashion industry) exist for more fiber-to-fiber recycled textiles?	x		x
Do you offer products with recycling content? If yes, what types of textiles, what recycling content, which type of recycling and what proportion of total sales? Do the specifications for virgin textile fibers and for recycled textile fibers differ (and if yes, how)?	x		
What are the main obstacles for your company/your suppliers to increase the share of recycled fibers?	x		
What are potential obstacles for using recycled fibers for production of new textiles?	x		
Do you have routines for tracking of chemical content in your products?	x		
What design aspects prolong the life time of textiles?	x		
What do you consider the largest obstacles for increased fiber-to-fiber recycling of textiles?	x	x	x
Which would be the main incentives for (increased) fiber-to-fiber of recycling of textiles?	x	x	x

appendix 3

Critical aspects for fiber-to-fiber recycling of textiles identified in the interviews

In total 43 critical aspects for fiber-to-fiber recycling of textiles were identified in the interviews carried out with stakeholders (fashion industry and waste management companies). These critical aspects are listed in Table 5. The table indicates the main category of the critical aspects as well as the number of interviewees that mentioned the critical aspects respectively (No. of references).

Table 5 Overview of the critical aspects for fiber-to-fiber recycling of textiles mentioned by stakeholders in the interviews carried out.

Critical aspect		No. of references
Material input to recycling		
MI 1	Lack of textiles available for recycling due to insufficient collection *There is a large potential to increase the collection of used textiles from consumers. The best collection rates in Europe are only around 50 percent. Large volumes are needed in order to create long term economic viability in recycling businesses.*	9
MI 2	Use of mixed fiber types in textile products *Most garments today consist of mixtures of natural and synthetic fibers, which is a big challenge for existing recycling processes.*	9
MI 3	Presence of chemicals and hazardous substances in textile products *Complex global value chains and differences in legislation make it difficult to control the chemical content in textiles.*	8
MI 4	Presence of metals, plastic etc. in textile products (e.g. zippers and buttons) *These items need to be removed before recycling, which can be time consuming and costly.*	5
MI 5	Lack of textiles for recycling due to insufficient sorting for recycling *Sorting for fiber-to-fiber recycling is often not profitable due to lack of recycling processes and low material prices. One main incentive for sorting for recycling is to avoid incineration cost.*	4
MI 6	Presence of colors (in textiles for recycling and/or in recycled textile fibers) *Colors have been specifically mentioned as potentially harmful among the chemicals used in textile production.*	4
MI 7	Presence of plastic prints on textile products *The plastic is melted into the fibers, which prevents recycling and may contain harmful substances.*	3

MI 8	Purity of input textiles for recycling in terms of fiber type (e.g. cotton, wool etc.) *Batches of sorted textiles for recycling according to a specific fiber type (e.g. cotton, polyester etc.) generally also include other fiber types. Only very small amounts of all textiles consist of only one fiber type (see also MI 2).*	3
MI 9	Lack of long term contracts with material suppliers (of textiles for recycling) *The market is limited, scattered and very cost sensitive.*	2
MI 10	Mechanical degrading of textile fibers (in use and recycling) *The quality of fibers is reduced through wearing, washing and in mechanical recycling processes.*	2
MI 11	Presence of spandex / lycra / elastane in textile products *These materials interfere with recycling processes, e.g. in mechanical recycling of jeans.*	2
MI 12	Presence of inlays in textile products *Shoulder pads and other details must be removed before recycling.*	1
MI 13	Use of different lining and outer materials in textile products *Materials need to be separated before recycling.*	1
MI 14	Use of threads in different materials than the fabric in textile products *Materials need to be separated before recycling.*	1
MI 15	Varying quality of input textiles for recycling (e.g. due to different sources) *Unsorted textiles (so called "original") has a very diverse composition in terms of quality; some not good enough for recycling. Different sorters might have different sorting criteria, resulting in different quality (e.g. fiber-type-purity) of output material from sorting.*	1
Markets		
M 1	Lack of demand for recycled textile fibers (from fashion industry, textile producers and retailers) *Textiles with recycled content have still a very small, but slowly increasing, share of total textile production.*	7
M 2	Lack of economic viability of textile sorting *Manual sorting is very cost intensive, especially in Europe.*	7
M 3	Lack of economic viability of textile recycling *Current low prices for virgin raw materials and need for research investments to scale up chemical recycling pose challenges.*	7
M 4	Lack of incentives for investments in textile recycling *See M 3 above. Alternative financing models may be needed.*	6
M 5	Definition of used textiles as waste (trade barrier) *The regulations for import/export of waste cause different starting positions for textiles made from virgin materials and textiles made from recycled textile fibers.*	5
M 6	Lack of demand for textile products with recycled fibers (from end consumers) *In many cases consumers fail to see an added value in recycled products.*	3

M 7	Low market prices for virgin textile fibers (primary raw materials) *Recycled fibers cannot compete on the market (has been different in the past e.g. when virgin cotton was more expensive).*	3
M 8	Low market prices for recycled textile fibers *Connected to M 7; to be able to compete with virgin fibers, recycled fibers may have to be sold at a loss.*	3
M 9	High transport costs (e.g. for Nordic textiles currently exported for sorting and recycling) *Long transport distances due to the lack of local sorting and recycling operations.*	3
M 10	Lack of infrastructure for circular textile value chain (currently only small material flows) *The industry is optimized for linear value chains and takes time to change.*	3
M 11	Higher market prices for recycled fibers than virgin fibers (for certain fiber types and volumes) *Sometimes more costly to produce recycled fiber (see M 7 and M 8).*	2
M 12	Import regulations for waste (trade barrier) *See M 5.*	2
M 13	Conflict of interest between textiles for reuse and textiles for recycling *Reuse is better from an economic and environmental point of view, but this means only lower quality fibers go to recycling.*	2
M 14	Minimum order quantity of recycled fibers too large for smaller companies *Some suppliers do not sell in small quantities.*	1
M 15	Lack of available volumes of recycled textile fibers for production of new textile products (small market) *Connected to the mixed fiber problem (see MI 2 and MI 8), limited collection rates (MI 1) and focus on reuse (M 13).*	1
Technology		
T 1	Lack of chemical textile recycling technology *Most chemical processes still in development stage; economically viable scale-up is needed!*	10
T 2	Lack / limitations of mechanical textile recycling technology *Often cannot produce the same qualities as virgin, and there is a limited amount of producers of recycled textiles.*	8
T 3	Lack of automated textile sorting to increase volumes of textiles for recycling *Would lower costs and enable quicker sorting of larger volumes of all qualities of textiles (also lower value volumes).*	7
T 4	Lack of automated textile sorting to increase purity (fiber type) of textiles for recycling *Tests show higher precision than manual sorting, e.g. results from sorting tests carried out within the SIPTex project.* (Ljungkvist & Elander, 2016)	7

T 5	Lack of investment in recycling technology *See M 4.*	6
T 6	Lack of investment to scale up sorting technology *Few incentives ongoing despite large interest and need.*	5
T 7	Lack of recycling technology for mixed fibers *No option available that can separate and recycle all contents in fiber mixtures (some processes can recycle one of two mixed fibers in a blend).*	3
T 8	Need for virgin fibers to increase quality of end product *Especially true for mechanically recycled fibers (see MI 10).*	3
T 9	Material losses in mechanical fiber-to-fiber recycling *Connected to low quality (short fiber length).*	2
T 10	Limitations as to what products can be produced from recycled fibers *Connected to quality issues.*	2
Information		
I 1	Lack of information regarding chemicals and hazardous substances in textile products *Current legislation (REACH) prohibits certain substances, but does not require disclosure of complete chemical content.*	3
I 2	Insufficient (and sometimes false) labelling of textile products *Labels can be worn or removed; and take too long to read in the sorting process.*	3
I 3	Unclear ownership of used textiles / textile wastes *For example between municipalities and collectors (not always regulated in contracts).*	1

appendix 4

Ranking of critical aspects by stakeholders (survey results)

The individual ratings in the survey carried out (see Section 4) were used for making a ranking of all critical aspects identified in the interviews. The rating of each aspect by each respondent was given a value: "No (little) impact" was given the value 0, "Small impact" the value 1, "Medium impact" the value 2 and "Large impact" the value 3. Answers "I have no opinion" were not given any value.

The score of each critical aspect was calculated according to the following formula:

$$Score_{Aspect\ x} = \frac{Sum\ of\ values\ given_{Aspect\ x}}{No.of\ answers_{Aspect\ x} - No.of\ answers\ "I\ have\ no\ opinion"_{\ Aspect\ x}}$$

Table 6 Ranking of critical aspects as to their impact on (increased) fiber-to-fiber textile recycling from stakeholders' perspectives.

Rank	Critical aspect	Category	Score
1.	Lack of incentives for investments in textile recycling	Markets	2.8
1.	Lack of recycling technology for mixed fibers	Technology	2.8
1.	Presence of plastic prints on textile products	Material input	2.8
2.	Use of mixed fiber types in textile products	Material input	2.7
2.	Presence of spandex / lycra / elastane in textile products	Material input	2.7
2.	Lack of chemical textile recycling technology	Technology	2.7
3.	Low market prices for recycled textile fibers	Markets	2.6
3.	Purity of input textiles for recycling in terms of fiber type (e.g. cotton, wool etc.)	Material input	2.6
4.	Lack of information regarding chemicals and hazardous substances in textile products	Information	2.4
4.	Lack of economic viability of textile recycling	Markets	2.4
4.	Import regulations for waste (trade barrier)	Markets	2.4
4.	Lack of investment in recycling technology	Technology	2.4
5.	Lack of economic viability of textile sorting	Markets	2.3
5.	Unclear ownership of used textiles / textile wastes	Information	2.3
6.	Insufficient (and sometimes false) labelling of textile products	Information	2.2
6.	Lack of automated textile sorting to increase purity (fiber type) of textiles for recycling	Technology	2.2
7.	Presence of chemicals and hazardous substances in textile products	Material input	2.1
7.	Low market prices for virgin textile fibers (primary raw materials)	Markets	2.1

7.	Higher market prices for recycled fibers than virgin fibers (for certain fiber types and volumes)	Markets	2.1
7.	High transport costs (e.g. for Nordic textiles currently exported for sorting and recycling)	Markets	2.1
7.	Lack of infrastructure for circular textile value chain (currently only small material flows)	Markets	2.1
8.	Use of different lining and outer materials in textile products	Material input	2.0
8.	Varying quality of input textiles for recycling (e.g. due to different sources)	Material input	2.0
9.	Lack of investment to scale up sorting technology	Technology	1.9
9.	Presence of metals, plastic etc. in textile products (e.g. zippers and buttons)	Material input	1.9
9.	Presence of inlays in textile products	Material input	1.9
9.	Use of threads in different materials than the fabric in textile products	Material input	1.9
10.	Definition of used textiles as waste (trade barrier)	Markets	1.8
11.	Presence of colors (in textiles for recycling and/or in recycled textile fibers)	Material input	1.7
11.	Mechanical degrading of textile fibers (in use and recycling)	Material input	1.7
11.	Lack of automated textile sorting to increase volumes of textiles for recycling	Technology	1.7
11.	Need for virgin fibers to increase quality of end product	Technology	1.7
11.	Limitations as to what products can be produced from recycled fibers	Technology	1.7
12.	Lack of textiles available for recycling due to insufficient collection	Material input	1.6
12.	Lack of demand for textile products with recycled fibers (from end consumers)	Markets	1.6
13.	Lack of textiles for recycling due to insufficient sorting for recycling	Material input	1.5
13.	Material losses in mechanical fiber-to-fiber recycling	Technology	1.5
14.	Minimum order quantity of recycled fibers too large for smaller companies	Markets	1.4
14.	Lack of demand for recycled textile fibers (from fashion industry, textile producers and retailers)	Markets	1.4
15.	Conflict of interest between textiles for reuse and textiles for recycling	Markets	1.3
16.	Lack of long term contracts with material suppliers (of textiles for recycling)	Material input	1.2
16.	Lack / limitations of mechanical textile recycling technology	Technology	1.2
17.	Lack of available volumes of recycled textile fibers for production of new textile products (small market)	Markets	0.7

appendix 5

Bundling of critical aspects into subcategories

The 43 critical aspects for fiber-to-fiber recycling of textiles were bundled into 16 subcategories (groups) under each main category of aspects. Table 7 gives an overview of the subcategories and indicates the aspects that were bundled into each subcategory.

Table 7 Overview of subgroups of critical aspects for fiber-to-fiber recycling of textiles.

Critical aspect		Included critical aspects*
Material input to recycling		
MI a	Supply of textiles available for recycling	MI 1, MI 5, MI 9
MI b	Use of mixed textile fibers in textile products	MI 2, MI 11, MI 13, MI 14
MI c	Presence of chemicals in textile products	MI 3, MI 6
MI d	Presence of non-textile materials in textile products	MI 4, MI 7, MI 12
MI e	Quality of textile fibers for recycling	MI 8, MI 10, MI 15
Markets		
M a	Demand for recycled textiles	M 1, M 6
M b	Economic viability of textile sorting and recycling	M 2, M 3, M 4, M 9
M c	Trade barriers for textile waste	M 5, M 12
M d	Market prices for textile fibers	M 7, M 8, M 11
M e	Supply of recycled textile fibers available for production of new textiles	M 10, M 14, M 15
M f	Conflict of interest regarding textiles for reuse and recycling	M 13
Technology		
T a	Availability of textile recycling technology	T 1, T 2, T 5, T 7
T b	Availability of textile sorting technology	T 3, T 4, T 6
T c	Limitations of available textile recycling (fibers and technology)	T 8, T 9, T 10
Information		
I a	Information regarding content in textiles for recycling	I 1, I 2
I b	Guidance on ownership of used textiles / textile wastes	I 3

* According to the numbers given in Table 5 in appendix 3.

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