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Full length article

Identifying the needs for a circular workwear textile management – A material flow analysis of workwear textile waste within Swiss Companies☆

Nadia Malinverno, Mélanie Schmutz, Bernd Nowack, Claudia Som *

Technology and Society Laboratory, Swiss Federal Laboratories for Materials Science and Technology (Empa), Lerchenfeldstrasse 5, CH-9014St. Gallen, Switzerland

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A B S T R A C T

The textile sector with its linear management leads to environmental damage and high amounts of post-consumer waste. Circular economy has been identified as a promising solution. Workwear is assumed to have high potential for circularity because of its high, constant, and uniform material quality and quantity. There is little research on categorized material waste flows of workwear. To fill this gap, workwear flows of eight Swiss companies in 2019 were collected and analyzed. The results show that 1.6 kg/y/worker of workwear are procured. Concerning waste management, 0.6 kg/y are reused, 0.7 kg/y are incinerated, and 0.3 kg/y are recycled. According to the extrapolation, 0.4 kg/y/capita of workwear were consumed. The most weight-represented material type is mixed material, dominated by polycotton. Natural material, is the second biggest category, followed by synthetic and cellulosic materials. This study emphasizes the importance to monitor workwear flow data to enhance cooperation throughout the textile value chain and initiate circular management.

1. Introduction

The textile industry is currently following an unsustainable linear model, that, due to its production, use, and disposal management, represents a stress on natural resources (Ellen MacArthur Foundation, 2020; Rengel, 2017). The inclusion of circular economy (CE) principles has been identified as a promising solution to this problem as they stimulate the reduction of resource consumption, the reuse of garments, and the recycling of materials (Desing et al., 2020; Ellen MacArthur Foundation, 2020). The European textile industry makes great efforts to become more circular and sustainable, by implementing different initiatives (ECAP, 2021; EURATEX, 2021; European Commission, 2017a; Textile Exchange, 2021; Wrap, 2017, 2021) and enhancing collaboration among actors along the entire textile value chain (Braungart et al., 2007; Hemkhaus et al., 2019; Manshoven et al., 2019).

To reach circular textile management all the different lifecycle steps of the textile value chain have to be considered; from production to procurement, lifetime, collection, and disposal. In the end of life (EoL), incineration should be prevented and reuse or recycling should be encouraged (EEA, 2019; Spathas, 2017). The literature provides strong evidence that textile reuse and recycling are, in general, preferable waste management options compared to incineration, however after cascade use of textiles, energy recovery via combustion process nowadays is the only viable solution (Beton et al., 2014; Dahlbo et al., 2017; Sandin and Peters, 2018; Schmidt et al., 2016; Zamani et al., 2015). When reuse and recycling are both considered, the former is found to be environmentally more beneficial than the latter, as it prolongues the life span of a textile (Beton et al., 2014; Dahlbo et al., 2017; Sandin and Peters, 2018; Schmidt et al., 2016; Zamani et al., 2015).

The recycling of textiles contributes to the circularity of the textile sector. There is mechanical and chemical recycling. In chemical recycling garments are dissolved in chemicals to retrieve the wanted material and quality (Hemkhaus et al., 2019; Rengel, 2017). This process is mainly applied to synthetic fibers (Textile Exchange, 2019). Furthermore, recycling a mixed-fiber product is feasible, but the end product is restricted to mono-fibers (Hemkhaus et al., 2019). There is also the possibility of mechanical recycling, especially applicable to natural fibers (e.g. cotton, wool), in which the material is color-sorted, shredded, and turned into a fibrous form (Hemkhaus et al., 2019; Palm et al., 2017; Textile Exchange, 2019). It should be emphasized that these recycling methods are currently mostly applied in an open-loop system (the waste product will be processed and used in another value chain, e.g. a t-shirt becomes isolation material for cars), as closed-loop recycling processes (the waste product will be processed and used within the same value chain, e.g. a t-shirt becomes textile fiber and can be used to produce new

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* Corresponding author.
E-mail address: claudia.som@empa.ch (C. Som).

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Abbreviations

CE	Circular Economy
ECAP	European Clothing Action Plan
EEA	European Environmental Agency
EoL	End of Life
MFA	Material Flow Analysis
NDA	Nondisclosure Agreement
PPE	Personal Protective Equipment

t-shirts) are still under development (Payne, 2015; Sandin and Peters, 2018). Moreover, it has been shown that when closing a textile loop the environmental impacts can be reduced and the quality can be controlled (Braun et al., 2021). Closed-loop recycling enables multiple recycling loops and in the future, infinite recycling loops are the goal as it was shown in Braun et al. (2021). To achieve a CE in the textile industry, the transition from open-loop to closed-loop textile-to-textile recycling is necessary (Geyer et al., 2016; Haupt et al., 2017; Meylan et al., 2014).

The recycling process is challenged by an inconsistent influx of high-quality material and different material compositions (Hemkhaus et al., 2019; Textile Exchange, 2019). Moreover, the sorting process is complicated by overly diverse and colored fibers (Palm, 2011; Piribauer and Bartl, 2019; Zamani et al., 2015). Therefore, the environmentally and economically sustainable recycling processes prerequisite known material composition (Piribauer and Bartl, 2019), high-quality material (Hemkhaus et al., 2019), uniform material (Rengel, 2017), and high quantities (ECAP, 2019b). It is assumed that these characteristics are represented in most of the waste generated in the workwear textile sector. The term workwear refers to garments of a simple and robust nature, including work suits, overalls, coats, jackets, and trousers, as well as a variety of similar models, which are often customized with company-specific badges and logos. It can also be expected that companies and workwear providers have control over the number of garments, their EoL and can influence their design actively, which makes the planning for recycling more convenient. Workwear would play a big role as soon as closed-loop recycling becomes more technologically and economically viable (Rengel, 2017).

In the workwear sector, there are emerging initiatives that aim to promote the circularity of management, such as the Resource Efficient Business Models (REBus), which was set up to implement pilot projects in the UK and the Netherlands (Dura Vermeer et al., 2017; REBus, 2017; Rijkswaterstaat, 2017; UMC Utrecht, 2017). There are also other approaches focusing on sustainable materials and the composition of workwear and its recyclability (DMOD, 2017; Kautsch et al., 2015; Procura+, 2017).

No data on the amount and material composition of workwear could be found in the current scientific literature. However, a first attempt to quantify workwear purchase, consumption, and waste was made by the European Clothing Action Plan (ECAP). The workwear consumption in 2015 in Europe was 93′000 t (ECAP, 2017c). Additionally, the European Environmental Agency (EEA) cites a consumption of 0.3 kg of workwear per capita in the years 2019 and 2020 (Duhoux et al., 2022). The data of both reports is based on European statistics on community production, whose level of accuracy is uncertain (European Union, 2019). Moreover, there is no specific data for every country. Both aspects indicate a data gap and the necessity of workwear textile flow data. Research on the workwear textile flows is required to initiate a circular and sustainable management strategy.

There are different studies in the textile and workwear sector covering the area of the whole lifecycle, the environmental impact of textiles, recommendations for a more circular and sustainable textile/workwear management, and the quantification of material flows of textiles and workwear (see *A*). There are just a few peer-reviewed studies on the whole lifecycle of textiles and none on workwear (Dahlbo et al., 2017; Koszewska, 2018; Nørup et al., 2019). The studies and reports are often focusing on the environmental impact of textiles and workwear. None of the studies examines workwear in terms of real material flows, waste amounts, waste categorization (e.g. in workwear categories like bottoms and tops), and recycling potential. A lot of reports and studies do come up with recommendations and guidelines (ECAP, 2017c; Ellen MacArthur Foundation, 2017; Hemkhaus et al., 2019; Koszewska, 2018; OVAM, 2020; Saltzmann, 2015; Tojo et al., 2012). There are some studies and reports that try to quantify the textile or workwear amounts, but the data is restricted and incomplete (Dahlbo et al., 2017; ECAP, 2017c; Nørup et al., 2019; Palm et al., 2014, 2015; Schmidt et al., 2016; Tojo et al., 2012; Wrap, 2011).

To fill this gap, this study aims to analyze the workwear textile flows within Swiss companies involved in the production, procurement, lending, distribution, washing, and repairing of workwear, for which the composition and quality of their workwear should be well known and the quantities of the same waste material are relatively high, which could be a starting point to identify the needs to transition towards a circular workwear textile waste management. Switzerland was selected because of its high interest and engagement in making the textile industry more sustainable and circular as demonstrated by the Swiss sustainable textiles initiative and the Swiss-charta for sustainable textiles (IP Kerenzerberg, 2019). In addition, Swiss companies develop products of high quality and high functionality, providing an opportunity to explore the potential circularity of waste. In Switzerland, there is a data gap regarding workwear textile flows, as only data on collected textile waste (55′400 t) and disposed of via household waste is known (52′000 t)(FOEN, 2013, 2020; Steiger, 2014).

In addition, this study includes the amount and material composition of workwear textiles flows within Swiss companies and researches the circularity and sustainability of workwear management. Finally, it investigates the management of workwear textile waste in Switzerland and determines how it can be improved.

2. Methods

2.1. System boundaries of materials

Workwear can be divided into the categories career wear, uniforms, and personal protective equipment (PPE) (ECAP, 2017c; Rengel, 2017). Career wear garments are used to represent corporate identity worn in business environments such as banks, post offices, schools, gastronomy, etc. Uniforms are very durable and high-quality custom-made garments, e.g., for military, logistics, telecom, hospital, and public institutions (cleaning, forestry, etc.). PPE is a high-performance, durable, and qualitatively high-grade clothing designed to protect the wearer from injury in a specific environment and used e.g., in the construction sector.

This study included all categories of workwear except PPE. PPE is subject to many norms, standards, and regulations (EU Parliament & Council EU, 2016; Marek and Martinková, 2018; SECO, 2015). This means that the possibility for changes in design, material composition, and other properties in this workwear category is very small. In addition, the materials in this category are very specific and can differ considerably depending on the function, which makes the recycling of such workwear particularly challenging (Rengel, 2017). The term “workwear” in this study will continue to be used to include career wear and uniforms.

In the material flow analysis (MFA) shoes and leather products (e.g., belts) were excluded due to the use of different materials and treatments in the EoL.

2.2. Data collection

2.2.1. Systematic approach for the selection and contacting of companies

To collect data on workwear flows in Switzerland, Swiss companies

Table 1
Material and workwear categories.

Types/ Categories	Components of material types and workwear categories
Natural Material	cashmere, cotton, merino wool, wool
Synthetic Material	elastane, lastol, polyacrylic, polyamide, polyester, polypropylene, polyurethane
Cellulosic Material	bamboo, lyocell, viscose
Mixed Material	mix of various materials
Tops	sweaters, t-shirts, blouses, cardigans, woven shirts, laboratory coats
Bottoms	trousers, skirts, underpants, jeans
Accessories	hats, socks, scarfs, ties,
Coats	softshell jackets, parkas, rain- and winter jackets
Thermal Wear	thermo shirts, thermo pants

were contacted via e-mail, by research on the internet, and by the network of Empa.[1] NDAs were signed with the companies and confidential business information is not used or shared in this study. The data was collected in the period from April to July 2021. Twenty-one different companies were contacted, and eight companies were willing to share their data and knowledge. The strategy was to contact larger companies, because they usually procure high quantities of workwear, and have better control over the number of garments, their EoL and may also have more similar concepts where uniform and circular solutions can be proposed.

This study aimed to include different economic sectors to be more representative, for a cross-sectoral analysis of workwear management and more diversity in workwear categories. For each sector, criteria had been set (see *A*). The sectors of retail, logistics, and telecom were included in this study as these companies have a high number of employees wearing workwear and they have a management strategy to produce, procure, distribute, maintain, and dispose of workwear. The criterion for the logistic and telecom sector was the number of employees, which was set at 15′000 and higher. In the retail sector, the threshold was set at 4′000 employees, because just a smaller retailer responded. Professional laundries were included in the study as they supply workwear to many different companies and hence have a very broad overview of all the lifecycle steps of workwear. The criterion for professional laundries was that they manage workwear with leasing contracts, including repairing clothes. The workwear production was integrated, as they are responsible for the implementation of sustainable material use and design. The criterion for the production sector was that it is located in Switzerland and has at least a part of its production process (e.g. sewing) in Switzerland. The second criterion was, that the workwear producer not only sells the garments, but also provides management services such as repairing, washing, or even disposing of them. The research sector was included because it is the sector in which we work and consequently the data should be more accessible.

Companies using mainly PPE were excluded. Furthermore, some additional sectors, such as building, bank or military, were not included in the study as they were not contacted, because nocontact person could be found, the contacted company did not respond, or had no data on their workwear.

2.2.2. *Questionnaire*

For the data collection, a questionnaire was used which was based on the study of Schmutz & Som (2022) analyzing the industrial textile waste, and was adapted for this study (see *A*). The questionnaire is intended to obtain workwear material flows of the interviewed companies. The quantity-wise most important workwear categories had to be described (by function, material composition, coating, lifespan, and data measurement) and the amounts of produced/procured workwear in a one-year timeframe had to be determined. Niche application of workwear that are produced only in small amounts were excluded. Afterward, it was clarified whether workwear was given, sold, or lent to the employee and whether the company offered repairing or washing services. Then it was asked whether the companies take back the workwear for disposal or not and had to determine how much waste was generated per workwear category. Lastly, the management of the workwear textile waste was investigated. The company should explain their obstacles and possibilities to recycle/reuse their workwear.

Interviews were conducted with eight companies to discuss their workwear management strategy, their workwear data and the questionnaire (see *A*). There was an exchange with experts from the design, textile, sustainability, and procurement departments. All data was treated confidentially and will be shown and discussed in an aggregated form.

2.3. *Material flow analysis*

The MFA aimed to quantify the total amount and the corresponding material composition of workwear produced/procured and disposed of in Switzerland. Procurement and disposal data of the companies were collected for the year 2019 to elaborate a static MFA. The geographical system boundaries of the MFA were drawn at the national level of Switzerland. The analysis incorporated waste management in Switzerland to find out how workwear was processed at the EoL.

For a detailed analysis, workwear was classified according to material types and workwear categories listed in Table 1. The material types include natural materials, synthetic materials, cellulosic materials, and mixed materials. Natural, synthetic and cellulosic materials are made of 100% of one of the listed materials. Workwear categories comprise tops, bottoms, accessories, coats, and thermal wear. The categorization was determined by the similarity of clothes function and the material composition. This categorization serves as a simplification for the determination of the recycling potential and the quantity comparison to evaluate which category is worth collecting or recycling.

Every company had a different method to report their workwear data, so the data received was very diverse. For further calculations in Excel, it was important to build up all data sets in the same structure with all the same information. In *A* there is an overview of all the calculations done.

The workwear flows were indicated in number of tonnes or number of articles per category of workwear produced/procured and disposed of. If the data was in pieces per category, their weights per piece had to be provided. The composition of the materials of the workwear was provided accordingly in percentages. If there was an incomplete indication about the weight per procured/produced workwear garment, an average value, calculated according to comparable data from other companies, was used (e.g., shirt 0.3 kg, trousers 0.6 kg).

For the calculation of the waste data in companies that stated that they take back workwear, but did not have data about their post-consumer workwear waste or data just of the total amount of textile waste (not workwear specific), it was assumed that the percentage of different items of workwear was the same as in procurement/production. In order to estimate a collected amount of workwear waste, an average value of the other companies that could provide data was used. The individual material waste mixes of the various companies were calculated and added up.

Regarding the waste flows of workwear not taken back by the companies, it was assumed that they are disposed of by the employee through commercial waste flows or in textile collection containers. The Swiss textile collection rate (52%) was used to quantify the amount of collected workwear in containers of textile collectors (FOEN 2013, 2020; Steiger 2014).

The assumption was made that the entire amount of workwear

[1] Empa is an independent research institution with a wide network of contacts through the textile labs. Additionally the companies trust this institution and there was no dependency relation to the companies.

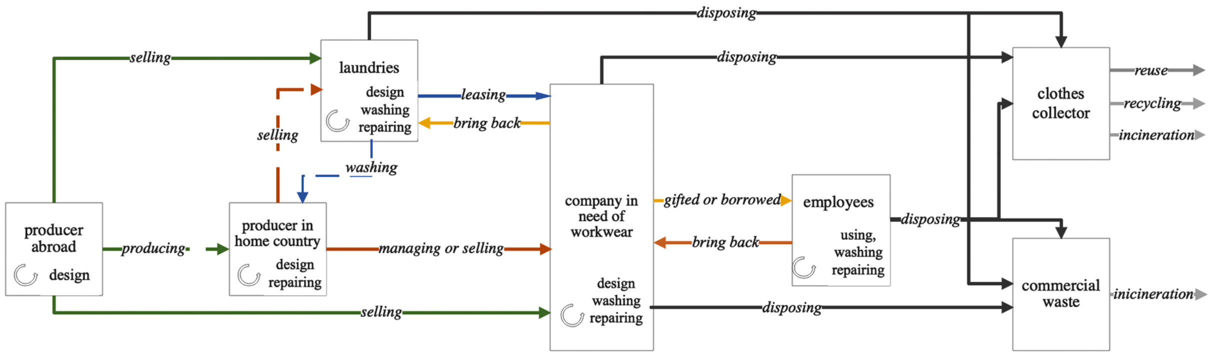

Fig. 1. Simplified overview of stakeholder relationships in the workwear management of the interviewed companies. The different colors of the arrows are to be assigned to the individual stakeholders. The black arrows are the disposal flows and the gray arrows are the EoL options.

produced/procured was disposed of at some point (i.e. the stocks and the lifetime of textiles were not considered). It should be noted that there was a possibility that workwear from other years, made of unknown materials and quantities, may be given to employees, however, this aspect could not be included in the analysis.

For the calculations of the waste management, the following simplification was assumed: If the workwear is disposed in household and commercial waste it is incinerated. For all the collected workwear in the company and textile collection containers, the EoL treatment data from Texaid was used, as it has a market share of 70% and is responsible for sorting, reuse, recycling and disposal of textiles in Switzerland (Rotzetter, 2022). Of the collected workwear 65% was reused, 30% was recycled in an open-loop system and 5% was incinerated (Rengel, 2017; Texaid, 2019).

2.4. Data extrapolation

To quantify the representativeness of this study the calculated workwear flows are extrapolated for the whole of Switzerland. For this, an average value in number of tonnes per employee is determined, which is calculated by dividing the tonnes of procured workwear in one company by the number of employees in the according company. For the calculation of the workwear, waste flows and the different EoL options, the ratio of the procured/produced and the upscaled workwear amount is determined. The quantities in the remaining life cycle steps are then multiplied by this ratio to obtain an approximate value.

According to EvB (2012) 2 million people in Switzerland used workwear in 2012. Since this is the only number known to us at this moment of the study, it is used as an approximation. The number of workwear amounts per employee and year is then multiplied by the number of people using workwear in Switzerland. To compare this value with the total textile waste per capita, the quantity per employee must be adjusted to the quantity per Swiss. This is calculated by the ratio of the number of people wearing work clothes in 2012 (2 million) and the number of people living in Switzerland in 2019 (8.6 million) (FSO, 2020).

3. Results

3.1. Overview of workwear management in Switzerland

To have a better understanding of the management of workwear in Switzerland, the results from the interviews with the experts from the companies are summarized and shown in a general overview in Fig. 1.

Producers are responsible for the implementation of the design, which can be decided by themselves or by their customers. The production can be executed in the home country or abroad. There are producers, which offer management contracts, meaning that a company in need of workwear pays for clothes and the provider is responsible for washing and repairing them. The finished workwear garment is sold directly to companies in need of workwear or laundries. It is assumed that the producer is not responsible for post-consumer workwear waste disposal.

Laundries procure workwear from producers abroad or in the home country, under consideration of certain standards (Amfori, 2021; Fair Wear Foundation, 2021; ISO, 2021; OEKO-TEX, 2021). They draft leasing contracts, including repairing and maintaining workwear, with the companies in need of workwear and execute size exchanges, stocking up and down, and replacement of workwear. Moreover, they provide tracking systems that allow them to monitor each piece of workwear. In the EoL workwear is returned automatically because of the leasing contracts and disposed of through a textile collector or commercial waste.

Companies in need of workwear let produce or lease workwear under certain standards (Amfori, 2021; Fair Wear Foundation, 2021; ISO, 2021; OEKO-TEX, 2021). Some companies provide the service of washing and repairing. The companies in need of workwear lend the workwear to their employees or give it to them for free. Often companies do not see themselves as responsible for taking back the used workwear, with the justification that they are the property of the employees. However, some collect and take back the clothes voluntarily. These clothes are then picked up by textile collectors, charitable organizations, or disposed of as commercial waste.

Employees are the users of workwear. If the companies do not provide repair or washing services, the employees must do it by themselves. The possibilities in the EoL are to bring them back to the company, or as disposal through household waste or to textile collector containers. If the textile waste goes into the household waste the garments are incinerated.

Clothes collectors are responsible for the sorting and the EoL of the textile post-consumer waste. They either reuse, recycle (in an open-loop system) or incinerate the collected workwear. However, the companies that have handed over the workwear to textile collectors usually do not know which EoL path their textiles are given to.

On asking the companies about the difficulties of workwear recycling, the main obstacles are the absence of a market and the fact, that recycling is not economical for them. When directly reusing the workwear, the companies see a safety problem with the logo. This should be removed, but it is still unclear which stakeholder should be responsible for executing it.

In addition, there seems to be a complex logistical collection and sorting problem of workwear waste, as space, time, and lack of technology are missing. For many interviewed companies, it is not possible to sort the returned workwear from other textile waste or to categorize the workwear itself. This leads to uncertainties in quantifying workwear waste. Another recycling problem is the high amount of workwear waste demanded by recyclers. One company does not reach these quantities to develop a collaboration.

Table 2
Data quality and completeness per interviewed company.

	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7	Company 8
Sector	Professional laundry	Professional laundry	Workwear producer	Logistics	Logistics	Telecom	Retail	Research
Quantitative Data	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Procurement Data	No	Workwear categories from biggest supplied sector	Materials used according to material purchase	Workwear Categories, total amount, and corresponding percentage of workwear categories	Amount of pieces procured (not categorized)	Workwear categories, amount of pieces	Amount of pieces procured (not categorized)	Amount of pieces per workwear category
Weight	No	Yes	Yes	Yes	No	No	Incomplete	No
Material	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Workwear Details (Function, Coating, Lifetime, Contaminants)	No	Function	No	Function	No	Lifetime	No	Function
Waste Data	No	Per workwear category	No	Total amount	No	Total amount	Total textile amount	No
Waste Management	No	No	No	No	No	No	No	No

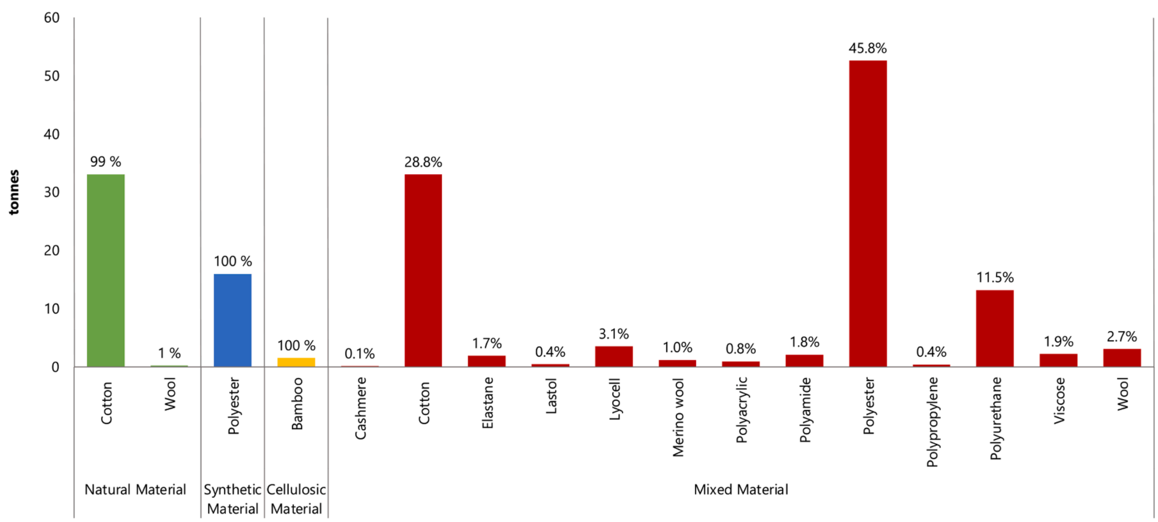

Fig. 2. Material composition of material types of the procured/produced workwear. The percentages correspond to the shares of the materials in the corresponding material types.

3.2. Data quality: incompleteness and its influence on the MFA

An overview of the data quality and completeness is given in Table 2. Two of the eight companies could not provide information on the quantity of their workwear categories, neither for procurement/production nor for waste. Three companies provided the number of pieces of workwear, but not in every case the exact weight of the garments. One company had no information about the material composition. The weight and material composition were then calculated according to the description in chapter 2.3. Almost none of the companies could provide detailed information on workwear. So the aspects of the function, contaminants (e.g. buttons, zippers, or logo), and lifetime could not be included in the MFA. Without lifetime data, it was not possible to make any statements about the total duration of the life cycle, to which time point the clothes were disposed of, and which workwear categories needed to be rebought the most.

One company had data on waste per workwear garment type, as they have a tracking system for every single piece. Three other companies provided data on the total amount of workwear waste but had no information about its composition. Another company provided the total amount of textile waste (unsold textiles and workwear) but not the workwear-specific waste. The rest was not able to provide such data. Four companies give their workwear at the EoL to a third stakeholder, which collects the clothes and reuses, recycles, or incinerates them. One company said that they started a pilot project with such a stakeholder but was not able to quantify the amount of workwear; thus, it is assumed that the employee is responsible for the disposal. The same scenario is applied to a company that does not collaborate with a collector.

None of the interviewees could indicate their workwear management, on how much workwear is reused, recycled, or incinerated. The reasons for this are the lack of monitoring, the responsibility of disposal left by the employee, or the delivery of used clothing left to collectors.

3.3. Material flow analysis

3.3.1. Material composition of workwear

The amount of workwear procured, and its material composition can be well determined with the companies' data. For the calculations, 68 different workwear categories from six different companies and 14 different materials were examined. The total amount of workwear procured in the year 2019 is 165 t (1.6 kg/worker). The unknown procurement/production of workwear from other years is not quantifiable. Moreover, it is not clear if workwear from other years was handed out to the employees. One company provided waste data that showed slightly higher amounts of waste than procurement, which was considered in the workwear waste flows.

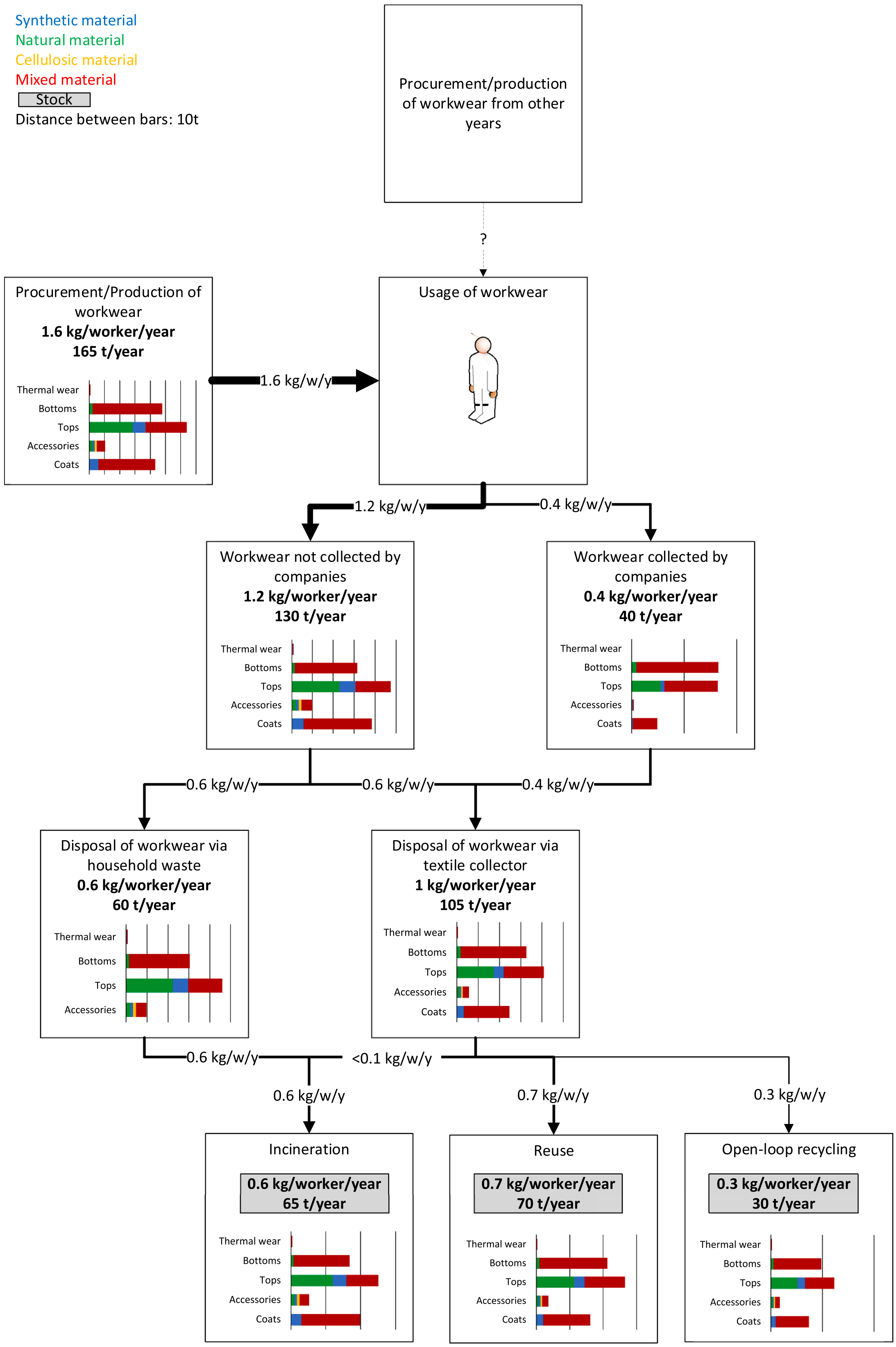

Fig. 3. MFA of workwear of the companies covered in this study grouped by material and workwear categories in the year 2019. The amounts reported for the flows are rounded to two significant figures and the nearest five.

The materials polyester (41%) and cotton (40%) cover 81% of the total aggregated material weight. Followed by polyurethane with 8% and lyocell, wool with 2%, respectively. The other materials, namely bamboo, cashmere, elastane, merino, polyacrylic, polyamide, polypropylene, lastol and viscose, are at or lower than 1%.

For a more detailed analysis, the relative amounts of the different materials are calculated for every lifecycle step and shown in Fig. 2. In the procurement, mixed materials accounted for most workwear garments with 69% of the total amount. Followed by 20% natural, 10% synthetic, and 1% cellulosic material, respectively. Mixed material included polyester accounting for 46%, followed by cotton with 29%, polyurethane with 11.5%, wool, lyocell with 3%, viscose, polyamide with 2%, elastane with 1.5%, merino wool, polyacrylic with 1%. Cashmere, lastol and polypropylene accounted for less than 1%, respectively. An interesting aspect to see is that the majority of the procured/produced workwear is made of a mixture of two to a maximum of four different materials. Mixes are mainly polyester with cotton, polyurethane, or wool. Cotton is also mixed with lyocell or elastane for more elasticity. The composition of the mixes and the number of different materials remain the same in all the steps described below.

Natural material includes cotton with 99% and wool with 1%. Synthetic materials contain only polyester and cellulosic material only bamboo. None of the other synthetic or cellulosic materials are found as mono-fiber in a garment. Consequently, cotton, wool, polyester, and bamboo are the only mono-fiber materials used in a workwear piece. The material compositions in the natural, synthetic, and cellulosic types are valid for all the steps explained. It should be noted that the majority of the 68 categories of workwear are made of only one material, but the quantities of these materials are much smaller.

3.3.2. MFA of material types

The material flow and the material types composition of workwear in the companies covered in this work are illustrated in Fig. 3. The total amount of collected waste by the companies in 2019 is 40 t, the rest of the procured amount is assumed to be not collected and disposed of by the employees. The collected workwear waste by the companies is composed of 80% mixed, 17% natural, and 3% synthetic material. Mixed materials contain 45% polyester, 37% cotton, 12% lyocell, 4% polyurethane, respectively. All the other materials had a percentage at or below 1%.

The amount of workwear not collected by the companies is 130 t Not collected workwear has a composition of 66% mixed, 21% natural, 12% synthetic, and 1% cellulosic material. The mixed material type includes 46% polyester, 26% cotton, 14% polyurethane, 4% wool, 2% elastane, polyamide, and viscose, respectively. All the other materials had a percentage at or below 1%. 60 t of the not collected workwear are disposed of via household waste. The material compositions are the same as in the previous step. The entire amount of workwear collected in companies and the amount of workwear brought to the textile collector by the worker is 105 t. This amount is disposed of via a clothing collector. 71% are mixed, 20% are natural, 8% are synthetic and 1% cellulosic material. Mixed material is composed of 46% polyester, 30% cotton, 10% polyurethane, 5% lyocell, 2% wool, and viscose. All the other materials had a percentage at or below 1%. In the EoL, workwear garments are either incinerated, open-loop recycled, or reused. According to the calculations, 70 t are reused and 30 t of workwear end up in the open-loop recycling. In both steps, the number of tonnes is composed of 71% mixed, 20% natural, 8% synthetic, 1% cellulosic materials. The mixed type includes 30% cotton, 46% polyester, 10% polyurethane, 5% lyocell, 2% viscose, and wool. All the other materials showed a percentage at or below 1%. The remaining 65 t of workwear are sent to incineration. The material type mix reads as follows: 67% mixed, 11% synthetic, 21% natural, 1% cellulosic material. The mixed material type is composed of 46% polyester, 26% cotton, 14% polyurethane, 3% wool, 2% polyamide, elastane, viscose. All the other materials had a percentage at or below 1%.

To conclude from the procured amount of workwear in the companies covered in this work, less than a third is taken back by the companies. In the EoL 41% is reused, 40% is incinerated and 19% is open-loop recycled. The results of the MFA show that every lifecycle step of workwear is dominated by mixed materials (66–80%). The composition of the mixes and the number of different materials remain the same in all the steps. The second-largest material type is natural material (16–21%). It is composed of mainly cotton and less wool. The next type is synthetic material (6–11%), which is dominated by polyester. The last type is cellulosic material (1–2%) consisting only of bamboo.

3.3.3. MFA of categorized material and workwear

The material flows are also analyzed according to workwear categories (see Table 1) and are illustrated in Fig. 3 (see A for more details of the material and workwear categories amounts). The majority of the procured workwear garments are accounted to the category tops (64 t), followed by bottoms (48 t), coats (43 t), accessories (10 t), and thermal wear (1 t). The categories tops and bottoms were collected in equal quantities (16.5 t), followed by coats (5 t), accessories (0.5 t), and thermal wear (<0.1 t). The amount of not collected workwear by companies is 48 t from the category tops, 38 t from coats, 31 t from bottoms, 10 t from accessories, and 1 t from thermal wear. 23 t of tops, 18.5 t of coats, 15 t of bottoms, 5 t of accessories, and 0.5 t of thermal wear are disposed of in the household waste. 41 t of tops, 33 t of bottoms, 24.5 t of coats, 5.5 t of accessories, and 0.5 t of thermal wear are collected by a textile collector. In the EoL 26.5 t of tops, 21 t of bottoms, 16 t of coats, 3.5 t of accessories, and <0.5 t of thermal wear are reused. In the open-loop recycling process, 12 t of tops, 10 t of bottoms, 7.5 t of coats, 1.5 t of accessories, and <0.5 t of thermal wear are repurposed. In the incineration, step tops accounted for 25 t, coats for 20 t, bottoms for 17 t, accessories for 5 t, and thermal wear for 0.5 t.

The workwear categories tops, bottoms, and coats make the highest amount of workwear. All the following material category shares in the workwear categories are given in ranges as they differ in the different lifecycle steps The differences are mainly caused by the collection of the companies because depending on whether a company takes back the workwear, other categories are represented more or less in a material flow.

Tops are made of 35–62% mixed, 34–48% natural, and 5–16% synthetic material, respectively. Consequently, in this quantitatively dominant category, there is a high percentage of mono-fiber materials. Bottom parts consist mainly of mixed materials (94–95%) or natural materials (5–6%). Coats are composed of 85–94% mixed materials, 5–15% synthetic, and 0–1% natural material. In the category of accessories, all material types are represented (34–50% mixed, 21–38% natural, 13–28% synthetic, and 0–16% cellulosic material) and therefore the category shows great variability, but around half of the materials are made of only one fiber. In the thermal wear category, 62–100% accounted for mixed and 0–38% for synthetic material. Consequently, a large part of this category is made of only one material depending on the lifecycle step, but the category is only weakly represented in terms of quantity.

3.4. Extrapolation of workwear amount in Switzerland

The calculated average value of consumed workwear per worker in the year 2019 is 1.6 kg [range, 0.24–3.9 kg]. The calculations are done with the data of four companies; as for the laundries, it was not known how many workers they supply, and one other company had incomplete data. The calculated amount of workwear per capita in Switzerland is 0.4 kg [range, 0.1–1 kg] (FSO, 2020). Multiplying the amount of workwear per capita with the number of 2 million people using workwear in Switzerland (EvB, 2012), this results in a rounded value of 3′200 t [range, 480–7′800 t] procured/produced and wasted workwear. By categorizing this amount this results in 1′200 t [range, 190–3′000 t] of tops, 900 t [range, 140–2′200 t] of bottoms, 840 t [range, 130–2′000 t]

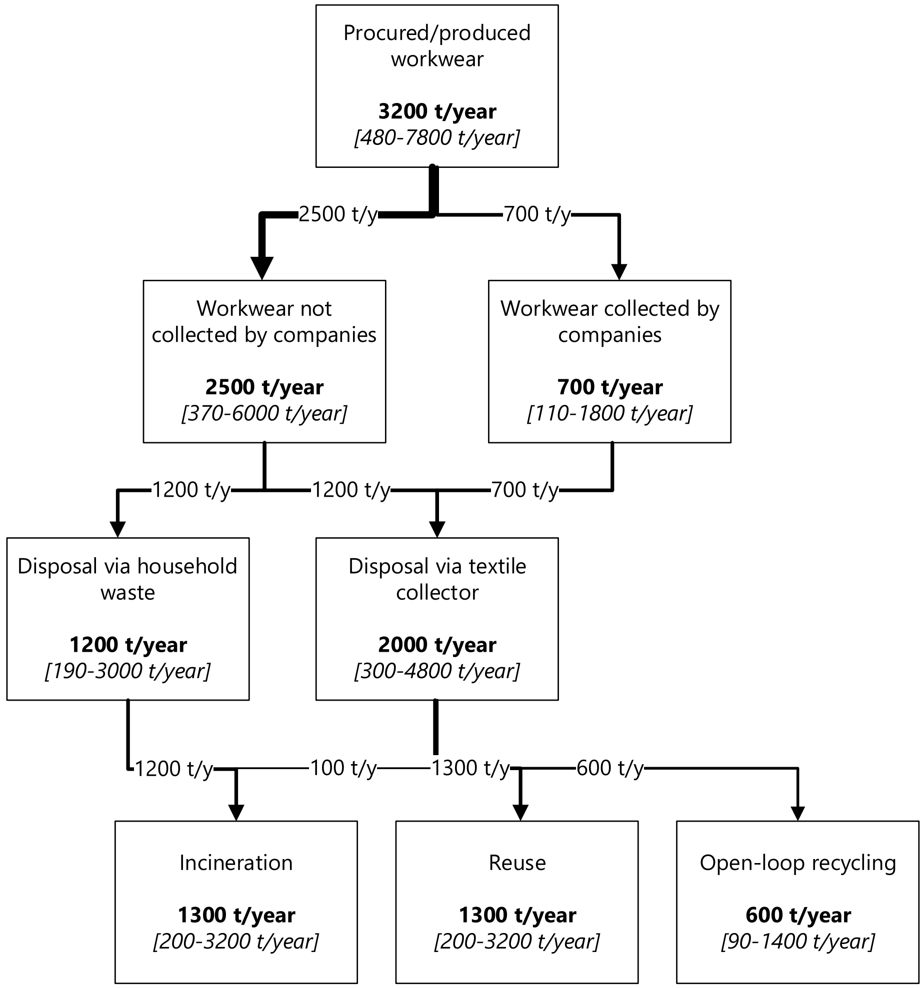

Fig. 4. Estimation of extrapolated amounts of workwear in Switzerland in 2019. The amounts reported are rounded to two significant figures. The value in brackets indicates the range.

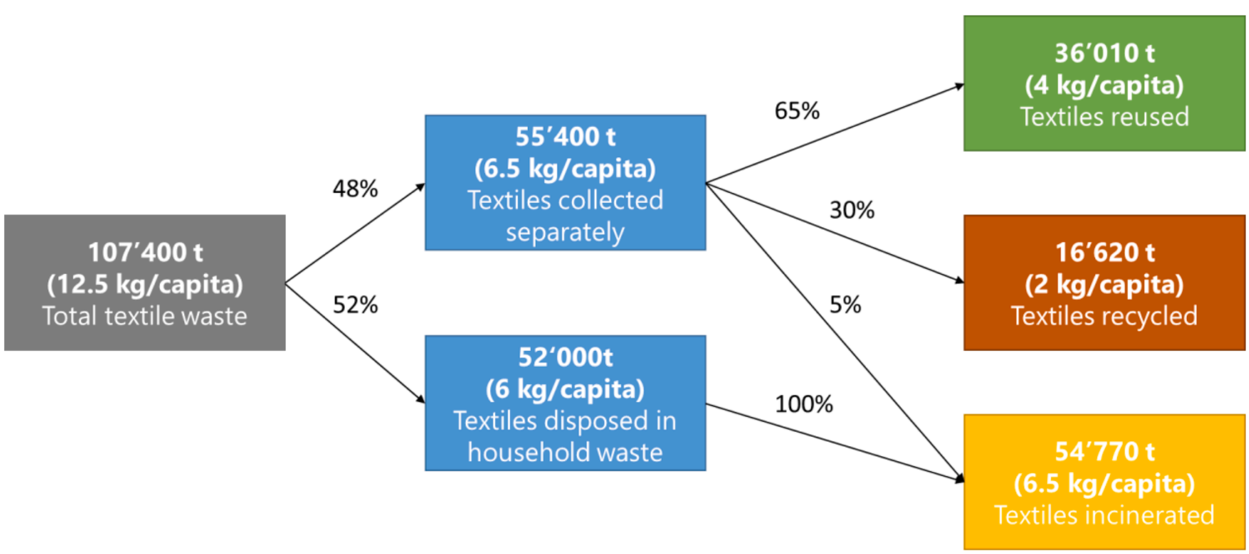

Fig. 5. Textile waste amounts in Switzerland in the year 2019 (FOEN 2013, 2020; Steiger 2014).

of coats, 200 t [range, 30–500 t] of accessories and 14 t [range, 2–33 t] of thermal wear.

With the ratios calculated for the subsequent workwear flows, the remaining quantities could be determined, all of which can be seen in Fig. 4. Consequently, 2′500 t [range, 370–6000 t] of workwear are not collected by companies, 700 t [range, 110–1′800 t] are collected, 1′200 t [range, 190–3′000 t] are disposed of in the household waste, and 2′000 t [range, 300–4′800 t] are disposed of by the textile collector. In the EoL 1′300 t [range, 200–3′200 t] are incinerated, 1′300 t [range, 200–3′200 t] are reused, and 600 t [range, 90–1′400 t] are recycled.

4. Discussion

4.1. Workwear amounts in comparison to numbers in literature

This paper is the first study that identified the amount and materials flows of workwear according to the material type and workwear category. Previously, only the total textile waste collected and disposed of through household waste was known in Switzerland, without material specifications and the categorization in workwear. The MFA shows that 165 t (1.6 kg/worker) of workwear in the companies covered in this work and an extrapolated amount of 3′200 t (0.4 kg/capita) of workwear are consumed in the year 2019 in Switzerland. The amount of workwear per capita or per worker per year allows being extrapolated and compared to data also from other countries.

The following Swiss textile waste data is compared for the first time with different sources and compiled in Fig. 5. The report of Swiss data shows that 55′400 t of textiles were collected in 2019 (FOEN, 2020) and 52′000 t of textiles were disposed of in household waste in 2012 (FOEN, 2013; Steiger, 2014). According to Rotzetter (2022), the amounts from 2012 to 2019 can be added up to become the total amount of 107′400 t of textile waste in Switzerland in the year 2019, as it is assumed that the amount of disposed of textiles in the household waste is comparable in these years. Detailed information on the exact percentage of textile waste that is disposed of, recycled, landfilled, or incinerated is not known (Wälti and Almeida, 2016), wherefore Texaid's collection, recycling, reuse, and incineration rates are used (Rengel, 2017; Texaid, 2019). The total textile waste in Switzerland in 2019 is 107′400 t, which corresponds to 12.5 kg of textile waste per capita (FOEN 2013, 2020; Steiger 2014).

The comparison of these amounts with the Swiss textile waste (107′400 t, 12.5 kg/capita) shows that the workwear corresponds to about 3% of textiles disposed of in Switzerland in the year 2019 (FOEN 2013, 2020; Steiger 2014). Moreover, the workwear amount of 3′200 t is twice the modeled value of textile production waste (1′505 t) in Switzerland in 2019 (Schmutz and Som, 2022). In the case of Swiss textile waste, it can be assumed that workwear is already included in the total amount since all types of textiles are represented in the statistics.

The available European workwear data is summarized in the report of ECAP (2017c). The data is based on European statistics on community production, whose level of accuracy is uncertain and it is not clearly defined what the different data categories contain. The consumption by the employed population in different countries was 0.18 kg in Netherland, 0.26 kg in the UK, and 0.94 kg in Denmark in the year 2015. The report of ECAP (2017c) used the number of employed personnel to calculate the workwear consumption. In Netherland 50% are employed, in the UK 48% and in Denmark 46%. However, not all employees use workwear, and therefore the Swiss number of 2 million people (25% of the population in 2012) using workwear is of much higher quality than the estimate used in a previous report that is not accurate.

In comparison to the 1.6 kg in Switzerland in 2019, the amounts in Europe are lower. By comparing the total consumption of workwear in Europe (EU 28) in 2015 was 93′000 t (0.18 kg/capita). The extrapolated amount of workwear can be compared with the consumption of workwear in Europe, as in this study the procured and disposed amounts of workwear are the same. The amount per capita is calculated by dividing it by the number of people in EU 28 in 2015 (Eurostat, 2015). Compared to 3200 t (0.4 kg/capita) of workwear in Switzerland this also makes up about 3% of the European consumption, but the per capita consumption is higher than the European one. Moreover, there is a report from the European Environmental Agency, based on European statistics, that cites 0.3 kg/capita of workwear consumed in 2019 and 2020 (Duhoux et al., 2022). This amount corresponds to the one found in this study (0.4 kg/capita). The comparison has shown that there is less and/or uncertain data available on workwear flows in Switzerland and Europe, making this study one of the first in the field with a comparatively solid basis.

4.2. Material composition and recycling potential

Our work allowed for the first time to obtain information on the materials used in workwear. In procurement, mixed materials accounted for most workwear garments with 69% (46% polyester, 29% cotton, 11.5% polyurethane, 3% wool, lyocell, 2% viscose, polyamide, 1.5% elastane, 1% merino wool, polyacrylic, <1% cashmere, lastol, polypropylene), followed by 20% natural (99% cotton, 1% wool), 10% synthetic (100% polyester), and 1% cellulosic material (100% bamboo), respectively. Another new insight gained from this study is the categorization of workwear in tops, bottoms, coats, thermal wear, accessories. The categorization is seen as an added value, as it can be used to identify the category with the greatest recycling potential and thus also contribute to the optimization of the collection and sorting of workwear.

According to the fiber and material textile market report, the market share is: 52% polyester, 23% cotton, 6.5% manmade cellulosic, 1% wool and down, and 17% other materials (Textile Exchange, 2020). There is a publication from the EU, that states that clothing is composed of 43% cotton, 16% polyester, approximately 10% acrylic, wool, and viscose each (Beton et al., 2014). The comparison between these shares and the results in this study shows that in all cases polyester and cotton are among the most used materials. However, in workwear, there is a higher share of polyurethane, which is used in the category coats for the coating, and wool. Both materials positively contribute to the durability of workwear. The other materials are more present in smaller quantities and are more often used in mixes. The material compositions of textiles are different in the reports and indicate a discrepancy in accuracy or knowledge in the textile sector.

Differences between normal clothes and workwear are assumed to be the usage of high-quality (Hemkhaus et al., 2019) and mono-fibers material in workwear (Rengel, 2017). This is seen in the majority of the workwear products in this study, which, however, are only present in a small proportion of quantities. The mixes in this study are mainly made of two or three different fibers, with a maximum of four. The mixes consist mainly of polyester with cotton, polyurethane, or wool and cotton with lyocell or elastane.

First insights about the material composition of the workwear are an added value of this study because it was not known about textile waste until now. The material composition is a knowledge that has a positive effect on the recycling of clothing, as the environmentally and economically sustainable recycling processes prerequisite known material composition (Piribauer and Bartl, 2019), uniform material, and high quantities (ECAP, 2019b).

Depending on the material, the way of the recycling process and product differs (Palm et al., 2017; Sandin and Peters, 2018; Sysav, 2021). The category "tops" has the highest share and amount of natural material and so the potential of being mechanically recycled, but the process leads to inferior quality fiber: the recycled fiber gets every time shorter and needs to be mixed with virgin material (Niinimäki et al., 2020; Patti et al., 2021; Rengel, 2017; Schmidt et al., 2016). Synthetic materials are present in all the workwear categories. The highest share is in the category "thermal wear" and "coats". However, the amount of thermal wear is rather small. Consequently, collection and recycling of coats would increase the chemical recycling potential, as it is mostly applied to synthetic fibers (Textile Exchange, 2019). The properties of recycled polyester equal virgin polyester if the purity of the input is given (Hemkhaus et al., 2019; Schmidt et al., 2016). The recycling of the cellulosic material bamboo fiber is not done according to the current knowledge in this study and therefore, the expansion and knowledge of its recycling potential are limited.

All the other materials are part of the mixed material type, which is a major barrier to high-quality textile recycling (Elander et al., 2017). There are possibilities of mechanical and chemical recycling, but it does not return a product of the same quality as the virgin material (Manshoven et al., 2019; Palme et al., 2017; Peterson, 2015). Such recycling, however, needs more development and research (EEA, 2019; Sandin and Peters, 2018; Schmidt et al., 2016).

It should be emphasized that the referred recycling process in this study is an open-loop system. This finding is also supported by other studies (Elander et al., 2017; Palm et al., 2014). As soon as closed-loop recycling becomes more technologically and economically viable (Hemkhaus et al., 2019; Rengel, 2017; Textile Exchange, 2019; Zamani, 2014), workwear can play an interesting role to enhance more circularity by moving the system from an open-loop to a closed-loop one (Geyer et al., 2016; Haupt et al., 2017; Meylan et al., 2014).

4.3. Limitations

In the present study, six different sectors (logistics, retail, professional laundry, producer, telecom, and research) managing workwear are represented. The companies studied are assumed to be well represented in their respective sectors, since there should be no major differences in the number of workwear per worker in a sector. However, for further research, it is necessary to have accurate data from more companies to obtain a broader representative picture, since sectors that mainly use PPE or did not respond to the request were not integrated into the study.

In the procurement/production step the material composition, the weight of the garments, and the workwear categories could be well determined, although in certain cases some data were incomplete, it was possible to determine them with average values. It has been shown that the quantities of workwear per worker vary among Swiss companies, but that the same type of workwear items in the different companies are similar in terms of material composition. Therefore, the material composition flows in the analysis can be considered to be relatively accurate in comparison to other aspects in this study. The present study does not cover all procured workwear, as not all categories (e.g. PPE, special categories in small amounts) are included, or no data was available for the total amount of procured workwear. In addition, workwear quantities from other years (i.e. the stocks and the lifetime of textiles) are not included in the analysis because they cannot be quantified. Therefore, in this study, the simplification was made that the entire amount of work clothes procured was disposed in the same year since there were no other figures on this and the workwear must be disposed of at some point.

There are some uncertainties concerning waste management since the Swiss collection rate had to use data from different years. It was not clear where the workwear would end up at the EoL when collected by the textile collectors., so, the assumption was made with the data from Texaid. For these reasons, in the EoL the different material types could not be considered, which leads to the fact that e.g. mono-materials were incinerated, although they could be recycled.

The extrapolation of workwear gives a good first impression of how much workwear is in circulation in Switzerland, although the extrapolation of the number of people using workwear is based on a different year (i.e., 2012) and calculations are not done with all the quantitative data, as for the laundries, it was not known how many workers they supply, and one other company had incomplete data, which makes the number somewhat less representative. The wide range of extrapolated workwear quantities is due to the fact that it was not as simple to obtain data and this study is therefore based on a small sample of companies. For this reason, there is a correspondingly large variation.

The analysis of the data quality for this study emphasizes that more precise monitoring of workwear flows is necessary. Through monitoring of amounts and material composition (incl. impurities, logos, etc.), company-specific circular workwear management can be developed, as this allows the current strengths and weaknesses to be analyzed. Especially the waste monitoring in the collection phase is important, as data collection and analysis contribute to more transparency and may enhance productive cooperation with other stakeholders (ECAP, 2017a, 2018a). With the help of this information, companies can provide an improved potential to sort more efficiently and to recycle or reuse higher amounts of waste.

4.4. Circularity in the workwear management

The companies considered in this study stated that during the designing process, the material strategy is crucial (Centexbel, 2021; ECAP, 2019d, 2019a). The use of mono-fiber-composed garments contributes to better recyclability (Rengel, 2017). Cotton and polyester, which are represented in the highest amounts in this study, are the most studied materials also regarding the technological recycling progress. So, they have higher possibilities to be recycled than the other materials used (Hemkhaus et al., 2019; OVAM, 2020; Palm et al., 2017). Moreover, for the environmental performance it is important to consider first the quality and long life span of the workwear and then the easy disassembly of the garment for better repairability and recyclability, which is furthermore enhanced by the inclusion of removable logo and compartments (Bauer et al., 2018; ECAP, 2019a; OVAM, 2020).

The interviewed companies stated that in the workwear production and procurement step they consider certain quality- and eco-standards/labels, to reassure good documentation and transparency (Bauer et al., 2018; ECAP, 2017c; GOTS, 2021; Textile Exchange, 2014). In order to additionally increase transparency knowledge sharing between the companies at key decision points within the procurement should be promoted to accelerate the take-up of circular procurement and scale up the impact reduction and the benefits associated with closing workwear materials loops (ECAP, 2017c, 2018b, 2019b; Procura+, 2017; REBus, 2017).

During the lifetime of work clothes, the interviews showed that there are two ways to manage them. Either they are leased from laundries/producers with management contracts or the companies that need work clothes buy/let produce them and manage them themselves. The laundries are responsible for washing, repairing, and disposing of the clothes. Additionally, laundries have a track system for traceability and stock control of workwear so they have an overview of all the garments in the system (ECAP, 2017b; European Commission, 2015; REBus, 2017). A contract for the supply, maintenance, and cleaning of the clothing is beneficial in environmental terms because the supplier is obliged to wash responsibly, as well as repair and replace damaged and worn-out workwear (ECAP, 2017b; European Commission, 2015; REBus, 2017). The interviewed companies that need workwear, however, only occasionally offer washing, repairing, or take-back of work clothes. Therefore, employees must take responsibility and should be well informed about how to use, wash, repair, and dispose of their workwear (Bauer et al., 2018; Cooper et al., 2013; ECAP, 2019e).

As seen in the interviewed companies, at the end of the use, there are two ways to handle workwear: Either workwear is returned to the companies, offering a take-back system, or the employee is responsible for the disposal. The collection of workwear is important as it serves to obtain frequently large quantities of high-quality material for reuse or recycling (Bukhari et al., 2018; DMOD, 2017; ECAP, 2018d; European Commission, 2017b; GEA Group, 2017).

A take-back system can be established by a company that manages its workwear by itself or by a company offering a leasing/management contract. The leasing contract has the positive aspect that the workwear will be returned due to the contract and the tracking system. However, in this state of the study, it cannot be said whether the collection is made more effective by leasing contracts or not. Through the collection in companies, waste monitoring could be further developed, which enables to categorize and determine the workwear waste. Consequently, in the future, material and amounts of workwear categories would be known and serve to better cooperate with textile recyclers or collectors. Although the workwear of the companies and the employees end up in the same stream of the textile collector, it is still important that the companies are held responsible to collect the clothing. This is to reduce the amount of work clothes disposed of in the household waste stream and to have the opportunity to collect large quantities of high-quality textiles regularly. As the companies interviewed for this study see a complex logistical collection and sorting problem of workwear waste, as space, time, and lack of technology are missing in their infrastructure, a strategic collection could be considered to overcome the problem of large material variety in post-consumer waste, by e.g., collecting just a certain workwear category with known material composition (ECAP, 2017c, 2018c; OVAM, 2020). Moreover, the companies could think about the exchange of information with sorters on the amount and material composition of workwear to elaborate solutions for sorting in the companies (Defra, 2011; ECAP, 2019c; OVAM, 2020; Saltzmann, 2015; Uniformreuse, 2009) and to talk about the removal of the logo/de-branding of the garment for security reasons (Rengel, 2017).

Currently, it is not possible to say how much additional work this would require for a company and whether it would be worthwhile to switch to leasing contracts in this context. The collection is also important to start joint projects with other companies to transfer high enough quantities of similar clothing to a recycler in the future and to promote closed-loop recycling, as the interviewed companies stated that a recycling problem is the high amount of workwear waste demanded by recyclers. One company does not reach these quantities to develop a collaboration and the necessary amount for recycling textiles is still to be determined.

In this study, it has been seen that in the EoL 41% of workwear waste is reused, 40% is incinerated, and 19% is open-loop recycled. To reach a circular workwear waste management, incineration should be prevented and reuse or recycling should be encouraged (EEA, 2019; Spathas, 2017). The literature provides strong evidence that textile reuse and recycling are, in general, preferable waste management options compared to incineration. When reuse and recycling are both considered, the former is found to be environmentally more beneficial than the latter (Beton et al., 2014; Dahlbo et al., 2017; Sandin and Peters, 2018; Schmidt et al., 2016; Zamani et al., 2015). Due to this fact, reuse is still the most sustainable option to be preferred at the moment. Consequently, companies could consider cooperation with charity institutions for reuse in second-hand shops or upcycling projects (ECAP, 2017c, 2018c; European Commission, 2016; Hemkhaus et al., 2019; Wrap, 2017).

Since the companies had little or no information on what to do with all of their workwear waste, incentives for companies to increase their interest in the EoL of their workwear have to be assessed to promote the urge for circularity, sustainability, and valuable solutions, which should include future waste monitoring and collaborations with recycler and textile collector. This could lead to an elaboration of a suitable EoL solution so that no resources are lost in a linear workwear management system.

5. Conclusion and outlook

This study demonstrates the flows of the workwear lifecycle of the interviewed companies and the extrapolated amount of workwear waste per year for Switzerland, including the type of materials and categories of workwear garments. The research showed that relevant amounts 1.6 kg/y/worker and 0.4 kg/y/capita of workwear occur in Switzerland. Based on this study, most of the workwear is reused. However, a considerable amount is incinerated and could instead be diverted into the flow of reuse or recycling to comply with CE principles. These results may provide a first basis to establish a circular workwear management strategy, as workwear fulfills the prerequisites for recycling by being uniform, of high-quality, known material composition, and by occurring in high quantities.

It has been seen that there are two main ways to manage workwear: Either workwear is leased from laundries/producers with management contracts or the companies in need of workwear manage it themselves. In such companies, the employees are often responsible for the disposal and therefore the EoL is less clear. The collection of workwear is important to obtain a sufficiently high and equal quantity of textiles for recycling and to determine the textile waste. However, all the disposed workwear ended in the same EoL pathways. One relevant result of this study was that the interviewed companies are still lacking qualitative and quantitative data on their workwear (waste) flows. The workwear management strategies and the barriers faced by companies to move towards a more circular textile industry were provided in this study. Therefore, there is a need for professional monitoring and data collection to decide on an efficient and circular management.

Professional workwear management has to start with the design and material choice for a long life span and end with the collection and adequate disposal respectively provide the basis to keep the materials as valuable resources in the loop by reusing and recycling it over infinite loops with as low effort as possible. Moreover, a close collaboration with all stakeholders of the textile life cycle chain, including collecting and recycling companies, is necessary to logistically manage CE sustainably and incentivize joint projects. In the future, a closer look at the organization of the EoL, the recycling potential and the efficiency of waste management strategies has to be taken on a national and regional level.

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CRediT authorship contribution statement

Nadia Malinverno: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Mélanie Schmutz:** Conceptualization, Methodology, Writing – review & editing, Visualization. **Bernd Nowack:** Writing – review & editing, Supervision. **Claudia Som:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

The data that has been used is confidential.

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Appendix

A. Workwear and textile research sector

Table A.1

Table A.1
Positioning of the paper in the workwear and textile research sector.

Author	Textile Type and Method	Peer-Reviewed	Quantitative Data	Material Composition	Workwear Categories	Recycling Potential	Recommendations
(Beton et al., 2014)	Report Textile: LCA	Red	Red	Red	Red	Red	Orange
(Dahlbo et al., 2017)	Study Textile: LCA	Green	Green	Red	Red	Red	Orange
(ECAP, 2017c)	Report Workwear: Literature Review, Interview	Red	Green	Red	Red	Orange	Green
(Ellen MacArthur Foundation, 2017)	Report Textile: Literature Review	Red	Red	Red	Red	Red	Green
(Hemkhaus et al., 2019)	Report Textile: Literature Review	Red	Red	Red	Red	Orange	Green
(Koszewska, 2018)	Study Textile: Literature Review	Green	Orange	Red	Red	Red	Green
(Nørup et al., 2019)	Study Textile: Quality Assessment	Green	Green	Red	Red	Orange	Red
(OVAM, 2020)	Guide Workwear	Red	Red	Orange	Red	Red	Green
(Palm et al., 2014, 2015)	Report Textile: MFA, Literature Review	Red	Green	Red	Red	Orange	Orange
(Rengel, 2017)	Report Workwear: Literature Review	Red	Red	Orange	Red	Orange	Orange
(Saltzmann, 2015)	Report Workwear: Category Plan	Red	Orange	Red	Red	Red	Green
(Schmidt et al., 2016)	Report Textile: LCA	Red	Green	Orange	Red	Orange	Red
(Tojo et al., 2012)	Report Textile: MFA	Red	Green	Red	Red	Orange	Green
(wrap, 2011)	Report T-Shirt: MFA, LCA	Red	Orange	Orange	Red	Orange	Red
This study	Study Workwear: MFA, Interview	Green	Green	Green	Green	Green	Green

Red: Aspect not fulfilled. Orange: Aspect partly fulfilled. Green: Aspect fulfilled.

B. Allocation of companies to sector and criteria

Table B.1

Table B.1
Number of companies with which data has been received and allocation of companies to their sectors and criteria.

Sector	Criteria	Number of companies
Professional Laundry	Manage workwear Provide leasing services	2
Workwear Producer	Part of the production in Switzerland Provide management services	1
Logistics	>15′000 employees	2
Telecom	>15′000 employees	1
Retail	> 4′000 employees	1
Research	Data accessibility	1

C. Questionnaire

The questionnaire is annexed with only one workwear category. The companies had a version with more lines.
Stofffluss von Arbeitskleidungs-Abfällen in der Schweiz
Generelle Informationen
Name Tippen Sie hier Ihren Namen.
Firma Tippen Sie hier den Namen Ihrer Firma.
E-Mail Tippen Sie hier Ihr E-Mail.
Was ist die Hauptfunktion Ihres Unternehmens (nur eine Antwort möglich):

¨ Grosshandel
¨ Detailhandel
¨ Transport und Logistik
¨ Medizinischer Bereich
¨ Forschung und Entwicklung
¨ Produktion
¨ Industrielle Wäscherei
¨ Andere: Tippen Sie hier, um Text einzugeben.

Welche der folgenden Aktivitäten ist in Ihrem Unternehmen am wichtigsten? (mehr als eine Antwort möglich):

¨ Lebensmittelverkauf
¨ Logistik
¨ Technische Dienste
¨ Produktion
¨ Transport
¨ Andere: Tippen Sie hier, um Text einzugeben.

Materialfluss der Textilien
Wo beschaffen Sie sich als ArbeitsgeberIn die Arbeitskleidung?

¨ Eigene Produktion der Arbeitskleidung im Inland (Bitte beantworten Sie auch 1.1).
¨ Eigene Produktion der Arbeitskleidung im Ausland.
¨ Externe Produktion der Arbeitskleidung bei einem weiteren Unternehmen im Inland.
¨ Externe Produktion der Arbeitskleidung bei einem weiteren Unternehmen im Ausland.
¨ Kauf der fertigen Arbeitskleidung von Verkäufer. Sie wählen aus schon konfektionierter Arbeitskleidung aus.
¨ Ausleihen der Arbeitskleidung bei einem weiteren Unternehmen.

Wenn Sie Ihre Produktion im Inland haben, welche der Produktionsschritte werden in der Schweiz durchgeführt?

¨ Naturfaserproduktion
¨ Filamentherstellung
¨ Spinnerei (Garnherstellung)
¨ Stoffproduktion (Strickerei, Weberei, Vlies)
¨ Veredelung
¨ Konfektion

Bitte listen Sie Ihre Arbeitskleidungskategorien (in Anzahl Stücke/2020 oder Tonnen) und deren Funktion auf und geben Sie die Materialzusammensetzung an und ob es grobe Schätzungen sind oder genauere Messungen. Falls Sie viele verschiede Produktkategorien haben, geben Sie bitte nur die mengenmässig wichtigsten Produkte an.

Definition: Unter einer **Arbeitskleidungskategorie** (z.B. T-Shirt, Schutzjacke, Weste etc.) verstehen wir ein Kleidungsstück, dass einer bestimmten **Funktion** (z.B. Schutz, Wiedererkennung etc.) zuzuordnen ist. Falls die Arbeitskleidungkategorie speziell ausgerüstet ist (z.B. Regenschutz mit PVC), notieren Sie bitte unter **Beschichtung** das Material der Ausrüstung (Prozentangaben sind nicht notwendig). Bei der **Materialzusammensetzung** (z.B. T-Shirt aus 100% Baumwolle oder eine Weste aus 50% Baumwolle und 50% Polyester etc.) sollen die unterschiedlichen Materialien aufgelistet werden in Prozenten. Unter **Lebensdauer** soll eine Angabe zu den Anzahl Jahren gemacht werden, wie lange die Arbeitskleidung getragen wird.

	Arbeitskleidungskategorien	Funktion	Beschichtung	Produktion (Anzahl Stücke/2020 od. Tonnen in 2020)	Materialzusammensetzung (%)	Lebensdauer	Messungen
P1	Arbeitskleidungskategorie, z.B. Jacke, T-Shirt, Hose ect.	Wählen Sie die Funktionen aus (mehrere Antworten möglich): ☐ Kälteschutz ☐ Regenschutz ☐ Windschutz ☐ Hygieneschutz ☐ Sicherheit (Leuchtstreifen, mechanisch/chemisch resistenter Stoff) ☐ atmungsaktive Kleidung ☐ Repräsentative Kleidung ☐ Servicekleidung ☐ Gesundheitskleidung	Material der Beschichtung, falls vorhanden	Anzahl Stücke in 2020	z.B. 100% Baumwolle, 50% Viskose und 50% Polyester, etc.	Angabe der Jahre, wie lange Arbeitskleidung getragen wird.	Wählen Sie ein Element aus.

Was ist der Anteil all dieser Arbeitskleidungskategorien im Total der Arbeitskleidung in Ihrem Unternehmen?

Geben Sie hier die% der Arbeitskleidungskategorien an.

Auf was achten sie besonders bei der Beschaffung/Herstellung der Arbeitskleidung?

¨ Material

Welche Eigenschaft des Materials ist wichtig?

¨ Preis
¨ Qualität

Wie definieren Sie Qualität?

¨ Bequemlichkeit
¨ Recyclierbarkeit
¨ Langlebigkeit
¨ Andere: Tippen Sie hier, um Text einzugeben.

Wie viele Kleidungsstücke/Uniformen werden pro Angestellten ausgegeben?

Geben Sie hier die Anzahl verschiedene Kleidungsstücke pro Person an.

Ist die Arbeitskleidung, die Sie bereitstellen personalisiert?

¨ Nein.
¨ Ja, mit Namen des/der Angestellten und Logo der Firma.
¨ Ja, mit Logo der Firma.
¨ Ja, mit Namen des/der Angestellten.
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Informationen Arbeitskleidung (Besitztum, Pflege)
Wie wird die Arbeitskleidung den Angestellten übergeben?

¨ Verkauft
¨ Geliehen
¨ Geschenkt
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Welcher der folgenden Dienstleistungen übernehmen Sie als ArbeitgeberIn?

¨ Waschen der Arbeitskleidung im eigenen Unternehmen.
¨ Waschen der Arbeitskleidung in einem externen Unternehmen.
¨ Reparatur der Arbeitskleidung
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Wie oft wechseln Sie das Design der Arbeitskleidung?

Tippen Sie hier, um Text einzugeben.

Wer designed Ihre Arbeitskleidung?

¨ Wir als Unternehmen designen selber.
¨ Ein externes Unternehmen designed für uns die Arbeitskleidung.
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Textilabfall
Wird die Arbeitskleidung nach Gebrauch wieder zu Ihnen zurückgebracht?

¨ Nein
¨ Ja
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Werden Kleider von MitarbeiterInnen wiederverwendet, die nicht mehr bei Ihnen arbeiten?

¨ Nein
¨ Ja
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Haben Sie Kriterien definiert, wann die Arbeitskleidung nicht weiterverwendet werden kann? Wenn ja welche (z.B. Löcher, Flecken, etc.)?

Tippen Sie hier, um Text einzugeben.

Aus welchen Gründen wird die Arbeitskleidung entsorgt? Nennen Sie bitte die drei wichtigsten Gründe.

- Tippen Sie hier, um Text einzugeben.
- Tippen Sie hier, um Text einzugeben.
- Tippen Sie hier, um Text einzugeben.

Sind Sie für die Entsorgung der Arbeitskleidung zuständig?

Tippen Sie hier, um Text einzugeben.

Bitte listen Sie gemäss dieser Definition bis zu 5 Abfallkategorien auf (in Anzahl Stücke/2020 oder Tonnen) und geben Sie die Grösse an (falls möglich geben Sie auch an, welcher Anteil des Abfalles Störstoffe enthält).

<u>*Definition:*</u> *eine **Abfallkategorie** wird definiert durch die **Arbeitskleidungskategorie**, die in der ersten Tabelle definiert wurden (P1-P5) (z.B. T-Shirt, Schutzjacke, Weste etc.) und **die Störstoffe** (z.B.* Reisverschluss*, Knöpfe, Dekomaterial Leutbänder, etc.). Für Ausrüstung: Farbe, Flammschutzmittel, funktionelle Oberflächenbehandlung, etc.). Eine Abfallkategorie umfasst die Abfälle von unterschiedlich zusammengesetzten Produkten.*

	Abfallkategorien	Abfall (t/2020)	Typ des störstoffes	Anteil mit störstoffe (%)
AK1	Arbeitskleidungskategorie, z.B. Jacke, T-Shirt, Hose etc.	Anzahl Stücke in 2020	☐Taschen aus anderem Material ☐ Knöpfe ☐ Reissverschluss ☐ Deko (z.B. Logo, Name) ☐ Schutzmittel ☐ spezifische Oberflächenbehandlung ☐ Knöpfe	%

Abfallmanagement

Definition: **Wiederverwendung** ***(“reuse”):*** *die Weiterverwendung der Abfallkategorie in der gleichen Form und Funktion (d.h. ohne chemische oder mechanische Behandlung).* ***Recycling:*** *Abfall wird chemisch oder mechanisch behandelt.* ***”Open-loop”:*** *der Abfall wird in anderen Wertschöpfungsketten (z.B. Bau, Möbel, etc.) als Rohstoff genutzt.* ***“Closed-loop”:*** *Abfall wird wieder in der gleichen Wertschöpfungskette (in der Textilindustrie) als Rohstoff genutzt*

Was passierte *gem*äss‌ diesen Definitionen mit den Abfallkategorien (in Anzahl Stücke/2020 oder Tonnen) in 2020?

Abfallkategorien	Abfallmanagement			
	Verbrennung	Wiederverwendung	"Closed-loop"Recycling	"Open-loop"Recycling
AK1	Anzahl Stücke in 2020 für AK1.	Anzahl Stücke in 2020 für AK1.	Anzahl Stücke in 2020 für AK1.	Anzahl Stücke in 2020 für AK1.

Was macht es schwierig Ihre textilen Abfälle weiterzuverwenden oder zu rezyklieren (mehr als eine Antwort möglich)?

¨ Keinen Markt (d.h. keine Rezyklierer)
¨ Keine Information über die Mengen und Eigenschaften der Abfallkategorien
¨ Abfallkategorien und Abfallmengen schwanken
¨ Technisch noch nicht machbar (z.B. fehlende Recyclingtechnologien)
¨ Nicht wirtschaftlich
¨ Logistik zu aufwendig
¨ Zu kleine Mengen pro Abfallkategorie
¨ Andere Klicken oder tippen Sie hier, um Text einzugeben.

Wie könnten die mengenmässig grössten Abfallkategorien Ihrer Meinung nach weiterverwendet werden? (Bitte beschreiben Sie bei 5 Abfallkategorie zwei Möglichkeiten, z.B. Dämmmaterial)

	Möglichkeit 1	Möglichkeit 2
AK1	Tippen Sie hier eine Möglichkeit.	Tippen Sie hier eine Möglichkeit.

Was sind ungefähr die jährlichen Entsorgungskosten für die textilen Abfälle (z.B. für Verbrennung oder Recycling)?

Geben Sie hier die Kosten in CHF/t an.

Können Sie bestimmte Abfallkategorien verkaufen?

¨ Nein
¨ Ja Wenn ja, geben Sie die Abfallkategorien an, die Sie verkaufen.

Mit welchen Massnahmen liessen sich Ihrer Meinung nach die Abfallmengen reduzieren?

Abschlussinformation

Haben Sie weitere Bemerkungen?
Tippen Sie hier, um Ihre Bemerkungen einzugeben.

D. Overview of Material and Methods used

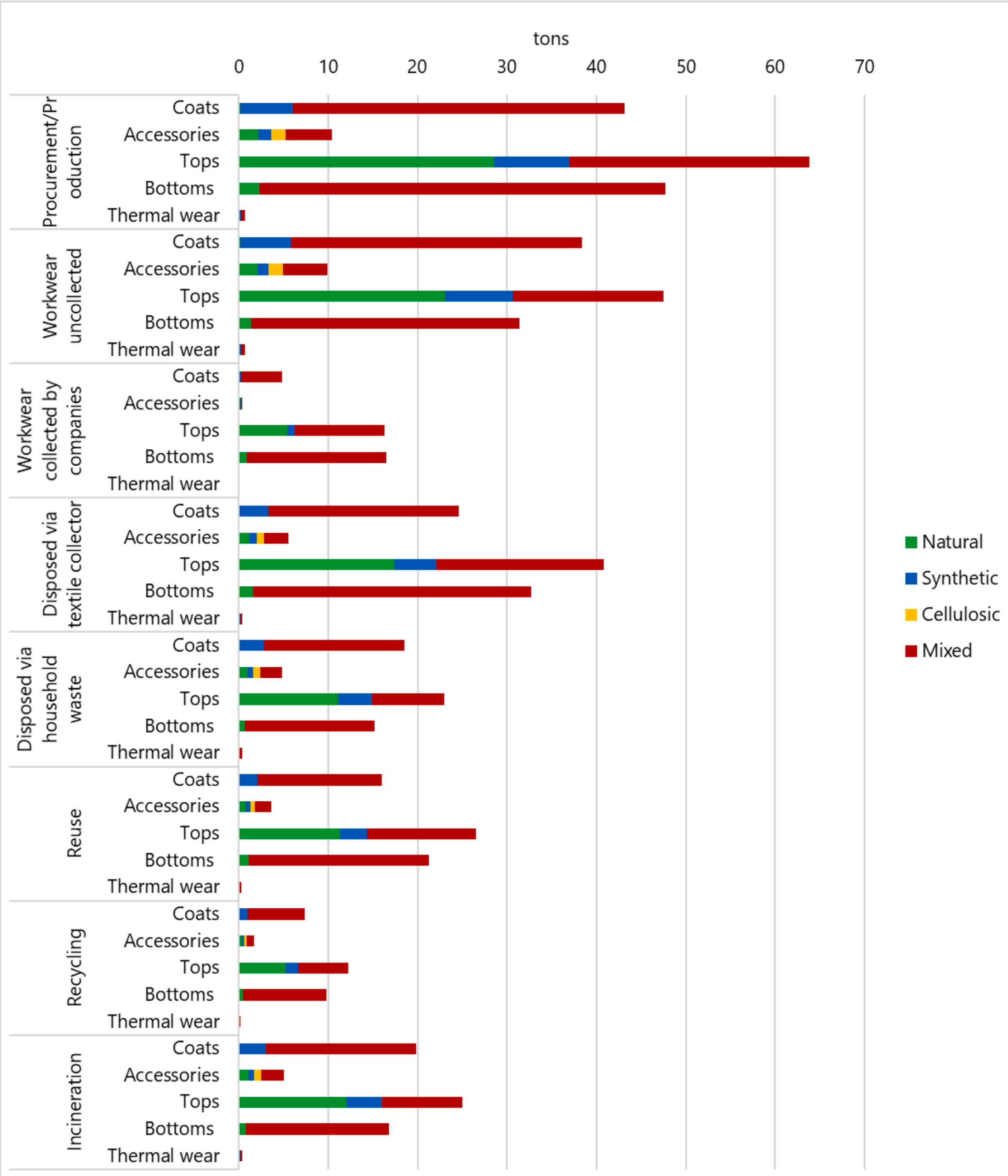
Fig. D.1

Fig. D.1. Overview of different calculations for the MFA.

E. Detailed Amounts of Material Categories in Workwear Categories

Table E.1

Table E.1
Material categories of workwear categories in the different life cycle steps.



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