mistra future fashion

environmental assessment of Swedish clothing consumption - six garments, sustainable futures

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A Mistra Future Fashion Report
Mistra Future Fashion is a cross-disciplinary research program, initiated and primarily funded by Mistra. It holds a total budget of SEK 110 millions and stretches over 8 years, from 2011 to 2019. It is hosted by RISE in collaboration with 15 research partners, and involves more than 50 industry partners.

www.mistrafuturefashion.com

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executive summary

context

The aim of this work was to map and understand the current environmental impact of Swedish clothing consumption. A life cycle assessment (LCA) was used to evaluate the environmental impact of six garments: a T-shirt, a pair of jeans, a dress, a jacket, a pair of socks, and a hospital uniform, using indicators of climate impact (also called "carbon footprint"), energy use, water scarcity, land use impact on soil quality, freshwater ecotoxicity, and human toxicity. The environmental impact of the six garments was then scaled up to represent Swedish national clothing consumption over one year.

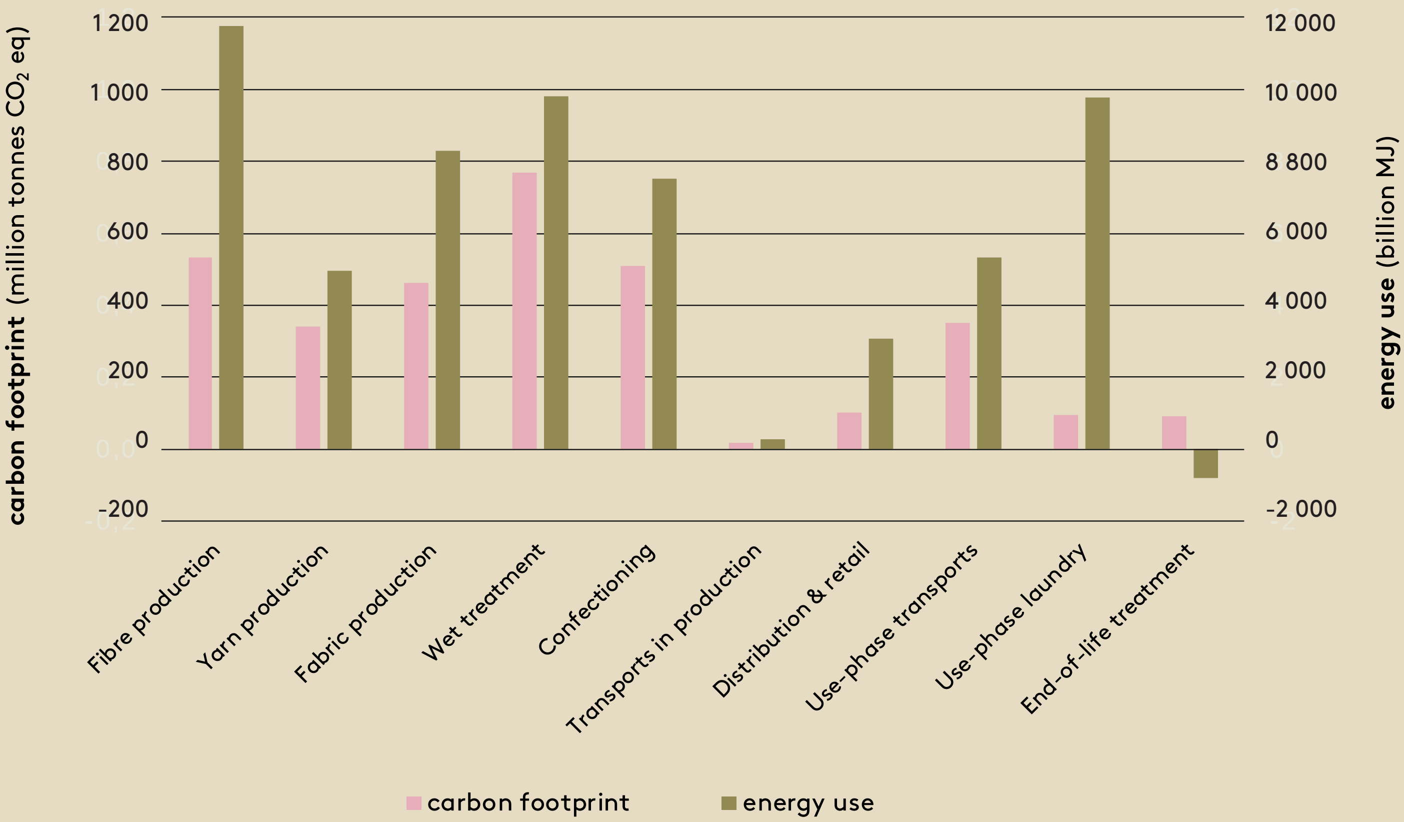
In addition to fulfilling this aim, the report is a unique and rich source of transparently documented inventory data on a large number of textile processes – hopefully this can be of use for other LCA practitioners. The report updates Roos et al. (2015), which was the first detailed LCA study of Swedish clothing consumption at the national level. Since the publication of the first edition, several LCA studies of textile production processes and global apparel consumption have been published, which have enabled us to refine the inventory model and benchmark the results.

The work was done in Mistra Future Fashion, a cross-disciplinary research program in 2011-2019 which aimed to enable a systemic change in the Swedish fashion industry leading to sustainable development in industry and society.

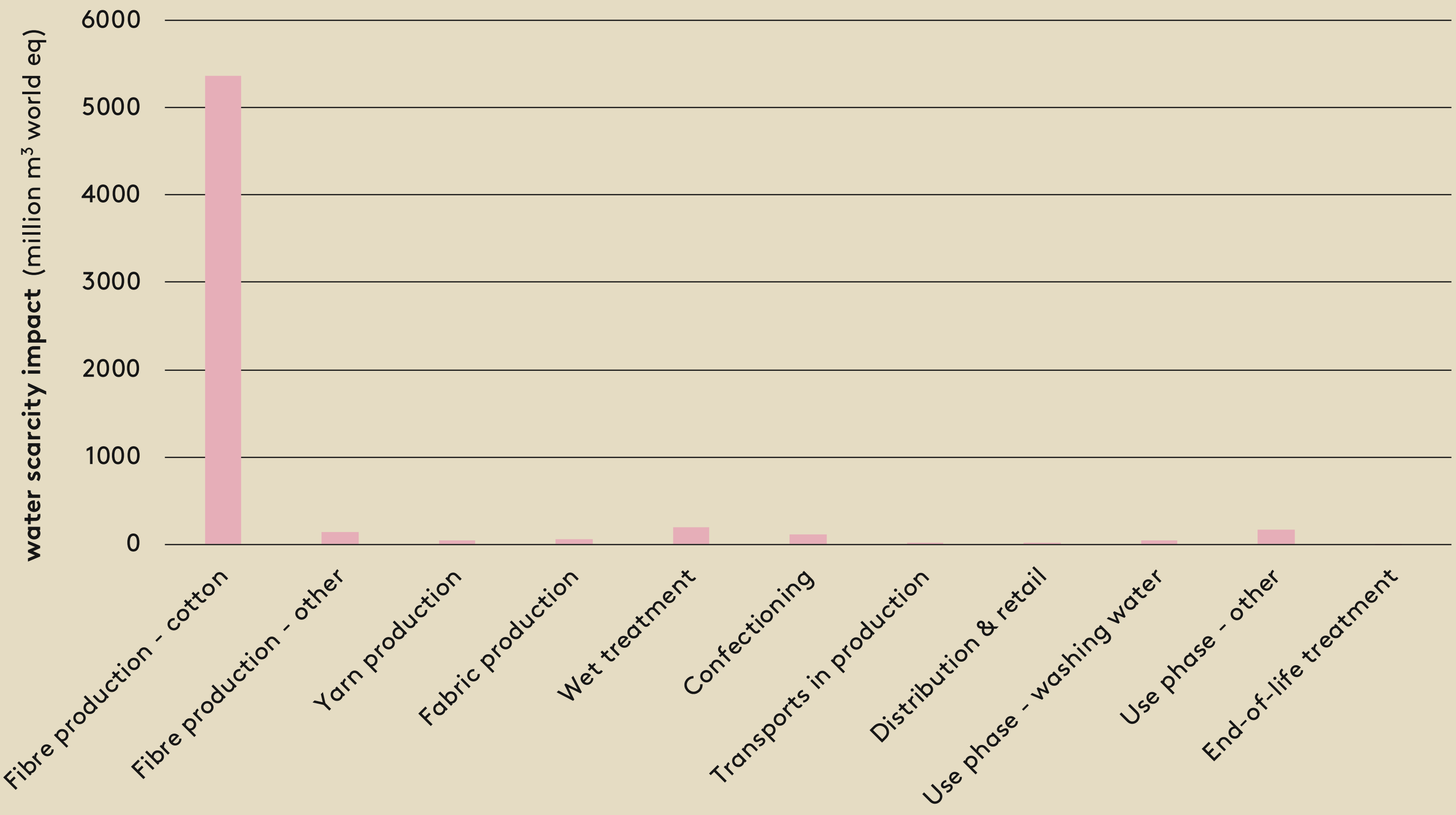
results

The figure below summarises the results for two of the studied indicators, carbon footprint and energy use, at the level of total clothing purchases and uses in Sweden over one year. All production processes are important climate- and energy-wise, particularly the heating of water for wet treatment processes. Fibre production and laundry activities use considerable amounts of energy, but as this includes a relatively high share of renewables, the contributions are lower in terms of carbon footprint.

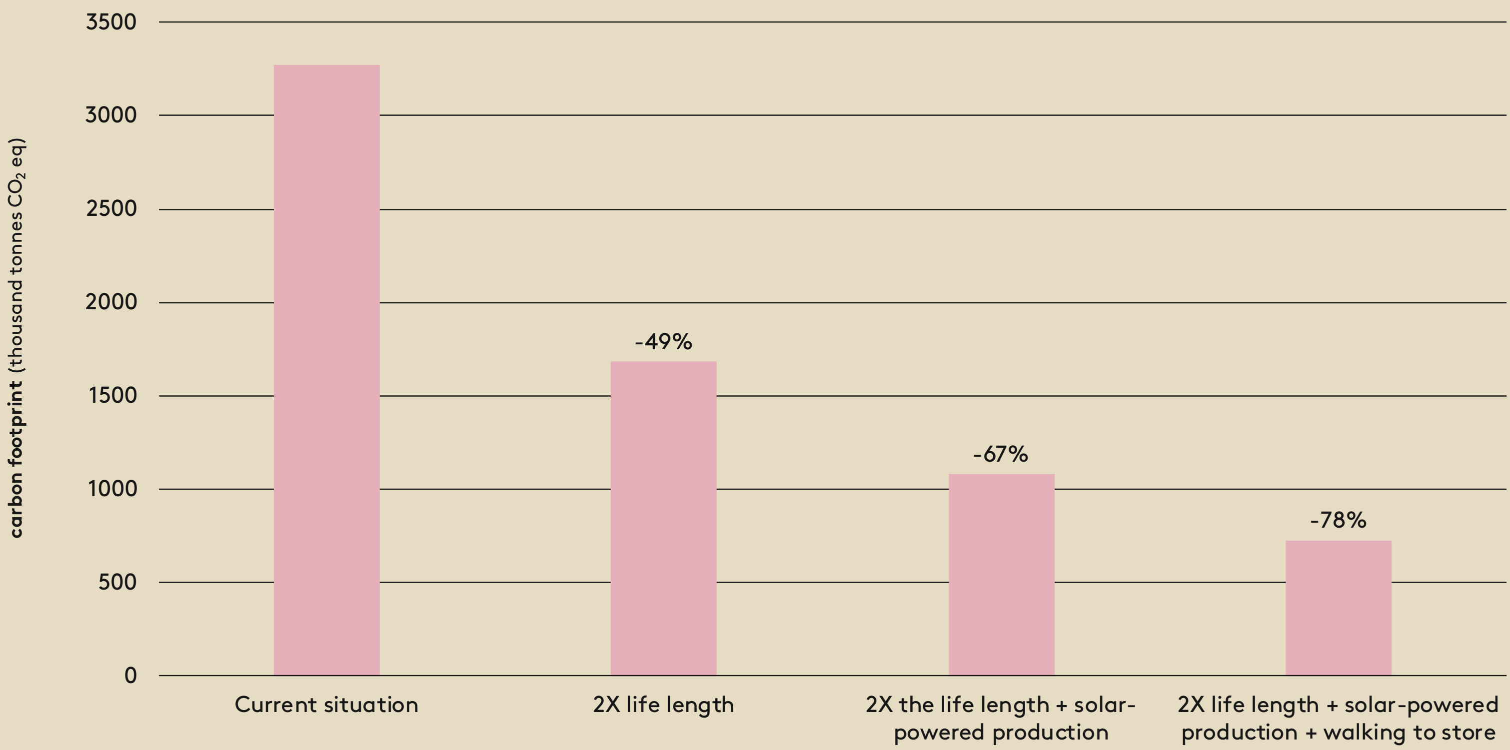
One aspect of the result may come as a surprise: the significance of the transport of the user back and forth from the store, which has generally been ignored in previous studies. We found this to be 11% of the overall life-cycle impact. The carbon footprint of Swedish clothing consumption is about 330 kg CO_2 eq. per person. Although this is only 3% of the carbon footprint of an average Swede, the climate impact of clothing needs to be reduced to basically zero in a sustainable future.



The figure below presents results for water scarcity, based on water consumption (water withdrawn from, but not returned to, a watershed) weighted according to the scarcity of the water in the country it is used. Fibre production completely dominates the life-cycle impact as it, relative other life-cycle processes, typically consumes large amounts of water in water-deprived areas. For Swedish clothing consumption in total, annual water use amounts to 610 scarcity-weighted cubic metres per person.



The figure below shows the national-level climate benefits of combining some of the interventions explored in the report. If each garment is used twice as many times before disposal, almost half the impact is mitigated – prolonging the active life of clothing requires manufacturers and retailers to make and market more durable garments, and it also requires users to buy fewer of them. Solar-powered electricity in production reduces another 18% and walking or taking a bicycle to the store saves another 11%. The report explores the effects of further interventions of impact reduction – changing from cotton to viscose fibres, improved chemical management, washing in lower temperatures – for several impact categories.



recommendations

Based on the results, the report gives recommendations to actors along the garment life cycle regarding how they can reduce the environmental impact of clothing. Among others, producers can use more renewable energy, improve chemical management and exercise their power as buyers of fibres, yarns and fabrics to influence other actors further down the supply chain.

Retailers can more consciously source garments from sustainable producers, support the transition to improved operations and promote and demand traceability and transparency in the supply chain, and facilitate and promote sustainable behavior among users, most importantly in terms of prolonging the use of each purchased garment.

Policy makers can use a wide array of policy tools to steer and promote cleaner production and better user behavior, particularly in terms of using clothes longer. And users can be more careful about using and taking care of the clothing already in the wardrobe; use clothes to their full technical life length; consider buying second hand or renting/borrowing; walk, bicycle or take public transportation to the store; and exert consumer pressure on retailers.

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'twice as many uses
per garment life-cycle
eliminated almost 50%
of impact, regardless of
impact category.'

1. introduction

The global clothing industry have tremendous sustainability issues to deal with, which will require reduced water consumption and use of finite resources, mitigation of greenhouse gas emissions and toxic pollution, among others. The present report aims to provide the Swedish apparel industry and its stakeholders with an up-to-date mapping of the environmental impact of Swedish clothing consumption and explore the potential of interventions for reducing this impact.

1.1 Mistra Future Fashion

The report was made in Mistra Future Fashion, a cross-disciplinary research program with a vision of enabling a systemic change in the Swedish fashion industry leading to sustainable development in industry and society. The program delivered insights and solutions to be used by the industry and other stakeholders to significantly improve the industry’s environmental performance and strengthen its global competitiveness.

The second phase of the program (2015-2019) was organised into four interdisciplinary research themes, focussed on design, the supply chain, the user, and recycling. This report was written by life cycle assessment (LCA) researchers involved in several of the four themes, and the report provides insights spanning across the themes. For more information on the program, visit www.mistrafuturefashion.com.

1.2 purpose of study

The overall purpose of LCA work in Mistra Future Fashion was to contribute to an improved understanding of the environmental impact of the current activities of the Swedish fashion industry and potential environmental benefits and downsides of various interventions for impact reduction. Such an improved understanding is essential for providing relevant guidance in the transition of the industry into a more sustainable one. Over the 8 years of the whole program, this work created numerous reports and scientific articles on the environmental implications of novel production technologies, recycling systems, business models, design strategies, and much more. To fully understand the implications of a change, one needs to also understand the current position: the environmental impact of the Swedish clothing consumption of today.

The purpose of the present report is thus to provide the Swedish fashion industry and its stakeholders with an up-to-date mapping of the environmental impact of Swedish clothing consumption and explore the potential of interventions for reducing this impact. The report also aims to summarise 8 years of LCA work in Mistra Future Fashion on the environmental potential of interventions for impact reduction.

In addition to fulfilling this aim, the report is a unique and rich source of transparently documented inventory data on a large number of textile processes, which can be of use for other LCA practitioners and the apparel industry.

1.3 structure of report

Next chapter presents the overall approach for addressing the purpose of the study along with further details on the LCA method, its application in this specific study and how the garment-level results were scaled up to the national level. Chapter 3 details the modelling of the six garments, including process flowcharts, modelling and data assumptions, and technical descriptions of the processes. Chapter 4 presents and discusses results, and Chapter 5 summarises other LCA studies in Mistra Future Fashion. Chapter 6 lists the main conclusions along with recommendations to specific stakeholders: producers, retailers, policy makers, and end users[1].

1.4 changes from previous version

The study is an update of a previous Mistra Future Fashion study (Roos et al. 2015). Focus has been on updating aspects which in Roos et al. (2015) were shown to significantly influence results and to make the study representative for the year 2019. One improvement is the addition of a sixth kind of garment, socks, which employ a new fibre type in the model: regenerated cellulose fibres (viscose). Thus, the study now covers five of the most common textile fibres: polyester, cotton, polyamide (nylon), elastane and viscose.

Other improvements include newer and more robust inventory data, updated statistics underpinning the use phase modelling and the scaling up to the national level, an updated set of impact assessment methods reflecting the latest developments of LCA methodology, and the correction of errors. See Appendix A for a detailed list of improvements.

[1] This report consistently uses the term end user (or user) instead of consumer, as end user is a term reflecting the use of the garment rather than its purchase and ownership, i.e. it puts emphasis on the function of the garment – a central concept in LCA. Also, traditional consumption and ownership, and the role of the consumer, are challenged in the emerging business models of the sharing/circular economy, rendering end user a more accurate and useful term than consumer.

2. method

2.1 overall approach

The goal of the study was addressed by means of LCA, which is a method for quantitatively assessing the environmental impact of products from a life cycle perspective. LCAs were carried out on six garments which together are representative for Swedish clothing consumption: a T-shirt, a pair of jeans, a dress, a jacket, a pair of socks, and a hospital uniform.

The environmental impact of each of these garments was assessed to permit detailed studies of garment life cycles, such as the examination of the environmental significance of different life cycle processes and the potential of garment-level interventions for reducing impact. The environmental impact of the six garments was then scaled up to represent Swedish national clothing consumption over one year. This permitted the study of broader aspects, such as the relative importance of different garments and the nation-wide potential of interventions for impact reduction.

The previous work done in Mistra Future Fashion on the environmental potential of interventions for impact reduction were summarised in terms of 11 abstracts, see Chapter 5.

2.2 life cycle assessment (LCA)

The study is based on the LCA method as outlined in ISO 14040 and 14044 (ISO 2006a, ISO 2006b). LCA is an internationally accepted and widely used method capable of assessing a wide range of environmental impacts over the life cycle of products and services.

In short, an LCA accounts for all environmentally relevant flows of energy and materials across the system boundaries, from cradle to grave (or cradle to gate, in more limited studies), and uses characterisation methods to "translate" these flows into predicted environmental impacts expressed in impact categories such as climate change, acidification, eutrophication, toxicity, water depletion and impacts of land use. In this way, LCA provides an overview of the environmental performance of the studied product and enables the identification of environmental hotspots in the product life cycle as well as comparisons with other products. This information is useful in decision making, such as in prioritising measures for improved environmental performance.

The LCA procedure consists of four steps, as explained below and illustrated in figure 2.1.

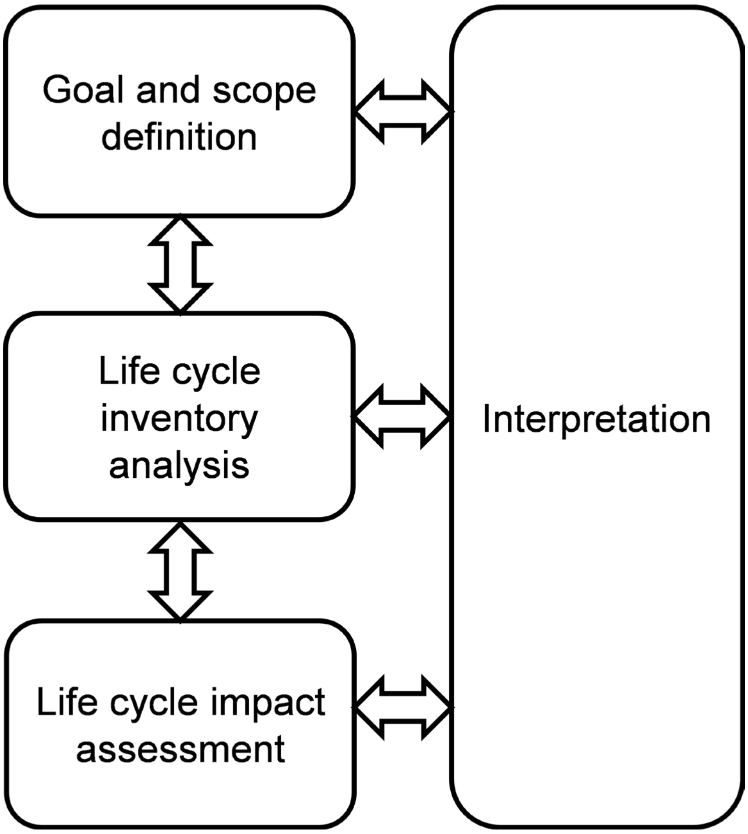


figure 2.1: Schematic illustration of the four phases of LCA and their interconnectedness.

I. Goal and scope definition: The aim of the assessment, the functional unit and the product life cycle are defined, including boundaries to other product systems and the environment. The functional unit is a quantitative unit reflecting the function of the product, which enables comparisons of different products with identical functions.

II. Life cycle inventory analysis (LCI): All environmentally relevant material and energy flows between processes within the defined product system, and between the system and the environment or other product systems, are quantified and expressed per functional unit. Flows between the defined system and the environment consist of emissions and the use of natural resources.

III. Life cycle impact assessment (LCIA): By means of characterisation/impact assessment methods, the LCI data is translated into potential environmental interventions, classified into impact categories. The LCIA can also include normalisation and weighting, in which results for several impact categories are aggregated on a single yardstick – these steps are not included in the present study.

IV. Interpretation: The result of the LCIA is interpreted, taking into account the goal and scope definition (e.g. the system boundaries) and the LCI (e.g. data gaps and data uncertainties), and recommendations are made to the intended audience.

2.3 LCA in this study

Below we present the general methodological choices of the LCA of the six garments. For further modelling details, see Chapter 3.

2.3.1 functional unit

In the present study, three different functional units were employed for different purposes. The first functional unit is one use for each of the six garments. One use here refers to the use occurring within a 24-hour time period, which can be the use of a pair of jeans during a full day, the use of a dress for a few hours in the evening, or the use of a jacket on several occasions in one day. Note that one use of a T-shirt is not comparable with one use of a dress or a jacket since they provide different functions. Having one use as the functional unit makes it possible to study functional improvements, such as the benefits of prolonged service life due to better fibre quality, new design strategies or alternative business models.

The second functional unit is one garment, as this (i) enables comparisons across the six garments (here one should be cautious as the different garments provide different functions), (ii) enables a discussion in relation to other studies (which often uses one garment as the functional unit), and (iii) is a basis for scaling up to the national-level impact.

Finally, as the results of the LCA of the six garments were scaled up to the national level, the third functional unit is the annual national consumption and use of clothing in Sweden.

2.3.2 modelling approaches

The study is a process-based LCA, which is a bottom-up modelling in which the environmental impact of the life cycle is mapped based on its constituting parts – the unit processes – which are modelled separately and in detail. This is contrasts to an input/output (I/O) LCA, in which the life cycle is modelled top-down by assigning a certain share of the flows or impacts of an industrial sector.

Furthermore, LCA studies are often classified as being either attributional or consequential. This has recently been challenged as a “fallacious and unnecessary” classification (Yang 2019). Nevertheless, the present study would by most LCA practitioners be seen as an attributional one, although there are some consequential elements related to allocation (see Section 2.3.3).

2.3.3 allocation methods

An important choice when conducting an LCA is how to allocate the environmental burdens of multi-functional processes between the functions. In the present study, several of the processes are multifunctional, for example cotton cultivation produces seeds and fibres, viscose production produces fibres and several by-products, waste incineration provides the disposal service as well as generating heat and power, transports distribute several products in one container, and laundry machines wash several garments at once.

In the present study, allocation of transports, retailing, laundry and similar processes were based on mass, as their impact can be assumed to scale by mass. For most other processes, the default allocation method of the used databases (see Section 2.3.5) were employed, most often economic allocation – as this is reasonable for processes with both material (e.g. pulp) and energy (e.g. electricity) outputs, and for processes with a clear distinction between a more valuable main product and less valuable by-products. For Ecoinvent datasets (see Section 2.3.5) involving recycling, the default cut-off allocation was used, which means that the burdens of the primary (first) production of materials is allocated to the primary user of the material, and the primary user is not allocated any credit for providing the recyclable material to a subsequent user. Consequently, the secondary user bears the burden of the recycling process, but no burden from primary production of the material entering the recycling process; in other words, this material input is free of environmental burden.

For waste management of textiles and packaging material, system expansion with substitution was employed (often seen as a consequential modelling element, see Section 2.3.2). This means that the heat and power generated when incinerating the material is assumed to lead to the replacement of the national annual market mixes of heat and power generation, respectively. This assumption could be questioned, both as it is a consequential element in an otherwise attributional study and as it is uncertain whether this reflects the actual consequence of adding textiles and packaging to the waste mix, but as it turned out to have negligible influence on results (see the low contribution from the end-of-life phase in the results presented in Section 4), the assumptions was not revised.

2.3.4 impact categories and characterisation methods

Table 7 shows the impact categories included in present report and corresponding characterisation methods. The study includes a subset of the impact categories and characterisation methods recommended in the latest version of the environmental footprint category rules (PEFCR) guidance (European Commission 2018), which represents the most current consensus in the European LCA community. The subset represents the most pressing environmental issues of the textile industry. Excluded impact categories are of less importance for the industry (e.g. ozone layer depletion and ionising radiation), or correlate with included impact categories (e.g. acidification correlated well with climate impact in Roos et al. 2015), or have not been possible to inventory in a satisfactory manner (e.g. freshwater eutrophication).

In addition to the PEFCR impact categories, an energy use indicator was included, accounting for both renewables and non-renewables, thereby reflecting a concern not just for the depletion of fossil resources (which in any case is strongly reflected in the climate change indicator) but also the equitable sharing of all energy resources among contemporary needs.

For toxicity, many substances currently lack published characterisation factors for the LCIA (Roos et al. 2017a). USEtox (Rosenbaum et al. 2008, Huijbregts et al. 2015) is currently the method that covers most chemicals, although also this model is lacking characterisation factors for many textile chemicals and their (sometimes more toxic) breakdown products. Therefore, the modelling of the toxicity is based on the framework created in Mistra Future Fashion (Roos 2016) where the life cycle inventory of textile processes is matched with characterisation factors in the impact assessment. Characterisation factors for toxicity are taken primarily from USEtox, the COSMEDE database (ADEME 2015) and Roos et al. (2017). The contribution from direct toxicity (direct emissions from foreground processes such as bleaching and dyeing) is reported separately from the background toxicity (toxic emissions from background processes such as fuel production and waste management).

For land use impact, the PEFCR guidance recommends the use of the soil quality index (SQI), which is an aggregated indicator based on four midpoint indicators modelled using the LANCA 2.5 model (de Laurentiis et al. 2019), reflecting four consequences of land use and land use change: biotic production loss, erosion, groundwater regeneration reduction, and infiltration reduction. SQI and LANCA 2.5 are not yet supported by the LCA software used in the present study (Gabi and Simapro), instead we calculated land use impact at the level of the four midpoint indicators using LANCA 2.3[2]. However, it turned out that the flows of land use and land use change in Ecoinvent 3.5 datasets have not been regionalized, instead a global average factor for each land use type have been automatically applied, yielding very uncertain results. Therefore, we decided to show results just for one garment, the T-shirt, and only qualitatively discuss the national-level results.

In Appendix D, each impact category and corresponding characterisation method are explained in further detail.

[2] LANCA 2.3 includes five midpoint indicators, but as two of them show strong correlation, one of these two was omitted when creating the aggregated SQI indicator (de Laurentiis et al. 2019). The present study only considered the four midpoint indicators included in the SQI indicator.

table 2.1: Impact categories presented in the study and corresponding characterisation methods.

Impact category	Characterisation method(s)	Unit for results	Reference for characterisation method
Climate change	Global warming potential with a 100-year perspective (GWP100), excluding biogenic CO2 emissions	kg CO2 equivalents	IPCC (2013) as implemented in Simapro and Gabi
Freshwater ecotoxicity	Ecotoxicity potential (USEtox 2.02 model)	Comparative toxic unit for (CTUe)	Huijbregts et al. (2015) as implemented in Simapro
Human toxicity, carcinogenic	Human toxicity potential (USEtox 2.02 model)	Comparative toxic unit for human (CTUh)	Huijbregts et al. (2015) as implemented in Simapro
Human toxicity, non-carcinogenic	Human toxicity potential (USEtox 2.02 model)	Comparative toxic unit for human (CTUh)	Huijbregts et al. (2015) as implemented in Simapro
Land use impact, biotic production loss	Biotic production loss potential (LANCA 2.3 model)	kg	Beck et al. (2010) and Bos et al. (2016) as implemented in Gabi
Land use impact, erosion	Erosion potential (LANCA 2.3 model)	kg	Beck et al. (2010) and Bos et al. (2016) as implemented in Gabi
Land use impact, groundwater regeneration reduction	Groundwater regeneration reduction potential (LANCA 2.3 model)	m3	Beck et al. (2010) and Bos et al. (2016) as implemented in Gabi
Land use impact, infiltration reduction	Infiltration reduction potential (LANCA 2.3 model)	m3	Beck et al. (2010) and Bos et al. (2016) as implemented in Gabi
Water scarcity	Water scarcity footprint (AWARE model)	m3 world equivalents	Boulay et al. (2018) as implemented in Simapro
Energy resources	Use of primary energy from non-renewable and renewable resources	MJ	Primary energy from non-renewable and renewable resources as implemented in Gabi (termed primary energy demand, PED) and Simapro (termed cumulative energy demand, CED)
Energy resources	Use of primary energy from non-renewable and renewable resources	MJ	Primary energy from non-renewable and renewable resources as implemented in Gabi (termed primary energy demand, PED) and Simapro (termed cumulative energy demand, CED)

2.3.5 software and databases

Two LCA software packages were used: Gabi Professional version 8.7 (Thinkstep 2019) and Simapro v 9.0.0.31 (PRé Sustainability 2019). For the impact categories of climate change and energy resources, each garment was modelled in both packages. This enabled cross-checking of inventory data and characterisation methods, which reduced risks of software-related errors. Also, it enabled a discussion of the implications of the choice of software for results. Furthermore, for practical reasons, the impact categories of toxicity and freshwater depletion were characterised in Simapro only, and land use impact was characterised in Gabi only. Background processes were modelled with data from databases, mainly Ecoinvent 3.5 (Ecoinvent 2019). Ecoinvent is available in several versions with different methods for allocating recycled material; in the present report, the version based on cut-off allocation was used as this is the version integrated in Gabi, see Section 2.3.3.

2.4 scaling up to the national level

The LCIA results of the six garments were scaled up to represent Swedish clothing consumption at the national level by using statistics of import, export and domestic production of garments in Sweden in 2017 as classified into 34 garment categories (Statistics Sweden 2019a). The six garments were chosen and modelled to be representative also for garments of other garment categories, therefore they cover different fibre content, production technologies and use patterns. More specifically, the association between the six garments and the 34 garments categories was based on the following prioritisation of criteria:

1. Knitted or woven construction

2. Fibre type (cotton, synthetics, regenerated, or denim)

3. Similarity, in terms of function of the garment, use pattern, etc.

Table 2.2 shows the resulting representation. See Appendix C for a list of all garment categories and the association between these and the six garments.

table 2.2: The six garments' representation of Swedish clothing consumption.

Garment	Volume (tonnes)	Share of modelled Swedish clothing consumption
T-shirt	20 873	21%
Jeans	22 165	22%
Dress	17 576	17%
Jacket	26 112	26%
Socks	8 495	8%
Hospital uniform	5 931	6%
Total	101 152	100%

The environmental impact of the total Swedish clothing consumption (including use) was then calculated by multiplying the LCIA results (for each of the six garments) per garment service life (i.e., not per garment use) with the net weight of national consumption (import plus production minus export) for each garment category the six garments were assumed to represent.

These results were aggregated to yield a total impact of clothing consumption in Sweden in one year. The representation of the national-level model in terms of fibres and fabrics are shown in figure 2.2. The shares of viscose and elastane reflect the global fibre market well, while cotton has a considerably higher share than its global market share of 27%, at the expense of polyester (Sandin et al. 2019). This is as expected as cotton is known to be a particularly popular fibre in Sweden.

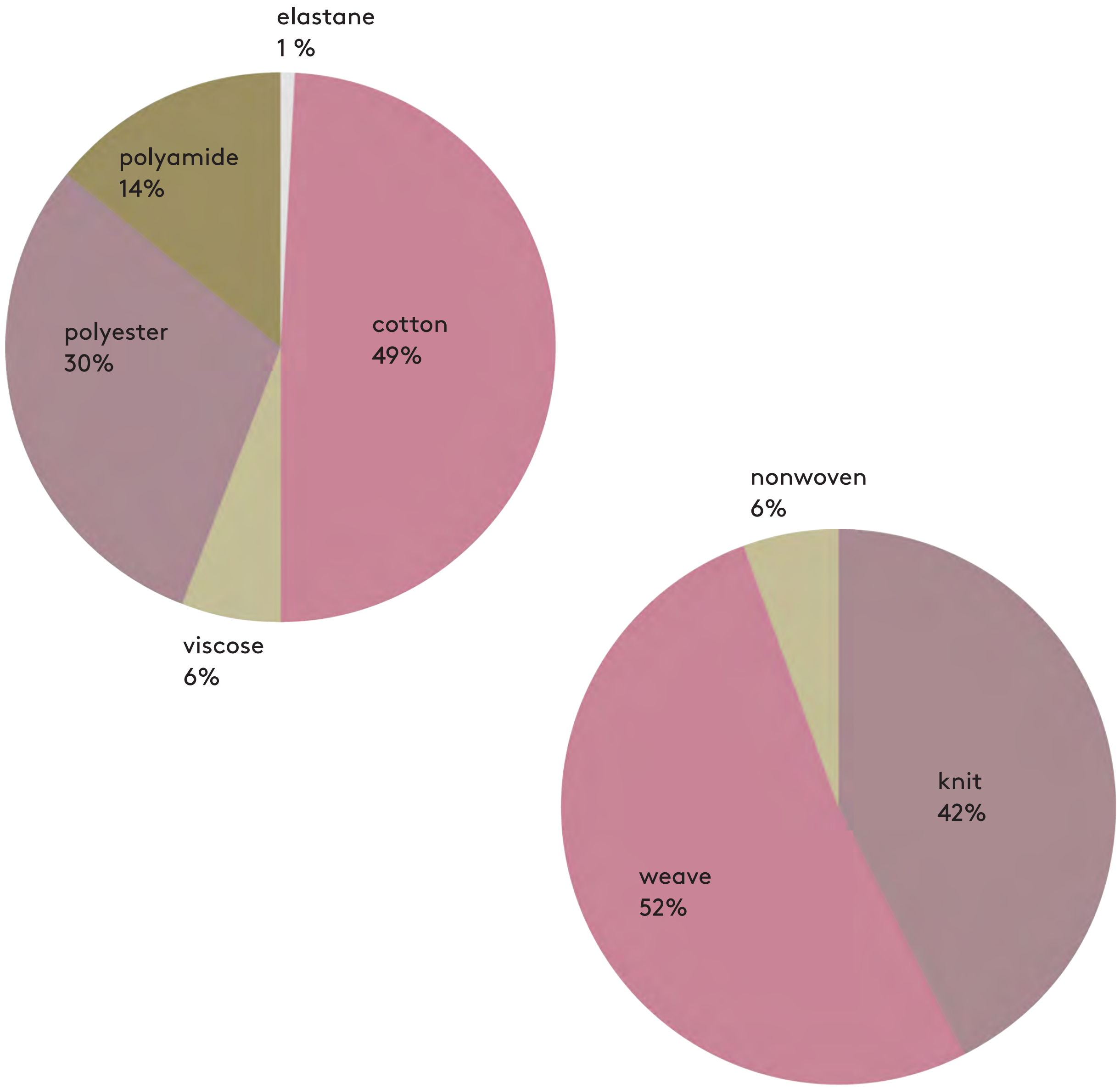
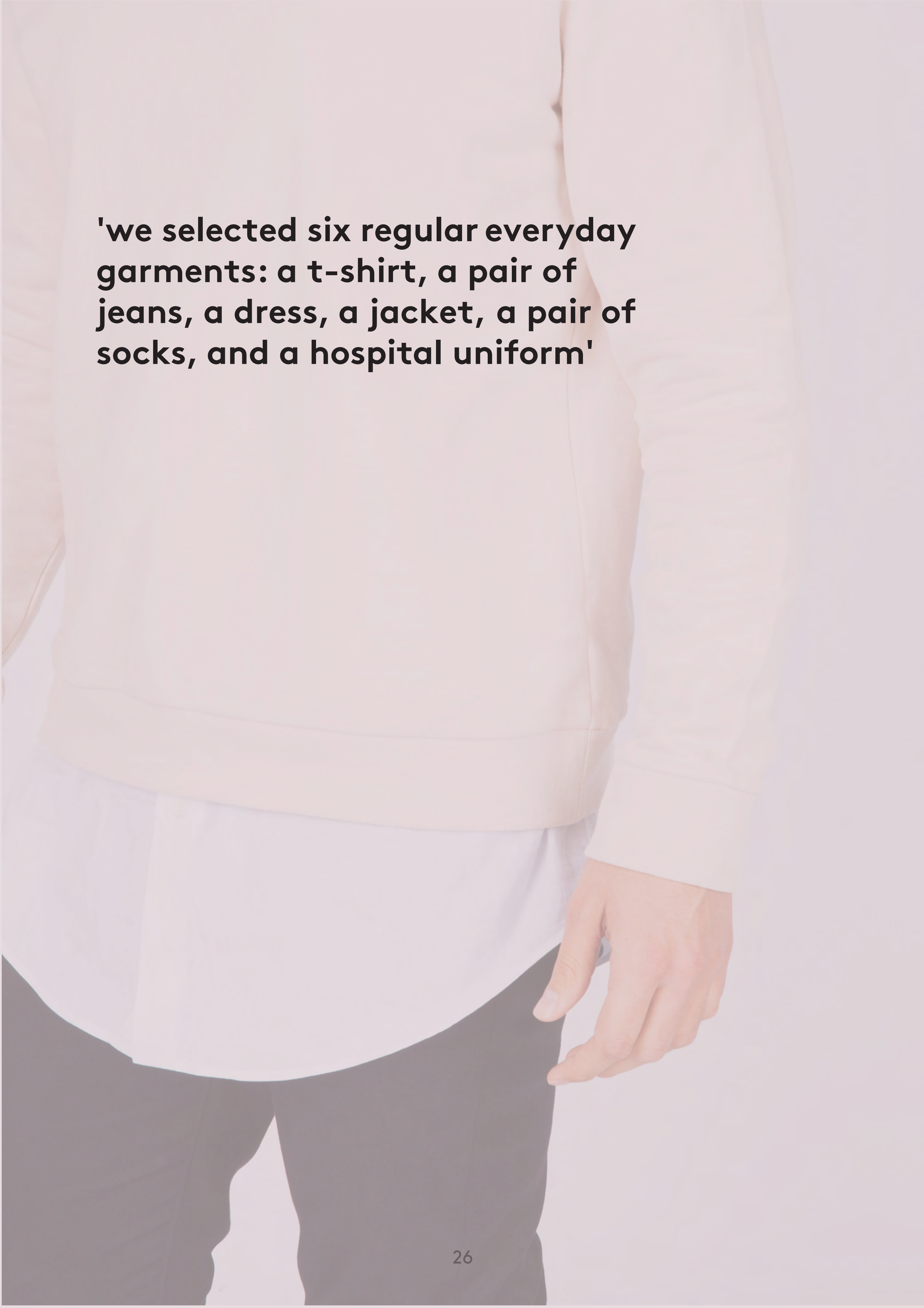


figure 2.2: Representation of the model of Swedish clothing consumptions, in terms of fibre and fabric types.



'we selected six regular everyday garments: a t-shirt, a pair of jeans, a dress, a jacket, a pair of socks, and a hospital uniform'

3 modelling of the six garments

3.1 selection of garments

The selection of the six garments was made with the primary aim that the garments should be representative for Swedish clothing consumption (and use), including regular, everyday clothing consumption as well as public sector procurement. Additionally, the intent was to choose garments with sufficiently different life cycles so that they would be able to show the significance of interventions in different life cycle phases for different types of garments. For example, T-shirts are washed more often than jackets, so jackets are expected to more clearly exemplify the value of changes to the garment life cycle outside the use phase.

We selected five regular, everyday garments: a T-shirt, a pair of jeans, a dress, a jacket and a pair of socks, and one garment from the public sector: a hospital uniform. Each garment is a common high-volume product that consists of materials that are used also for other types of garments and can thus represent other garments in the scale up to the national-level (as was explained in Section 2.4).

3.2 overview of the garments

Table 3.1 summarises key parameters for the modelling of the six garments. For each garment, the table shows a photo of an example item provided by a retailer in the Mistra Future Fashion consortium. The material composition of each garment was acquired by weighing its components, except for the hospital uniform, for which this data was given by Roos (2012). The weight and material content of the example items were used as starting points in the garment modelling, but subsequent modelling was done to represent generic garments rather than the specific example items.

table 3.1: Key modelling parameters for the garments selected for the LCA study.

garment	t-shirt	jeans	dress	jacket	socks	hospital uniform
mass	110 g	477 g	478 g	444 g	43 g	340 g
textile material	100% cotton	98% cotton 2% elastane	100% polyester	43.6% polyamide 37.6% polyester 18.8% cotton/ elastane mix	72% viscose 27% polyamide 1% elastane	50% cotton 50% polyester
other material	-	3% other material: zipper, buttons, leather label	-	13% other material: zippers, buttons	-	1% other material: buttons
packaging	9 g	33 g	33 g	31 g	3.4 g	0.22 g
inter-continental transport	Ship 100%	Ship 100%	Ship 100%	Ship 100%	Ship 100%	Ship 100%

garment	t-shirt	jeans	dress	jacket	socks	hospital uniform
details of fabrics	110 g white cotton tricot, single jersey, 169 dtex	Weave consisting of: 299 g blue cotton warp, 578 dtex 144 g white cotton (93%)/ elastane (7%) weft, 470 dtex	241 g printed black & white polyester weave, cover part, 119/114 dtex (warp/ weft) 231 g black polyester tricot, under part, 114 dtex	57 g black and 110 g olive-green polyamide weave, cover part, 200/90 dtex (warp/ weft) 59 g orange polyester weave, lining, 70 dtex 85 g polyester nonwoven, padding (dtex not measured) 72 g black and olive-green cotton (90%)/ elastane (10%) tricot, gussets, 300 dtex (estimate)	43 g black viscose (72%)/ polyamide (27%)/ elastane (1%) tricot, 300 dtex (estimate)	340 g blue cotton (50%)/ polyester (50%) weave, 200 dtex (estimate)
retail	Includes stores, staff transports	Includes stores, staff transports	Includes stores, staff transports	Includes stores, staff transports	Includes stores, staff transports	No retail
user transport	50% car 50% bus 17 km distance (back and forth to store)	50% car 50% bus 17 km distance (back and forth to store)	50% car 50% bus 17 km distance (back and forth to store)	50% car 50% bus 17 km distance (back and forth to store)	50% car 50% bus 17 km distance (back and forth to store)	Distribution between laundry and hospital included
number of uses	30	240	26	140	27	75
laundry	Washed after 2 uses % dried with heat[3]: 34 % ironed: 15	Washed after 10 uses % dried with heat: 29 % ironed: 15	Washed after 3 uses % dried with heat: 19 % ironed: 18	Washed once % dried with heat: 21 % ironed: 5	Washed after 1 use % dried with heat: 58 % ironed 1	Washed after 1 use % dried with heat: 100 % ironed: 0

[3] Drying of laundry is performed with or without added heat, but for the purpose of this report we use the term "drying" for the case when heat is added.

garment	t-shirt	jeans	dress	jacket	socks	hospital uniform
end-of-life treatment	Municipal incineration with cogeneration of heat and electricity					
share of modelled Swedish consumption	19%	22%	17%	26%	6%	10%

3.3 process flowcharts

Processes flowcharts for each of the six garments are shown in figures 3.1-3.6. Not all transports are depicted in the figure, neither are background processes, such as power generation and production of input chemicals, nor minor foreground processes, such as production of thread, although all these processes are included in the garment models. Each product system consists of four phases: production, distribution and retail, use and end-of-life. Sections 3.4 to 3.7 describe the modelling of each phase in detail.

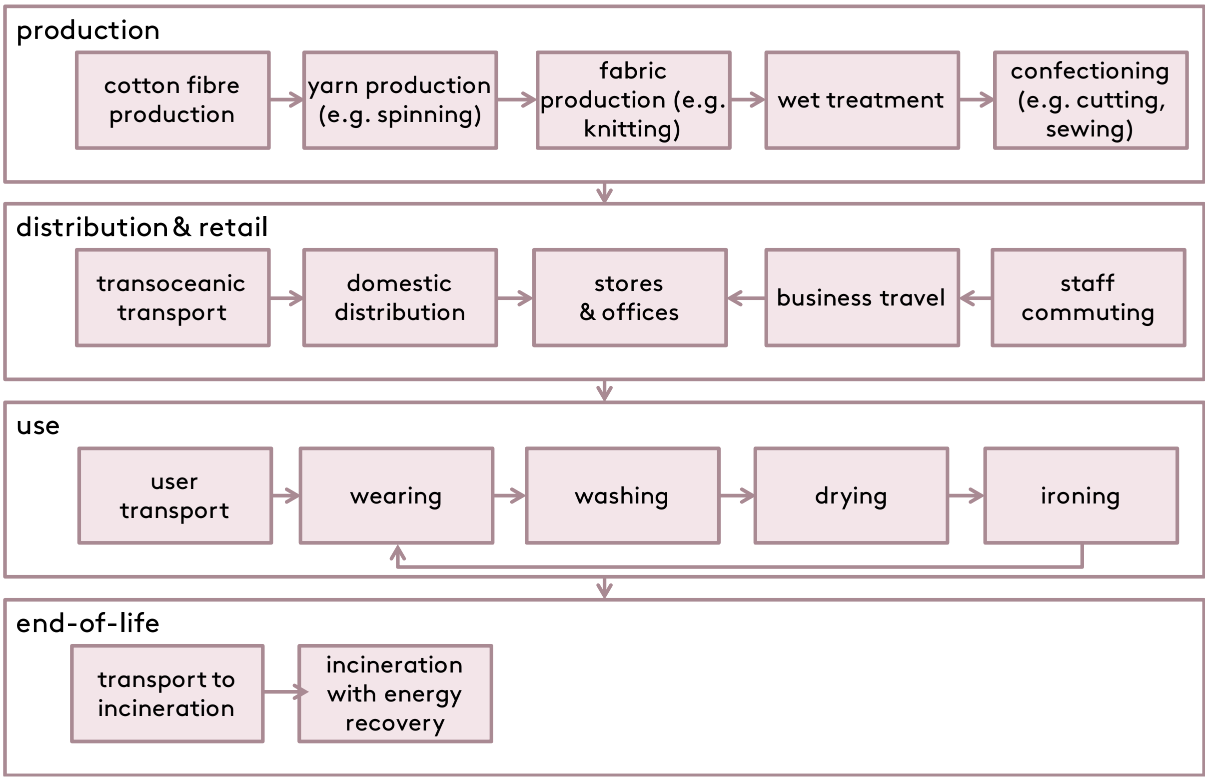


figure 3.1: T-shirt process flowchart.

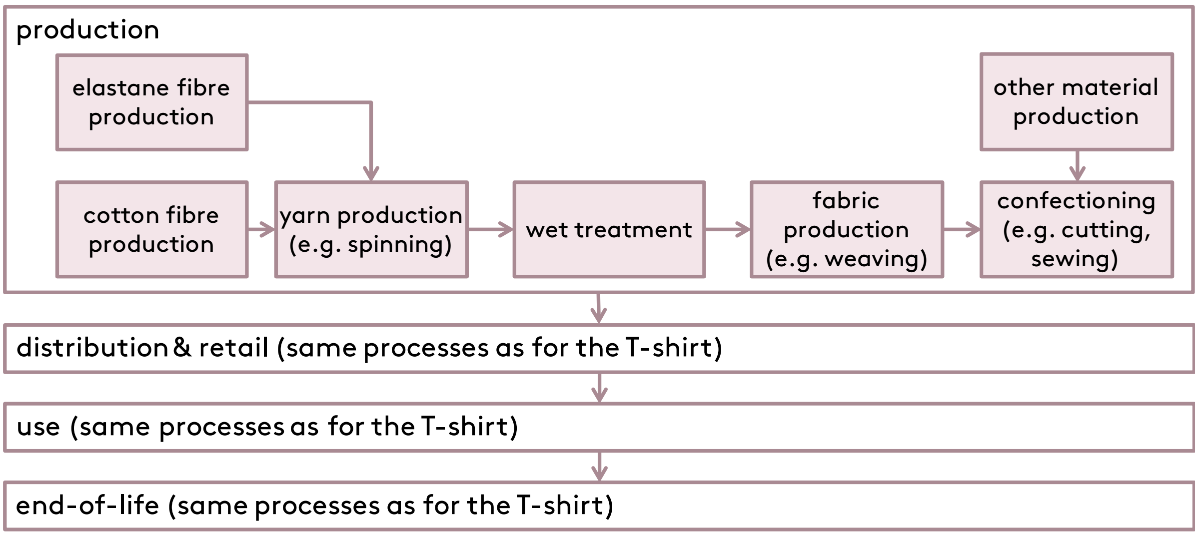


figure 3.2: Jeans process flowchart.

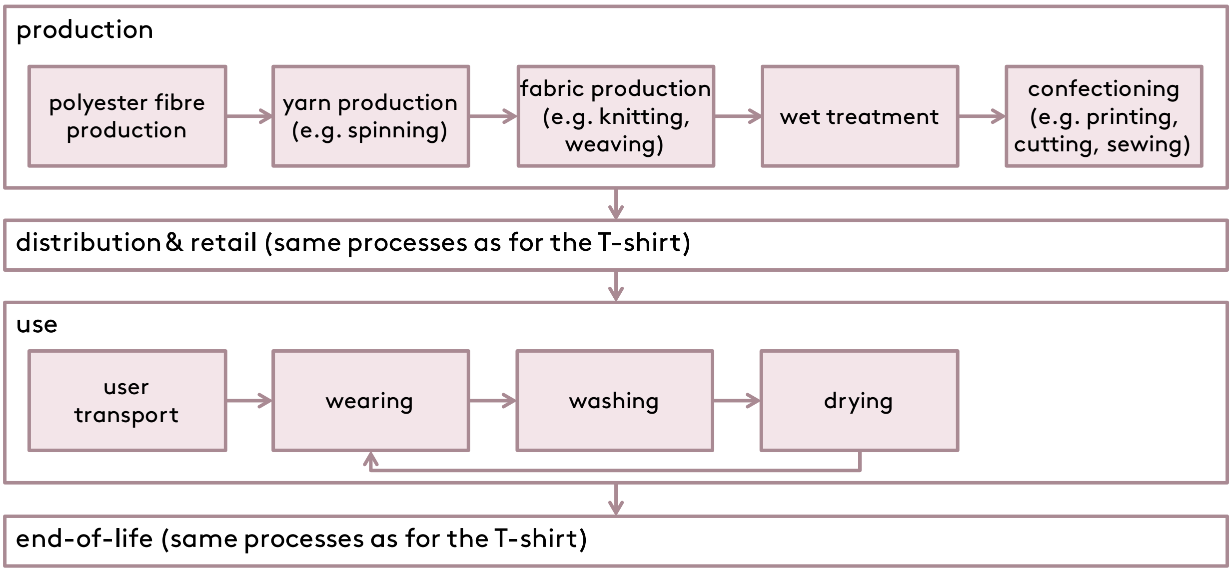


figure 3.3: Dress process flowchart.

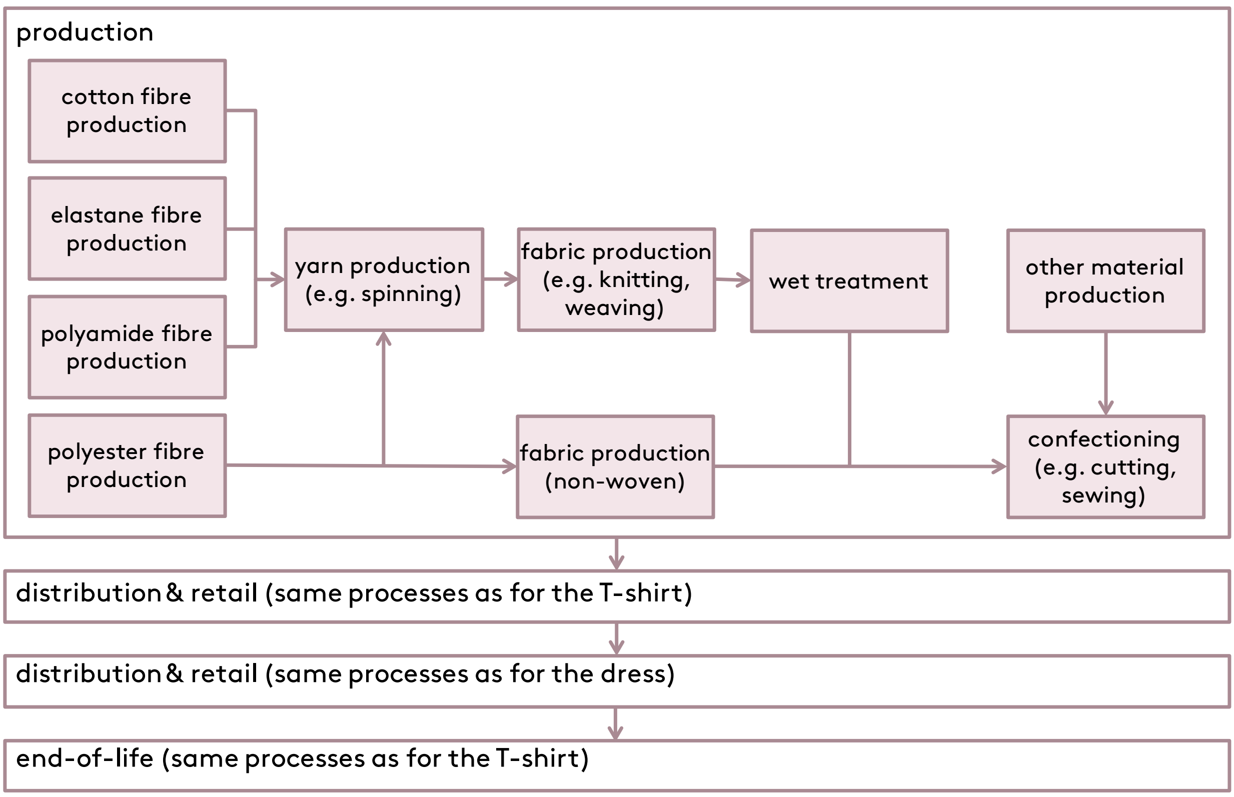


figure 3.4: Jacket process flowchart.

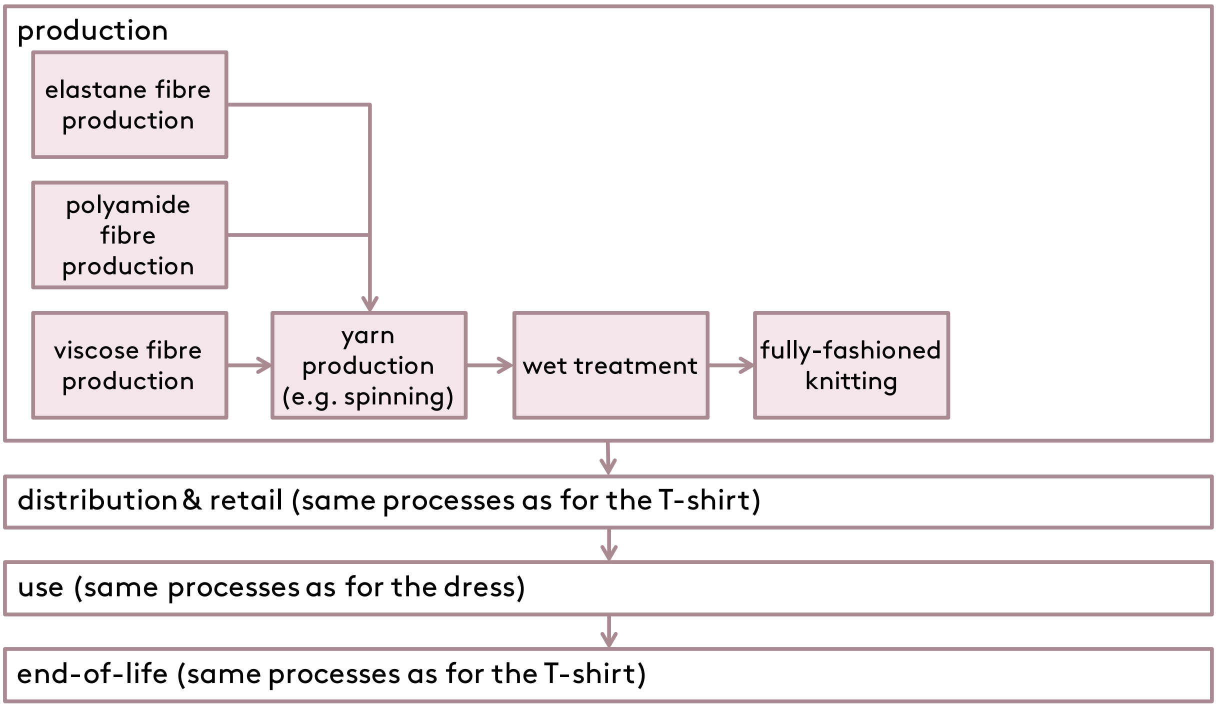


figure 3.5: Socks process flowchart

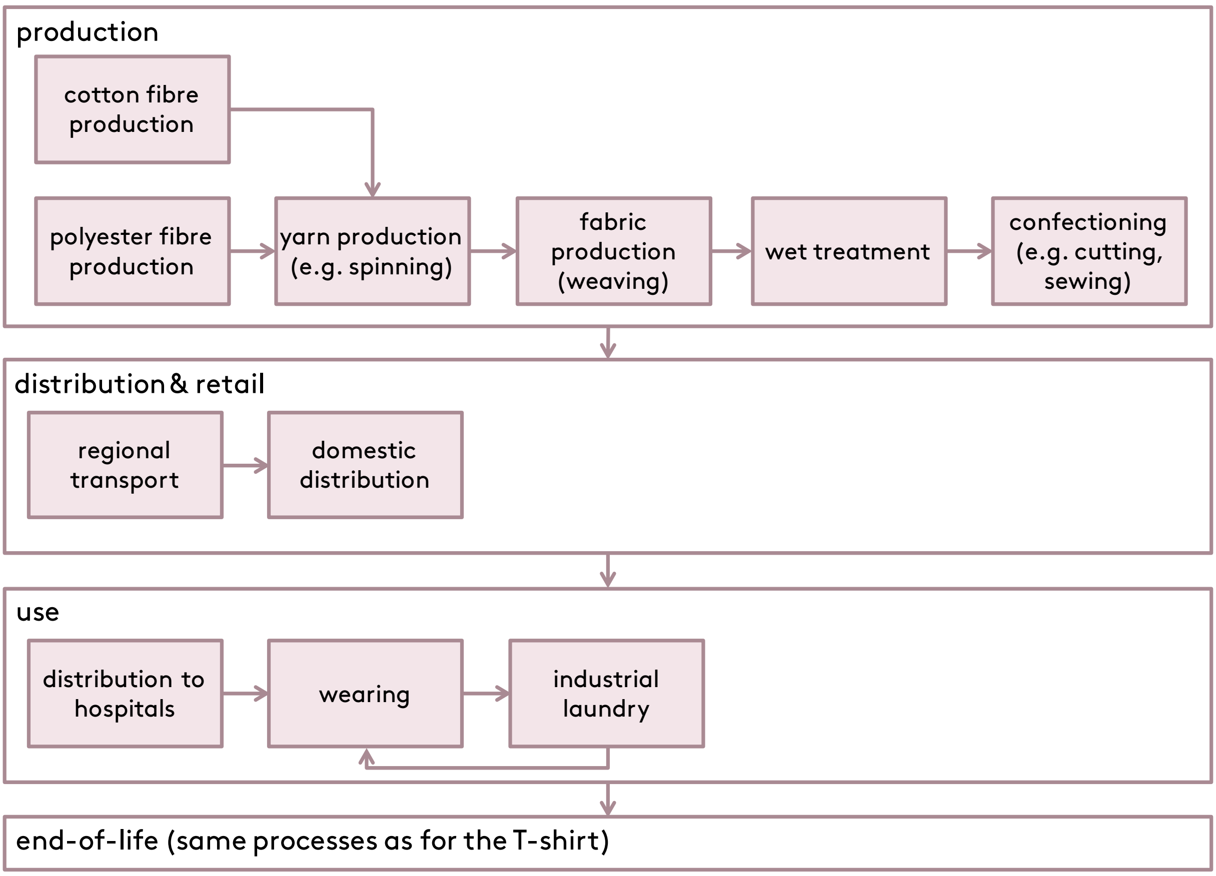


figure 3.6: Hospital uniform process flowchart.

3.4 modelling of the production phase

For most garments, the production phase includes fibre production, yarn production, fabric production, wet treatment, and confectioning. Below is an overview of these production steps, and subsequent sections outline how they were modelled.

The fibres in the six garments are synthetic fibres derived from crude oil (polyester, polyamide, elastane), regenerated cellulose fibres produced from wood (viscose), and natural fibres grown on farms (cotton)[4] . Synthetic and regenerated fibres are used as filament yarns or cut to staple fibres, whereas cotton fibres are staple fibres by nature. Filament fibres are twisted into yarn and sometimes texturised, whereas staple fibres are made into yarn in a sequence of processes (not all fibre types are subject to all these processes): opening, carding, combing, drawing, roving, spinning, twisting and winding. To produce the fabric, the yarn is either woven or knitted, or a nonwoven fabric is produced directly from staple or filament fibres.

The choice of wet treatment method depends on the material, the type of fabric and the intended design. Light-coloured materials are often bleached, and sometimes bleaching is also used as a pre-treatment before dyeing to darker colours. Reactive, vat or direct dyes are used for cellulose materials, whereas disperse or vat dyes are used for synthetics. Synthetics can also be dyed by adding pigment during fibre production, which is a dry process (in contrast to a later wet treatment). Additionally, colour and design can be added via printing on the textiles in the confectioning, which typically also includes cutting, sewing, finishing, ironing and packaging.

In addition to the main processes described above, there is also production of accessories to the garments, such as zippers, buttons, paper labels and packaging, and supplementary processes such as lighting, air conditioning and ventilation of premises.

Subsequent subsections in this chapter provide details on how the production processes were modelled in the present study. All textile production processes (i.e. foreground processes) were assumed to be quite modern, best available technology (BAT[5]) or close to BAT, as this facilitates a discussion of necessary impact-reduction interventions that goes beyond "changing to BAT". This means that the calculated environmental impact of the Swedish clothing consumption is a slight underestimation. Due to the poor traceability of raw fibre materials and other materials used in garment manufacturing, and due to the global trade in raw materials for the fashion industry, global average inventory data is assumed for all material inputs (i.e. background processes) to the textile manufacturing. Manufacturing of machinery and equipment such as weaving looms or dyeing machines were not included in the models of foreground processes, but they are (in most cases) included by default in the Ecoinvent datasets used to model background processes (there contribution to results were found to be insignificant).

In the production phase, electricity, heat, waste management and transports were modelled in the same manner regardless of process. These common modelling assumptions and datasets are described below.

[4] For further information on the raw materials, production methods, technical properties and environmental impact of textile fibres, see "the Fiber bible", a recently published, two-part report from Mistra Future Fashion (Rex et al. 2019, Sandin et al. 2019). The second part is summarized in Section 5.2 of the present report.
[5] BAT is a term defined in European Commission (2013).

3.4.1 common inventory data across production processes

production of electricity used in production

As the garment models were designed to be statistically representative for Swedish clothing consumption, foreground production processes were assumed to be powered by a fictional electricity mix representing the electricity mixes of the countries which dominated Swedish direct and indirect imports of clothes in 2013-2017 (Statistics Sweden 2019a, Eurostat 2019). A 5-year average was used to smooth out annual variations. Producing countries contributing with more than 1% of direct imports were included: China, Bangladesh, Turkey, India, Pakistan, Vietnam and Cambodia, which constitute 49.3% of direct imports (and, for the year 2017, 82% of direct plus indirect imports).

The fictional mix was created in proportion to each country's share of Swedish direct clothing imports, as shown in figure 3.7. Each country's electricity mix was modelled using an Ecoinvent market dataset (medium voltage), which accounts for electricity generated within the countries, imported electricity, grid losses and emissions related to the building of grids and transformers. For some foreground production processes, country-specific datasets were used instead of the dataset of the fictional mix – this was done if a certain production country clearly dominates production (e.g., for polyester fibre production, melt spinning was assumed to be sited in China, hence the Chinese electricity mix was assumed). All background datasets (e.g. production of polyester granulates) were taken directly from the Ecoinvent database without further modification. For further modelling details, see Appendix B (table B 2).

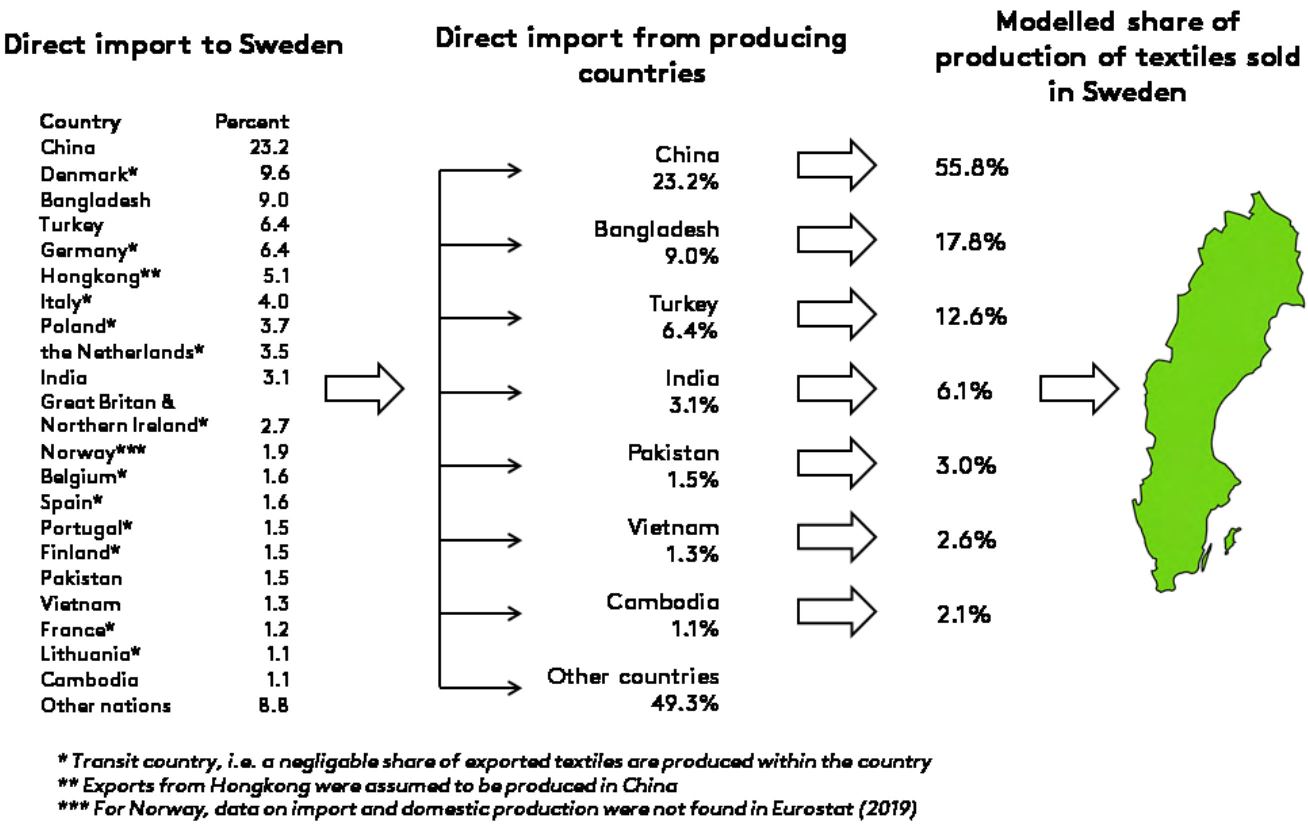


figure 3.7: Illustration of the modelling of the production electricity mix.

production of heat used in production

For modelling the production of heat used in production, we assumed Ecoinvent market datasets on global supply of heat from either light fuel oil or natural gas (depending on whether the collected inventory data specified "gas" or not).

transports between production processes

As a proxy for all transports between production facilities, a transport of 750 km was assumed between fibre production and the subsequent production facilities. The distance was based on Althaus et al. (2007a), and the transport was modelled using an Ecoinvent market dataset on a 16-32 tonne EURO 4 lorry transportation.

management of textile waste from production

Industrial waste from textile processes is generally a valuable by-product and reused for manufacturing of scarves, money bills or for energy production within the factories. It was assumed that these textiles are incinerated after these different additional uses. Emissions from this incineration are included, but no credit for substitution of heat or electricity was granted. The latter is because this heat is most often already accounted for in the data on heat use collected from textile factories (as data usually reflects net heat demand). Emission data for the different textile fractions (cotton, viscose, polyester, polyamide, elastane) was modelled using various Ecoinvent datasets, see Appendix B (table B 4).

3.4.2 fibre production

cotton fibre production

Cotton is a natural fibre grown in cotton plantations, most often using large quantities of irrigated water, pesticides and fertilisers, although the variations between sites are large (Sandin et al. 2019). Following harvesting, the fibres are ginned and baled.

In the modelling of cotton cultivation, ginning and baling, for most impact categories we used data from Cotton Inc (2016) as implemented the Ecoinvent 3.5 database. However, for the impact categories of climate change and energy use, we decided not to use this dataset as it yields considerably lower climate impact results compared to the results shown in the original Cotton Inc report – instead we used the cotton production dataset in the Gabi Professional database, which also is based on Cotton Inc (2016). As Gabi Professional datasets are not available in SimaPro, the cotton production process was not included in when characterising climate impact results in Simapro – instead the climate impact and energy use results of the process as characterised in Gabi was added to the results of the Simapro model via Excel. For further modelling details, see Appendix B (beginning of fibre production section).

polyester fibre production

Textile polyesters are commonly produced from dimethyl terephthalate (DMT) and ethylene glycol (EG). The dominating raw material for DMT and EG are fossil petroleum, although EG is sometimes made from bio-based feedstock. In the present study, it is assumed that the polyester is of 100% fossil and virgin origin.

The dried polyester polymer granulates are transported to extruders where they are melted and pumped to spinning packs held in a spin manifold. The spin packs contain spinnerets with a large number of fine holes through which the melted polymer flows to form filaments. Any contaminants in the polymer are removed by filtration prior to the spinneret. Spin draw finish is applied as an aid to subsequent processing, which consists of mineral oil, esterified oil, anti-static agents, etc. The spun fibres are drawn to optimise their tensile properties. Staple fibres are cut to the required fibre length, which e.g. enables mixing with natural fibres, before being baled ready for dispatch (European Commission 2007).

An Ecoinvent dataset on polyethylene terephthalate (PET) production were used to model the polyester polymer production. Data from Idemat (2012) and the polymer BREF document (European Commission 2007) were used to create a dataset for melt spinning into fibres. Chinese market electricity mix was assumed for powering the melt spinning since China is the main synthetic fibre producer (Oerlikon 2010). Further modelling details are found in Appendix B (table B 5).

polyamide fibre production

Polyamide is a synthetic material also known as nylon. There are two types of polyamide: PA 6 and PA 66. For the jacket, PA 6 was used, which is produced by polyaddition of caprolactam rings producing a macromolecular chain, whose length is determined by the presence of a chain terminator (e.g. acetic acid). Due to the equilibrium situation of the polyaddition reaction, the conversion of the caprolactam to PA 6 is 89–90%, the rest being monomer and cyclic oligomers. These oligomers must be removed by hot water extraction, in other words 'washing' the polymer chips in a counter-current demineralised water flow (European Commission 2007). After drying, the fibres are melt-spun and drawn to filament yarn or cut to staple fibres as described above. During the melt spinning, the caprolactame content rises again and is partially emitted during the following thermal treatments (European Commission 2003). The thread lines are entangled with compressed air and then lubricated with special chemicals (spin finish) that give the yarn the required physical properties. Some effluents and fumes are produced in this section and sent to a treatment facility.

For modelling the production of PA 6 fibres, an Ecoinvent dataset was used along with data from Idemat (2012) and the polymer BREF document (European Commission 2007). Chinese market electricity mix was assumed for powering the melt spinning since China is the main synthetic fibre producer (Oerlikon 2010). See Appendix B (table B 6) for further details.

elastane fibre production

Elastane is a synthetic material also known as spandex or lycra. Elastane is a polyurethane (PU) blend, spun to fibres through dry spinning (solvent-based spinning). In the present study it was assumed that elastane is 100% PU (usually there is a smaller content of rubber which is excluded here), spun with dimethylacetamide (DMAC). PU and DMAC production were modelled using Ecoinvent datasets. Data from the textile BREF document (European Commission 2003) was used for the dry spinning. Chinese market electricity mix was assumed for powering the melt spinning since China is the main synthetic fibre producer (Oerlikon 2010). Further modelling details are found in Appendix B (table B 7).

viscose fibre production

Viscose is a regenerated cellulose fibre, produced by first dissolving pulp made from plant fibres, most often fibres from birch or eucalyptus wood, using sodium hydroxide and carbon disulphide. The solution is then pressed through the holes of a spinneret into an acid spin bath, usually containing sulphuric acid, sodium sulphate and zinc sulphate, forming filament fibres which then are cut into staple fibres, washed, dried and baled (Eriksson 2015).

For modelling viscose fibre production, an Ecoinvent dataset on global, average production was used, see Appendix B for further details (beginning of fibre production section). This dataset has been shown to yield average LCIA results in relation to other LCIA results available literature (Peters et al. 2019).

3.4.3 yarn production

The materials of the studied garments are made either from staple fibres or filament fibres (see table 3.2), which determines the steps involved in the yarn production.

Production of filament yarn consists of texturising, drawing, twisting and winding. The filaments entering this process are sometimes called partially oriented yarn (POY), whereas the final yarn is called fully drawn yarn (FDY) or drawn and texturized yarn (DTY).

Production of staple yarn consists of all or some of the following steps: opening, carding, combing, drawing, spinning, twisting and winding (European Commission 2003). In further detail, staple yarn production begins with opening of the bales containing staple fibres. The fibres are sent into the carding machine where impurities and short fibres are sorted out. Combing is only required for cotton fibres to sort out the fibres that are too short for spinning high quality yarn but were not removed in the carding, this fraction is suitable to use for production of money bills. Then follows the spinning. In the present study, all staple yarns were assumed to be spun using a technique called ring spinning which gives a smooth yarn with good pilling resistance and high strength. A spinning oil was assumed to be used. After the spinning, the staple yarn is twisted to hold for knitting or weaving. Winding includes relaxing the yarn and rolling the yarn up on rolls for the customers.

The energy use of yarn production depends strongly on yarn size (a thicker yarn, i.e. a higher dtex, means lower energy use). Table 3.2 lists the yarn sizes of the materials of five of the studied garments, and the assumed electricity use in yarn production – below follows the reasoning and references behind each of these assumptions. The Idemat database (Idemat 2012) lists data on electricity consumption for yarn spinning with different dtex[6], however, the documentation does not show what type of equipment is used and whether supplementary processes are included. Instead difference sources were used for the different yarns, such as a review of available data on various textile processes (van der Velden et al. 2014) and Laursen et al. (2007), which provide generic formulas for calculating, based on yarn size, electricity use in yarn production for three yarns: a 100% synthetic ring yarn, a combed 65% polyester/35% cotton ring yarn, and a combed 100% cotton ring yarn. The formula is valid for yarn sizes of 130 to 600 dtex.

For the T-shirt, with a 169 dtex yarn, van der Velden et al. (2014) provide data, originally from Kaplan and Koç (2010), on electricity use in the production of combed knitting cotton yarn of 200 dtex (3.06 kWh/kg) and 120 dtex (5.52 kWh/kg). Assuming electricity consumption scales approximately linear with yarn size between these two data points, yields an estimated electricity use of 4.02 kWh per kg yarn. The formula in Larsen et al. (2007) on combed cotton ring yarn yields an energy use of 3.96 kWh per kg yarn for a 169 dtex yarn. Based on these two numbers, 4 kWh per kg yarn was assumed.

For the jeans, with yarn sizes of 470 (cotton/elastane mix) and 578 dtex (cotton), the most relevant data in van der Velden et al. (2014) was on ring spinning of combed cotton yarn of 330 dtex suitable for weaving: 1.88 kWh per kg yarn. This suggests that yarns with 470 or 578 dtex would require perhaps 1 or 1.5 kWh of electricity use per kg yarn. On the other hand, the Larsen et al. (2007) formula for cotton ring yarns yields electricity use of 2.45 kWh for a 470 dtex yarn and 1.91 kWh for a 578 dtex yarn, i.e. substantially higher. Based on these two sources, 2 kWh per kg yarn was assumed.

[7] dtex = the mass in grams per 10 000 metres.

For the dress, with polyester staple yarns of 114 and 119 dtex, the closest data in van der Velden et al. (2014) was that on on ring spinning of 100% synthetic yarn of 130 dtex: 3.70 kWh per kg yarn – Larsen et al. (2007) is given as original source, and the Larsen et al. formula for a 100% synthetic ring yarn indeed yields 3.70 kWh per kg yarn for a 330 dtex yarn. The Larsen et al. formula was thus used in the present study, although 114 and 119 dtex is slightly below the recommended 130-600 dtex interval, resulting in 3.78 kWh and 3.76 kWh per kg yarn for the 114 and 119 dtex yarns, respectively. To avoid excessive precision, 3.8 kWh per kg yarn is assumed for both these yarns.

For the 70 dtex polyester staple yarns in the jacket lining, no useful data was provided by van der Velden et al. (2014), so the Larsen et al. formula was used once again, although 70 dtex is outside the recommended dtex interval, yielding an electricity use of 4 kWh per kg.

For the 300 dtex yarn in the jacket gussets, which mostly consist of cotton staple fibres (and some elastane), the Larsen et al. formula for cotton ring yarn was used, yielding an electricity use of 3.3 kWh per kg yarn. Here, data in van der Velden (2014) was of little help, as it, for 300 dtex cotton yarns, only provides data on rotor spinning, which requires much less energy.

For the jacket polyamide filament yarns of 90 (weft) and 200 (warp) dtex, data from van der Velden (2014) was used. For the processing of POY into DTY several figures are given: 1.21 kWh/kg yarn (83 dtex), a mean of 10 machines, originally from ITMF (2010); 0.5-0.6 kWh/kg yarn (104 dtex) and 0.7-0.9 kWh/kg yarn (52 dtex), originally from a source missing in their reference list ("Barmag 2011"); 2.18 kWh/kg yarn (unspecified dtex), originally from a confidential source. Due to the uncertainties of the latter two original sources, the data originally from ITMF (2010) were used as a basis for two conservative estimates: 1.5 kWh per kg 90 dtex yarn, and 0.75 kWh per kg 200 dtex yarn (note that these numbers are in between the numbers of the other two data sources).

For the socks, the yarn largely resembles that of the jacket gussets (300 dtex staple yarn consisting mostly of cellulosics), thus the same electricity use was assumed in yarn production.

For the hospital uniform, with 50% cotton/50% polyester 200 dtex staple yarns, the Larsen et al. formula for a combed 65% polyester/35% cotton ring yarn was used, resulting in 3.8 kWh per kg yarn. This number is in between the two data points on cotton/polyester 200 dtex yarn provided by van der Velden (2014): 1.60 and 7.00 kWh/kg yarn.

An important environmental aspect of yarn production is material losses. For staple yarns consisting of 50-100% cotton, material losses are based on a Cotton Inc (2016) dataset on knitted cotton yarn as implemented in Gabi, which states losses from fibre to knitted fabric of 12.2%, based on the average of 13 production facilities in Asia and South America. As losses in the knitting of cotton fabric are about 1.5% (Larsen et al. 2007), 11% losses were assumed in yarn production (11% followed by 1.5% equals a total loss of 12.2%).

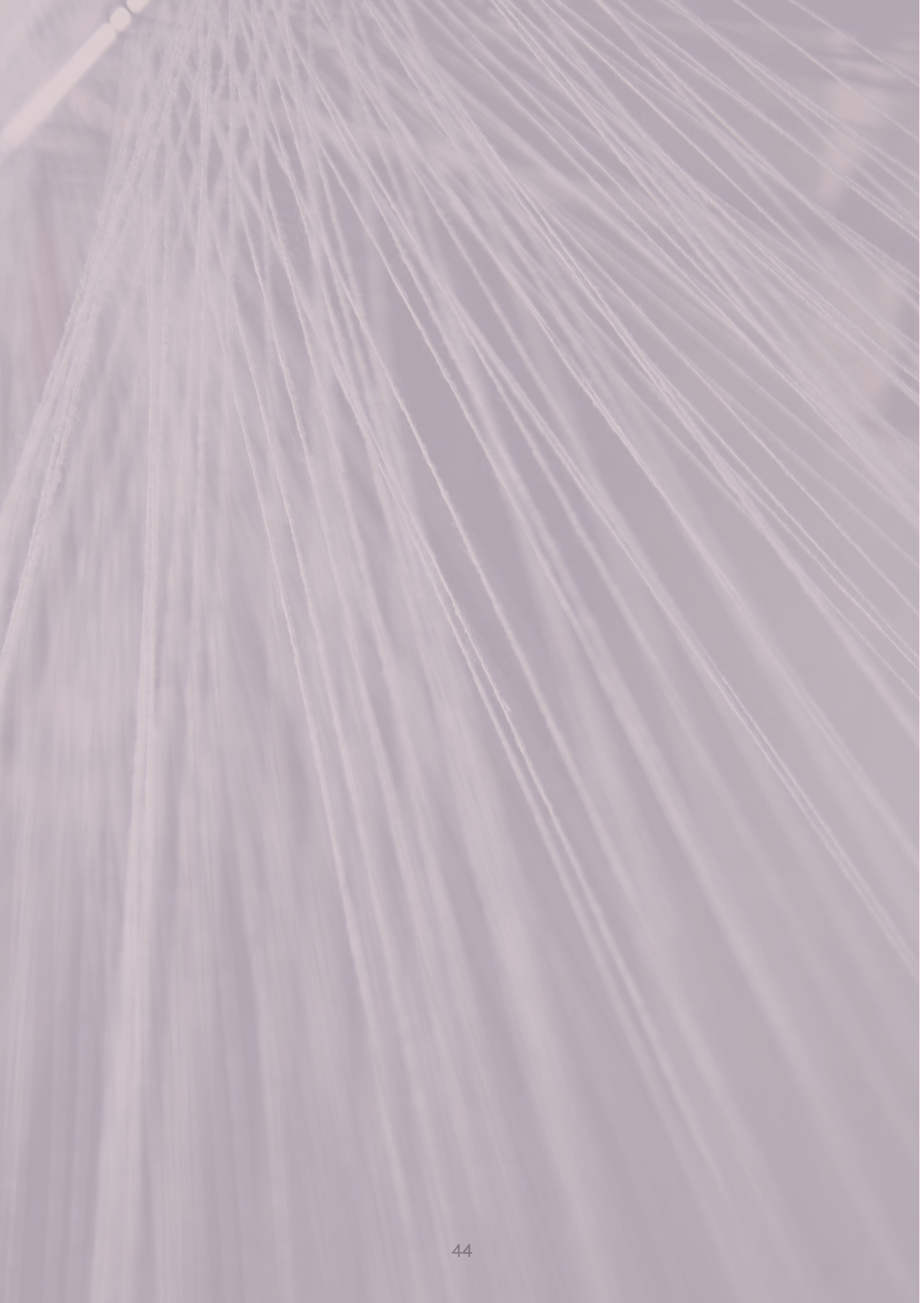
For staple yarns consisting of more than 50% synthetic or viscose fibres, losses in the opening and carding step are considerably lower than for cotton and combing is avoided altogether, and the subsequent steps usually have negligible losses (drawing, roving, spinning, twisting and winding). Based on a visit to a synthetic staple yarn production facility in South Korea, the total material losses in synthetic staple yarn production were assumed to be 0.5%. The same material losses (0.5%) were assumed also for the production of viscose staple yarns and synthetic filament yarns.

In yarn spinning, a small amount of spin finishes was assumed to be employed (0.0016 kg/kg yarn).

Further details on the modelling of yarn production are found in Appendix B (tables B-8 to B-17).

table 3.2: Assumed electricity use in yarn production for materials in five of the studied garments. Yarn size is based on measurements of the example items (except for the gusset fabric of the jacket and fabric of the socks, which were estimates).

colour of fabric	direction	fibre content	yarn size (dtex)	assumed electricity use in yarn production (kWh/kg yarn)
T-shirt				
White	Tricot	Cotton staple fibres	169	4
Jeans				
White	Weft	Cotton (93%) and elastane (7%) staple fibres	470	2
Blue	Warp	Cotton staple fibres	578	2
Dress				
Black (under part)	Tricot	Polyester staple fibres	114	3.8
Black & white (cover part)	Warp	Polyester staple fibres	119	3.8
Black & white (cover part)	Weft	Polyester staple fibres	114	3.8
Jacket				
Black (cover part)	Warp	Polyamide filament fibres	200	0.75
Black (cover part)	Weft	Polyamide filament fibres	90	1.5
Green (cover part)	Warp	Polyamide filament fibres	200	0.75
Green (cover part)	Weft	Polyamide filament fibres	90	1.5
Orange (lining)	Warp	Polyester staple fibres	70	4
Orange (lining)	Weft	Polyester staple fibres	70	4
Black/green (gussets)	Tricot	Cotton (90%) and elastane (10%) staple fibres	300	3.3
Socks				
Black	Tricot	Viscose (72%), polyamide (27%) and elastane (1%) staple fibres	300	3.3
Hospital uniform				
Blue	Weft	Cotton (50%) and polyester (50%) staple fibres	200	3.8
Blue	Warp	Cotton (50%) and polyester (50%) staple fibres	200	3.8



3.4.4 fabric production

knitting

The T-shirt, the dress, the jacket and the socks consist of knitted tricots either in whole or in part. The tricots of the T-shirt, the dress and the jacket are made in a circular knitting machine, whereas the socks are knit in a fully-fashioned sock knitting machine – this means that fabric production and confectioning are one and the same process[7].

As for yarn production, the energy use of the knitting depends on yarn size and type of machine. Data from van der Velden (2014) indicate large differences in data of electricity use between sources, spanning from 0.16 kWh per kg fabric for the circular knitting of a cotton 300 dtex rotor yarn (original source ITMF 2010), to 8.08 kWh per kg fabric for knitting (including winding) for the fabric of a pair of cotton briefs (unknown dtex; original source Collins and Aumônier 2002). The only data which van der Velden (2014) explicitly specify is for circular knitting of ring yarn (i.e. the knitting process of the present study) is data from ITMF (2010) on 200 dtex yarn: 0.19 kWh per kg fabric.

Cotton Inc (2016) provides data on electricity use of knitting reflecting the average of six knit fabric manufacturers, amounting to 0.26 kWh per kg fabric (unspecified dtex). Idemat (2012) provides data on cumulative energy demand (CED) of knitting of 83 dtex, 200 dtex and 300 dtex yarns: 5.5, 2.3 and 1.5 MJ per kg fabric. Characterising the Ecoinvent 3.5 dataset on the European electricity medium voltage market mix (Idemat most often reflects European factories) in Gabi results in primary energy demand (the equivalent to CED in Simapro) of 11.78 MJ per kWh electricity produced. Assuming this transformation factor between the CED of the Idemat data and the electricity use in the knitting process, gives electricity use of 0.47 kWh (83 dtex), 0.20 kWh (200 dtex) and 0.13 kWh (300 dtex) per kg fabric. Notably, ITMF (2010), Cotton Inc (2016) and Idemat (2012) suggest electricity usages of the same order of magnitude, thus these were used as the basis for the estimates of the present study.

For the 169 dtex tricot of the T-shirt and the 114 dtex tricot of the dress, it was assumed that electricity use scales linearly with dtex between the Idemat data on 83 and 200 dtex, which results in 0.21 kWh (169 dtex) and 0.33 kWh (114 dtex) per kg fabric. For the 300 dtex tricots of the jacket, the Idemat data on 300 dtex tricots was assumed: 0.13 kWh per kg fabric. For the socks, which are produced in a fully-fashioned sock knitting machine, data from Roos (2013) was used: 4.15 kWh per kg ready-made socks. Following the knitting machine, a sock toe seam is sewn.

Material losses were assumed to be 1.5%, based on Larsen et al. (2007). The lubricant was assumed to correspond to 8% of the weight of the knit.

For the socks, it should be stressed that the yarn is treated by wet processes (see Section 3.4.5) prior to knitting. For information about the packaging done prior to distributing the socks to the retail phase, see Section 3.4.6.

Further details of the modelling of knitting are found in Appendix B (tables B-18 to B-20).

[7] Part of this process is presented in this section ("Fabric production") and part in the Confectioning section. In the results sections, this stage of the production of the socks is either sorted under "fully-fashioned knitting" or, in the aggregated national-level results, as part of fabric production.

weaving

The jeans, the dress, the jacket and the hospital uniform are fully or partly made from woven fabrics. In the weaving process, yarns are assembled together on a loom and a woven fabric is obtained.

Electricity use during weaving depends on the yarn size and the type of machine. Van der Velden et al. (2014) provide data on the electricity use in weaving from several sources, for instance: (i) 4.38 kWh and 2.97 kWh/kg fabric with air-jet weaving of 200 and 300 dtex yarns, respectively (original source ITMF 2010); (ii) 1.82-4.19 kWh/kg fabric (average: 2.65), based on three weaving mills in Sweden producing different fibre blends (confidential source, dtex not specified); (iii) 3.86-4.76 kWh/kg fabric (confidential source, dtex not specified). Remaining figures span from 1.35 kWh (air-jet weaving of 65% polyester/35% cotton fabric) to 19.50 kWh (40% polyester/60% cotton weave of 100 dtex yarn) per kg fabric. Most of these references indicate no or negligible use of other forms of energy. We interpret this as steam (used for moisture control) and pressurized air (used for air-jet machines) are being generated on-site from electricity. Further, Idemat (2012) provides data on the CED of weaving for 10 different yarn sizes, spanning from 32.1 MJ (500 dtex) to 1069.2 MJ (15 dtex) – using the same transformation factor as applied above for knitting, this corresponds to range of 2.72 to 90.8 kWh per kg fabric.

Idemat (2012) was used as a starting point for estimating electricity use of weaving in the present study, as the Idemat data seems to be in the same range as the data provided by van der Velden et al. (2014) (except for very fine fabrics with very low dtex), and as it provides data for a large number of yarn sizes. For materials that did not correspond directly to any of the yarn sizes specified in Idemat, it was assumed that electricity use scales approximately linearly with yarn size between the two closest data points. Moreover, the mass-weighted average of the yarn sizes of the weft and the warp was assumed. The resulting electricity use data is shown in table 3.3.

Material losses were assumed to be 1.3% on incoming yarn, based on Larsen et al. (2007). The amount of added sizing agent was assumed to correspond to 5% of the weight of the weave, and to result in emissions to air and water. Further details of the modelling of weaving are found in Appendix B (tables B-22 to B-26).

For the denim, the two yarns were assumed to be produced separately and treated by wet processes (see Section 3.4.5) prior to weaving: the white cotton/elastane yarn via spinning, bleaching and drying; and the blue cotton yarn via spinning, dyeing and drying.

nonwoven fabric production

The jacket contains a nonwoven polyester padding. Nonwoven materials are produced from either staple fibres or filament fibres. For the jacket padding, polyester staple fibres were assumed. The staple fibre nonwoven line is an entirely dry process, with no air emissions, water emissions or water use. Fibres that are cut off from edges are assumed to be recirculated, thus materials losses are assumed. The process includes opening and blending, carding, needle punching and padding. Electricity use was assumed to be 5.4 kWh per kg fabric, based on a non-public study from 2011 carried out by Swerea IVF (presently known as RISE Research Institutes of Sweden), with data collected from a specific operator. Further modelling details of nonwoven production is found in Appendix B (table B 27).

table 3.3: Assumed electricity use in fabric production for materials in five of the studied garments. Yarn size is based on measurements of the example items (except for the gusset fabric of the jacket and fabric of the socks, which were estimates).

colour of fabric	direction	fibre content	yarn size (dtex)	assumed electricity use in fabric production (kWh/kg yarn)
T-shirt				
White	Tricot	Cotton staple fibres	169	0.21
Jeans				
White/blue	Weave	Warp: cotton (93%) and elastane (7%) staple fibres, weft: cotton staple fibres	470/578 (warp/weft), 551 (average)	2.4
Dress				
Black (under part)	Tricot	Polyester staple fibres	114	0.33
Black & white (cover part)	Weave	Polyester staple fibres	119/114 (warp/weft), 116.5 (average)	8.3
Jacket				
Black (cover part)	Weave	Polyamide filament fibres	200/90 (warp/weft), 167 (average)	5.1
Green (cover part)	Weave	Polyamide filament fibres	200/90 (warp/weft), 167 (average)	5.1
Orange (lining)	Weave	Polyester staple fibres	70 (warp and weft)	19.5
Black/green (gussets)	Tricot	Cotton (90%) and elastane (10%) staple fibres	300	0.13
White (padding)	Non-woven	Polyester staple fibres	Not measured	5.4
Socks				
Black	Tricot	Viscose (72%), polyamide (27%) and elastane (1%) staple fibres	300	4.15
Hospital uniform				
Blue	Weave	Cotton (50%) and polyester (50%) staple fibres	200	6.8

3.4.5 wet treatment

For white and light-coloured natural materials, bleaching is needed. Bleaching also improves the dyeing and can be used as a pre-treatment also before dyeing to darker colours. The type of dyestuff and auxiliary chemicals applied depends on the fibre. For cellulose materials such as cotton, reactive dyes, vat dyes or direct dyes are used. For synthetic materials such as polyester and polyamide, disperse dyes and sometimes vat dyes are used. Synthetic fibres can also be coloured by adding pigment already in the fibre production process, which is a dry process instead of the wet treatment. Further, colour and design can be added via printing on the textiles.

Normally, a textile wet treatment process for knitted fabric includes the following steps: bleaching/dyeing process (in jet/air-jet or jigger), opening, drying and fixation in stenter frames. Opening refers to the mechanical opening of the wrinkled "tube" of fabric that has been pressed through the jet-machine. The electricity use of the opening process is assessed to be insignificant in comparison to the energy use of drying. The main energy use in the wet treatment stems from the heating of water in the baths for pretreatment, dyeing and washing. For woven fabrics, continuous processes (pad batch, foullard) are common in the wet treatment although batch (exhaust) dyeing is also used. Woven fabrics are also dried and fixed in stenter frames. For yarn dyeing, the machinery is either bobbin dyeing machines or hank dyeing machines for very delicate materials.

Whether the material is dyed as yarn or as fabric depends on design and production volume. Continuous yarn dyeing can only be applied for large production volumes. To be able to create patterns like chequering or stripes, yarn dyeing must be applied. The wet treatment does, however, almost always begin with a wash and end with a finishing process. All the wet treatment processes include treatment of waste water and air emissions. For more information on dyeing, printing and wet treatment, the reader is referred to the BAT reference document (BREF) for the textiles industry (European Commission 2003)[8].

The modelling of the wet treatment is based on the framework created in the Mistra Future Fashion research (Roos 2016). The combinations of wet treatment processes, dyeing and printing for the six different garments are summarised in table 3.4, along with assumptions on electricity and heat use. Electricity and heat use for the bleaching, dyeing and drying processes were taken from the Idemat database (Idemat 2012). For the printing process for the dress, specific supplied data was used (Roos et al. 2011). The process descriptions (recipes) for the T-shirt, jeans, dress and jacket were compiled by Otterqvist (2015).

The compositions of different chemical products (chemical mixtures) were taken from TEGEWA's International Textile Auxiliaries Buyer's Guide 2008/09 (TEGEWA 2008) or provided by a textile chemicals manufacturer. The LCI modelling of emitted substances and their subsequent transformation products was conducted with the intention of subsequently calculating toxicity impact results with the USEtox model (Rosenbaum et al. 2008). A major implication of this adaptation to USEtox is that the model is time-integrated, which means that all emissions as well as transformation into degradation products in the environment is assumed to occur instantly (at time zero).

[8] A new BREF document for the textile industry will be released in about 2 years.

The following assumptions were made for the emissions and waste water treatment (for the reasoning behind these assumptions, see Roos et al. (2018)):

- 95% of property-lending substances (dyes, durable water repellents (DWR), softeners, etc.) will stay on the product.
- 0.1% of the content of all chemicals is degraded to common breakdown products if nothing else specified.
- 0.1% of all volatile compounds are emitted to urban air after atmospheric emission treatment (average scenario).
- 1% of the polymer content of polymeric wet treatment chemicals remains as monomers from the production process.
- 90% of reactive chemicals are degraded during wet operations.
- Salts are soluble ions that are not degraded.
- Persistent compounds are not degraded.
- Dissociating substances are handled by the LCIA method (USEtox 2).
- 90% of all chemicals in liquid effluents are removed in the waste water treatment process

For further information on the modelling of chemical use and emissions in wet treatment, see Appendix B (tables B-28 to B-38).

table 3.4: Overview of wet treatment, dyeing and printing processes for the six garments, and the assumed energy use of each process. Details of each process are found in Appendix B.

Processes included in wet treatment	T-shirt	Jeans	Dress	Jacket	Socks	Hospital uniform	Assumed electricity use (kWh)	Assumed heat use (MJ)
Bleaching of fabric for T-shirt	X	-	-	-	-	-	0.7	30
Dyeing denim blue yarn for jeans warp yarn	-	X	-	-	-	-	0.7	30
Bleaching of white cotton/elastane yarn for jeans weft yarn	-	X	-	-	-	-	0.7	30
Dyeing polyester tricot black in jet dyeing machine	-	-	X	-	-	-	0.7	30
Pretreatment in jet machine of polyester weave before printing	-	-	X	-	-	-	0.7	30
Dispersion print of polyester weave on rotation printer	-	-	X	-	-	-	0.112	1.9
Dyeing polyamide weave black and green in beam dyeing machine	X	-	-	X	-	-	0.7	30
Dyeing polyester weave orange in jet dyeing machine	-	-	-	X	-	-	0.7	30
Dyeing cotton/elastane tricot green in jet dyeing machine	-	-	-	X	-	-	0.7	30
Dyeing viscose/ polyamide/elastane tricot black in jet dyeing machine	-	-	-	-	X	-	0.7	30
Dyeing cotton/polyester weave blue in jet dyeing machine	-	-	-	-	-	X	0.7	30
Drying and fixation of cellulosics in stenter frame	X	X	-	-	-	X	0.8	8
Drying and fixation of synthetics in stenter frame	-	-	X	X	-	-	0.8	8

3.4.6 confectioning

The confectioning process includes cutting, sewing, printing, finishing, ironing, packaging and supplementary processes such as lighting, air conditioning and ventilation for personnel premises.

As a starting point for modelling the electricity use in confectioning, we used data from Fimreite and Blomstrand (2009), which specifies 1.5-2.0 kWh per hour of sewing. Assuming 1.75 kWh, this translates to 0.029 kWh per minute. This covers several confectioning processes (cutting, sewing, heating of facilities, etc.), although the data has been alloca-ted to garments based on sewing time. This resembles data in Roos (2012) (0.0217 kWh/min) and Roos (2013) (0.0265 kWh/min), collected at confectioning factories in Latvia and China, respectively.

Roos (2012) provides data on resource use for confectioning of the hospital uniform: 0.06 l of water and 0.5 l of natural gas (for heat - about 0.02 MJ), respectively, per garment. This data is assumed for the confectioning premises of the other garments as well, once again allocating based on sewing time, which yields 0.002 l and 7.1E-4 MJ per minute of sewing, respectively.

Data on sewing times from Fimreite and Blomstrand (2009) were used as a starting point when estimating the sewing times of the garments, except for the hospital uniform for which data was from the model underpinning the Roos (2012 report (the sewing time is, however, not stated in the report). Fimreite and Blomstrand specify sewing times of 45 minutes for simple garments such as everyday trousers, 85 minutes for more complicated garments such as more functional outdoor trousers, 135 minutes for even more complicated garments such as shell jackets with light lining, and 180 minutes for the most complicated garments such as heavy winter jackets.

The assumed sewing times and the resulting energy and water use for the confectioning is found in table 3.5. Below the table, further information on the confectioning is provided. Additional details on the modelling of confectioning processes is found in Appendix B (tables B-40 to B-44).

table 3.5: Assumptions on electricity, heat and water use for the confectioning of five of the garments, based on assumed sewing times (these numbers exclude energy and water use in washing and ironing done prior to packaging, see below text).

Garment	Assumed sewing times (minutes)	Electricity use (kWh)		Heat use (MJ)		Water use (kg)	
		per garment	per kg garment	per garment	per kg garment	per garment	per kg garment
T-shirt	10	0.29	2.64	0.007	0.065	0.020	0.182
Jeans	45	1.31	2.74	0.032	0.067	0.090	0.189
Dress	85	2.47	5.16	0.060	0.126	0.170	0.356
Jacket	135	3.92	8.83	0.096	0.216	0.270	0.608
Hospital uniform	28	0.81	2.39	0.020	0.058	0.056	0.165

There are some further processes in confectioning, which add to the energy and water use of table 3.5. The T-shirt, the jacket, the dress and the hospital uniform were assumed to be ironed once, and the jeans was assumed to be washed once, prior to packaging. For these activities, we assumed the same energy, water and detergent use as in residential laundry, see Section 3.6.3. For the hospital uniform, the ironing time was assumed to be 6 minutes.

Waste material from the cutting is normally around 15-20% of the incoming material (Roos 2012). For the T-shirt (a relatively simple garment), 15% waste was assumed, and for the jeans, the dress, the jacket and the hospital uniform, 20% waste were assumed. The confectioning templates were assumed to be 5% of the material's weight. It was assumed that the textile waste is incinerated after different additional uses, see Section 3.4.1.

accessories and packaging

For the T-shirt, jeans, dress, jacket and socks, estimates on the weight of zippers, buttons, paper labels and thread were based on the example garments in table 3.1. The individual packaging of each garment was weighed by hand. Based on this, a generic estimate was made for all garments: 20 g plastic packaging and 60 g corrugated board boxes per kg garment.

For the hospital uniform, confectioning modelling was done as in Roos (2012), which is in turn is based on supplier data and assumptions. The weight of plastic buttons and thread was based on assumptions. No washing label is applied, as this information is printed in the back of the garment. Following production, the uniforms are packed in corrugated board boxes with a rubber band around every five uniforms. Each box contains 50 uniforms, weigh 200 g, and is recirculated 20 times. The rubber bands were assumed to weigh 2 g and be recirculated 10 times.

Ecoinvent datasets were used to model the production of all accessories and packaging materials. No drying agents or biocides (for protection against e.g. mould during the transport) were assumed to be applied. Further modelling details are found in Appendix B (tables B-40 to B-44).

3.5 modelling of the distribution & retail phase

The garments were assumed to be transported from Asia to Europe by ship. Some rough assumptions were made about ports, vehicles and distances, see Appendix B (table B 45 and table B 46). As the results show that production phase transportation is a rather insignificant environmental aspect, these assumptions were not refined.

The subsequent distribution and retail phase was modelled based on data from H&M, the largest retailer in Sweden, on distribution of goods, energy use at stores and offices, and staff commuting to work and business trips (HM 2012). Electricity to stores was assumed to be supplied by the Ecoinvent market dataset on supply of Swedish low-voltage electricity, which accounts for electricity generated within Sweden, imported electricity, grid losses and emissions related to the building of grids and transformers. Heat was assumed to be supplied by the average Swedish district heating, see Appendix B (table B 47).

All purchases were assumed to be done in physical stores, rather than via online platforms. This was motivated by the absence of any sector-level data on the percentage of online sales in Sweden (Statistics Sweden 2019b). This will be something to refine in a possible future study, as online sales increase and as data becomes available.

For all garments except the hospital uniform, 1% of the textile materials were assumed to be lost in the retail process, as most surplus are eventually sold via sales, outlet stores and "bargain corners" (Carlsson et al. 2011). This waste was assumed to be incinerated with energy recovery, in the same manner as the incineration at end-of-life (see Section 3.7 and Appendix B, table B 59). Material losses from fibre production to retailing are summarised in Appendix B (table B 1). The weight of packaging waste was assumed to be the sum of the packaging materials described in Section 3.4.6.

For the hospital uniform, there was no retail phase, as hospital textiles are subject to public procurement. The uniforms were instead assumed to be distributed directly from production to the customer (hospitals or large-scale laundry services). The same transport distances and modes were assumed as in the distribution of the other garments – this was deemed to be a sufficiently good proxy as the contribution of distribution was found to be negligible in the previous version of this report, Roos et al. (2015). Waste treatment of the packaging material was disregarded, as the weight of packaging material per hospital uniform was found to be negligible.

Further modelling details for distribution and retail are found in Appendix B (table B 45 and table B 46).

3.6 modelling of the use phase

For the retailed garments (T-shirt, jeans, dress, jacket and socks), the use phase includes the user's transport back and forth to the store and the residential laundering (washing, drying and ironing, depending on garment). For the hospital uniform, the use phase includes industrial laundering and the transport back and forth between the laundry facility and the hospital. The use phase was modelled to reflect Swedish conditions.

Using garments exposes users to chemicals via direct skin contact and via linting of fibres from the garments that can be inhaled. Allergic skin reactions to textiles are commonly documented (Malinauskiene 2012) while concerns are also raised for the content of carcinogenic, mutagenic and reproduction toxic substances (Poulsen et al. 2011). However, direct exposure of the user to textile-borne chemicals was, not included in the present study.

3.6.1 transportation

The distance of the user's transport back and forth to the store was assumed to be 17 km per kg of purchased garments (8.5 km/kg in each direction), whereof 50% was assumed to be done by car and 50% by public transport (bus). These assumptions were based on Granello et al. (2015), a survey conducted within Mistra Future Fashion with the purpose to (among others) produce data for this report. In the survey, 66% of the respondents answered 2-15 km for the distance to the store, thus the middle of this interval (8.5 km) was assumed. According to the survey, most users purchase 2-3 garments each trip, which roughly amounts to an order of magnitude of 1 kg considering the weight of the garments in the present report (see table 3.1). "By foot" and "bicycle" are also common transportation modes (28%) according to Granello and colleagues, but as these modes probably are used chiefly for shorter distances, we assumed these are comparably insignificant per transported km. Further details of the user transport modelling are found in Appendix B (tables B-48 to B-52).

The distribution of the hospital uniform to the hospitals and back to the laundry was assumed to be made with trucks driven by rapeseed methyl ester (RME), with a fuel consumption of around 0.005 l per kg of garment for the 75 washes, based on Roos (2012). Further details of laundry transport modelling are found in Appendix B (table B 57).

3.6.2 use and laundry behavior

The average number of uses per garment was estimated from the average number of garments a Swede purchases per year (excluding second hand) and assumptions of the number of days the garments are used per year, assumptions based on surveys of user behavior carried out in Mistra Future Fashion (Granello et al. 2015, Gwozdz et al. 2013). The number of garments purchased per year was in turn based on net annual imports (in tonnes) of specific garment categories (for which the six garments were assumed to be representative, see Appendix C, and which corresponds to the garment categories in the surveys) in Sweden in 2017 (Statistics Sweden 2019a), and assumptions on the weight of typical garments of each garment category.

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table 3.6: Key parameters for the use phase modelling of the six garments.

Garment	Number of uses	Number of washing cycles	Reasoning and references behind use phase assumptions
T-shirt	30	15	Swedes buy about 6.7 T-shirts/year/capita, based on Statistics Sweden (2019) and the weight of a typical T-shirt (166 g) according to Carlsson et al. (2011). Based on Granello et al. (2015), it was assumed Swedes wear T-shirts 200 times/year, yielding about 30 uses/T-shirt. It was assumed T-shirts on average are used 2 times before wash, based on Gwozdz et al. (2013), where 2 uses before wash was the most common alternative (38.6%) for "shirts/T-shirts/tops" and Granello et al. (2015), in which 2-3 uses before wash was the most commonly chosen alternative followed by 1 use before wash.
Jeans	240	24	Swedes buy about 0.85 pairs of jeans/year/capita, based on Statistics Sweden (2019) and the weight of a typical pair of jeans (700 g) according to Carlsson et al. (2011). It was assumed Swedes wear jeans 200 times/year, based on Granello et al. (2015), where the most commonly chosen alternative was >250 times, closely followed by 151-250 times and <151 times. It was assumed jeans on average are used 10 times before wash, based on Granello et al. (2015), for which the most commonly chosen alternative was 6-14 uses before wash.
Dress	26	8.7	Swedish women buy about 2.6 dresses/year/capita, based on Statistics Sweden (2019) and the weight of the jeans in table 3.1. It was assumed women in Sweden wear a dress 50 times/year and wash it after every third use, based on Granello et al. (2015), in which 6-50 uses/year was the most commonly chosen alternative, followed by 51-150 uses/year (here the 29% answering "never" has been excluded, as these presumably mainly are the 25% male respondents), and 2-3 uses before wash was the most commonly chosen alternative, followed by 4-5 uses.
Jacket	140	1.4	Swedes buy about 2.3 jackets/year/capita, based on Statistics Sweden (2019) and the weight of the jacket in table 3.1. It was assumed Swedes wears a jacket 325 days/year (based on the assumption that the Swedish climate requires the wear of an outer garment most of the days of a year) and that a jacket is washed every 100 times. These assumptions were done without evidence, as the surveys did not provide useful data on typical use patterns of jackets (96% of respondents in Granello et al. (2015) said they use jackets >15 times before washing).
Socks	27	27	Swedes buy about 13.8 pairs of socks/year, based on Statistics Sweden (2019) and the weight of the socks in table 3.1. It was assumed that Swedes use in average a pair of socks a day and that socks on average are washed after every use. These assumptions were done without evidence, as the surveys did not provide useful data on typical use patterns of socks.
Hospital uniform	75	75	Hospital uniforms are assumed to be used on average 75 times and washed after every use, based on Roos (2012). A minimum 75-use service life is according to the requirements in the procurement specifications. Some uniforms are, however, lost before that (e.g. stolen by patients), but as some are used considerably longer, 75 was deemed to be a reasonable assumption on the average number of uses.

Furthermore, it was assumed that the quantity of garments in Swedish wardrobes is approximately constant on a year-to-year basis; in other words, that the clothing purchases made over one year's time roughly correspond to the annual usage of clothing. Assumptions on the number of washing cycles per lifespan was also based on Granello et al. (2015) and Gwozdz et al. (2013). Table 3.6 shows the resulting number of uses and washing cycles per lifespan for each garment, along with further details on the underlying assumptions. The estimated number of uses before wash can be compared

3.6.3 residential laundry

Residential laundry includes washing, drying and ironing. The preparatory studies for the ecodesign directive for domestic washing machines (Faberi et al. 2007) and tumble dryers (Lefèvre 2009) were used for data on electricity and water use, as further described below.

A washing temperature of 40°C was assumed for the T-shirt, jeans, dress and jacket as this is the most common (78%) washing temperature according to Gwozdz et al. (2013) and for Sweden according to Faberi et al. (2007) (the average temperature in Sweden is ~48°C, but this includes washing of linen, underwear and towels). For socks, 60°C was the assumed washing temperature.

The average washing load in Sweden is 59% of a full load (Faberi et al. 2007). Assuming a 6 kg capacity washing machine (most common machine capacity according to Faberi et al. (2007)), the average load was thus assumed to be 3.6 kg. As the average washing machine in 2005 was 5.6 years old (Faberi et al. 2007), it was deemed reasonable to assume that the electricity use of today's average machine corresponds to the most energy efficient 6 kg capacity washing machine in 2005. The electricity use of an average load was then assumed to be 27% lower than for a full load (25-29% according to Faberi et al. (2007)), and standby and other low power modes were assumed to increase the energy use by 6% (4-8% according to Faberi et al. (2007)). The above data was used to calculate electricity use for washing in 40°C, the 60°C washing was then assumed to use 80% more energy, based on Faberi et al. (2007).

To calculate water use in washing, it was assumed that the amount of water is adjusted to the amount of load, which was standard for most machines already in 2005 (Faberi 2007). Also, the water use of the most efficient machines available in 2005 was assumed (Faberi et al. 2007) (this assumption was not updated following 2015 edition of this report, as water use in washing was found to be negligible in a life-cycle perspective). Furthermore, it was assumed that the same water use per kg of load is used as a fully loaded 6 kg capacity washing machine. Further, the loss (evaporation) of water in washing and drying was assumed to be 1 l per kg garments, regardless of material – this is a worst-case estimate, as 1 l per kg was deemed reasonable for cotton, whereas it should be lower for synthetics (this simplification was not revised as it turned out to have negligible influence on results). Other water was discharged to wastewater treatment systems assumed to be in the same catchment as the water supply.

Based on the PEFCR by AISE (2016), it was assumed that the amount of liquid detergent used corresponds to the recommended dosage of 75 ml (71.3 g) for a normal wash, which corresponds to 15.8 g per kg wash. Inventory data of detergent production was based on

AISE (2016), with some modifications because of the Swedish context. No softeners were assumed to be used. Further details of the detergent modelling can be found in Appendix B (table B 58).

Drying of laundry is performed with or without added heat, but for the purpose of this report the term "drying" is used for the case when heat is added. For drying the laundry, the use of tumble dryer was assumed. In Sweden, drying cabinets ("torkskåp") and drying rooms ("torkrum") are also common means of drying washed garments, but as the energy use of such cabinets or rooms can vary greatly, and data was unavailable for an average drying room, the electricity use of a tumble dryer was deemed to be a reasonable proxy also for this practice. The tumble dryer was assumed to be a condenser dryer adhering to the A classification of the European energy label, which corresponds to the most energy efficient tumble dryer in 2008 (Lefèvre 2009). Furthermore, the tumble dryer was assumed to be a 5 kg capacity dryer filled to 59% of full load with some extra electricity use due to standby modes – these assumptions are consistent with Lefèvre (2009). Condensing tumble dryers contribute to the heating of the premises in which they are placed, particularly in cold months, whereas other types of air-vented tumble dryers increase the need for heating (Lefèvre 2009). In the present study, such effects on the heating systems were disregarded. Drying was not assumed after every wash, but after a certain percentage of washes depending on garment, based on Granello et al. (2015): 34% for the T-shirt, 29% for the jeans, 19% for the dress, 21% for the jacket, and 58% for the socks.

Energy use per minute of ironing, and number of minutes each garment is ironed, was from Beton et al. (2014). Furthermore, it was assumed that the T-shirt and jeans are ironed after 15% of the washes, the jacket after 5% of the washes, and the socks after 1% of the washes, based on Granello et al. (2015), and the dress after 18% of the washes, based on data from Lefèvre (2009) on synthetic materials.

Modelling details for residential washing, drying and ironing are found in Appendix B (table B 54, table B 55, table B 56).

3.6.4 industrial laundry

For modelling industrial laundry of the hospital uniforms, data inventoried at TvNo Textilservice AB was used (Roos 2012). Each uniform is in average used 75 times and washed after every use. Energy use for the washing and drying of 1 kg of garments is 0.4 kWh electricity and 6.8 MJ heat from internal combustion of wood pellets. Water use is 12 l for washing of 1 kg garment, with an estimated loss (evaporation) of 1 l (see above reasoning) and other water being discharged to wastewater treatment systems assumed to be in the same catchment as the water supply. The same detergent was assumed as for the residential laundry.

3.6.5 production of electricity and water used in laundry

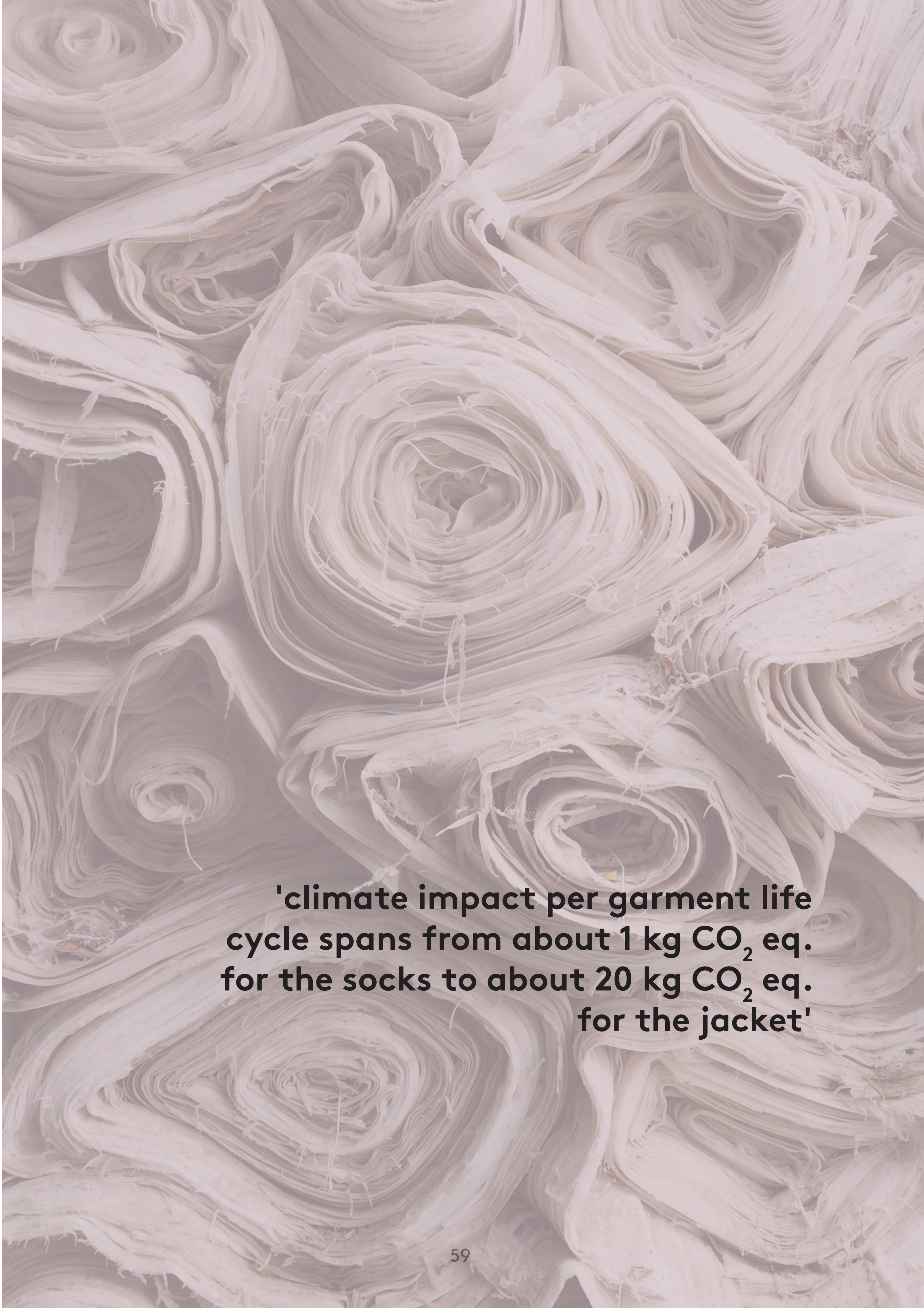
Electricity was assumed to be supplied by the Ecoinvent market dataset on supply of Swedish low-voltage electricity, which accounts for electricity generated within Sweden, imported electricity, grid losses and emissions related to the building of grids and transformers. In a sensitivity analysis, the influence of instead assuming the Ecoinvent market dataset for European mix of low-voltage electricity. Water was assumed to be supplied by the Ecoinvent market dataset for European tap water.

3.7 modelling of the end-of-life phase

At their end-of-life, the garments were assumed to be incinerated at a municipal waste incineration plant with cogeneration of heat and electricity, as this is the common means of textile waste management in Sweden (Palm et al. 2014). Some garments will enter the second hand market or change ownership by other means prior to being sent to waste management – but eventually most of these garments will be incinerated (the fraction being exported to second hand markets abroad, whereof some may end up in landfills, is disregarded in the present study). Ecoinvent datasets on the incineration of similar materials were assumed, see Appendix B (table B 59). These were deemed reasonable proxies considering the impact categories selected for the present study (if other impact categories were to be considered, other datasets may be more suitable).

As mentioned in Section 2.3.3, system expansion with substitution was applied to handle the multifunctionality of the incineration process (i.e., the cogeneration of heat and electricity). This means that while the LCA includes the emission of abiogenic carbon dioxide and other atmospheric contaminants, the studied garments are given credits for the means of heat and electricity production that are supposedly avoided as a consequence of the cogeneration of heat and electricity. The avoided electricity production was assumed to be the same Ecoinvent market dataset on Swedish electricity supply as was assumed for the laundry processes, see Section 3.1.11. The avoided heat production was assumed to be the average Swedish district heating in 2017, see Appendix B (table B 47).

The transportation from the user to the incineration plant was as assumed to be 30 km for all garments, using an Ecoinvent dataset on European average transport by a EURO6 lorry with a capacity of 3.5-7.5 metric ton.



'climate impact per garment life cycle spans from about 1 kg CO_2 eq. for the socks to about 20 kg CO_2 eq. for the jacket'

4 results & discussion

This chapter presents the environmental impact of the six garments, the scaled-up national-level impact, and the potential benefits of a set of interventions for impact reduction. The results are presented for the three different functional units of the study (see Section 2.3.1): per one use of each garment (where the number of uses differ between garments), per garment, and the annual consumption and use of clothing in Sweden. First, some results for all garments are compared (Section 4.1) followed by the results of the national-level scale up (Section 4.2). Then more detailed results follow for each garment (Sections 4.3-4.8), followed by results from some scenarios for reducing impact (Section 4.9). In the end, there is a general discussion on uncertainties, concluding that all results in the report should be considered order-of-magnitude estimates.

For climate impact, energy use and land use, results are from the Gabi model unless otherwise stated, and for water use and toxicity results are from the Simapro model. Not all results are shown for each impact category. Most importantly, due to weaknesses in the LCI data, land use impact results are not shown for each garment and at the national level, and for toxicity only results of direct emissions from textile processes are shown. The aim has been to make each presentation and analysis of results meaningful with respect to the underlying uncertainties.

Sensitivity analyses testing the influence of the choice of software (Gabi or Simapro) are presented in Appendix E. Modelling in two software packages in parallel has enabled us to identify and correct several errors in both models, thereby increasing their robustness.

4.1 comparison across garments

Figures 4.1-4.4 show results for climate change and energy use for the six garments, per garment service life and per garment use. Climate impact per garment life cycle spans from about 1 kg CO2 eq. for the socks to about 20 kg CO2 eq. for the jacket, and per use it spans from about 40 g CO2 eq. for the socks to about 700 g CO2 eq. for the dress. Energy use per garment life cycle spans from about 26 MJ for the socks to about 320 MJ for the hospital uniform, and per use it spans from about 1 MJ for the socks and the jeans, to about 11 MJ for the dress. As the six garments represent different and common material content, production methods and user behavior these intervals (1-20 kg CO2 eq. and 26-320 MJ per garment life cycle) can be seen as typical climate impact and energy use figures for most types of garments with average use patterns.

To put above numbers in perspective, comparisons can be done with other product categories. The per-garment impact of a pair of socks corresponds to about 40 g beef, 1 l milk or 10 kg potatoes produced in Sweden, whereas a jacket corresponds to about 0.75 kg beef, 20 l milk or 200 kg potatoes (RISE 2019). In relation to travelling with an average car, the impact per life cycle of a pair of socks corresponds to about 3 km of travel and a jacket to about 60 km (an average car is here represented by an Ecoinvent dataset on a fleet-average car in Europe, with well-to-wheel emissions of 326 g CO2 eq. per km, which was the dataset used to model half of the use-phase transportation).

The results reveal that the number of uses per garment service life strongly influences the relative importance of different garments. The socks and the T-shirt, two relatively simple garments, have low impact per garment service life compared to the other garments, but due to relatively low number of uses per garment service life (30 and 27, respectively) the impact per use is similar or higher than for the jeans (240 uses). In terms of impact per use, the dress (26 uses) is particularly important, which emphasises the needs for using each purchased dress for a longer time than done in average. The importance of extending the number of uses per service life is further discussed in Section 4.9. In terms of energy use, the result for the hospital uniform is also relatively high per use, which is because the uniform is washed between each use in rather high temperatures (70-90°C).

In terms of the importance of different life cycle phases, the key role of production is evident. Fibre/yarn production, wet treatment and confectioning are important for all garments. Fabric production is also important for garments made of woven fabrics (jeans, dress, jacket, uniform). The importance of the sewing time is reflected in the increasing impact of confectioning from the T-shirt (10 min sewing time), to the hospital uniform (28 min), the jeans (45 min), the dress (85 min), and the jacket (135 min). The user transport back and forth from the store is important for both climate impact and energy use (for all garments except the hospital uniform, which does not have such a transport) whereas the use-phase laundry is of little direct importance in terms of climate impact (due to the relatively low-CO2 energy mix of Sweden) but more important in terms of energy use (especially for the frequently washed uniform). Of course, more frequent laundering will shorten polymeric chains (Palme et al, 2014) and thereby potentially reducing the number of uses, so even in Sweden, the laundry can play an important indirect role in determining impacts per use.

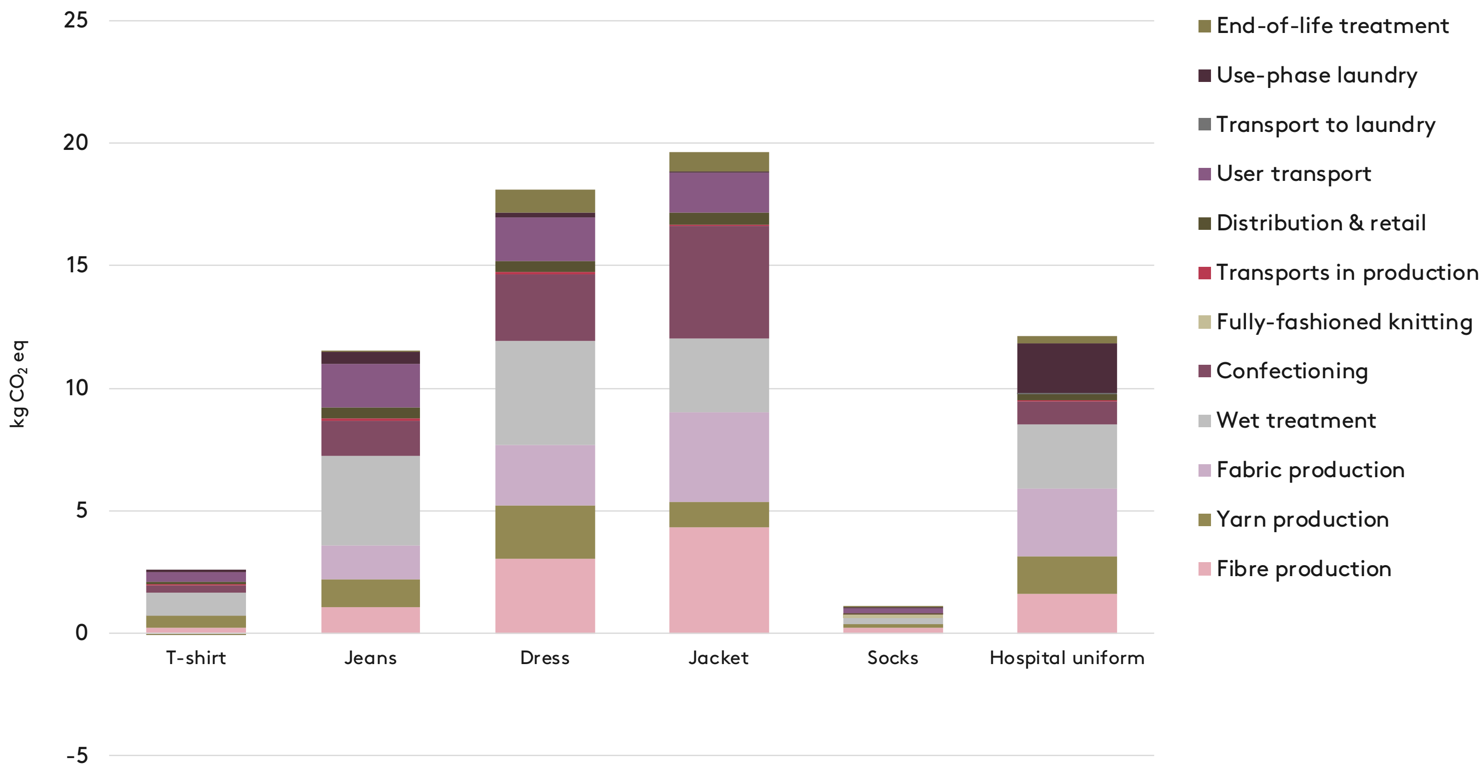


figure 4.1: Climate impact of the six garments, per garment life cycle.

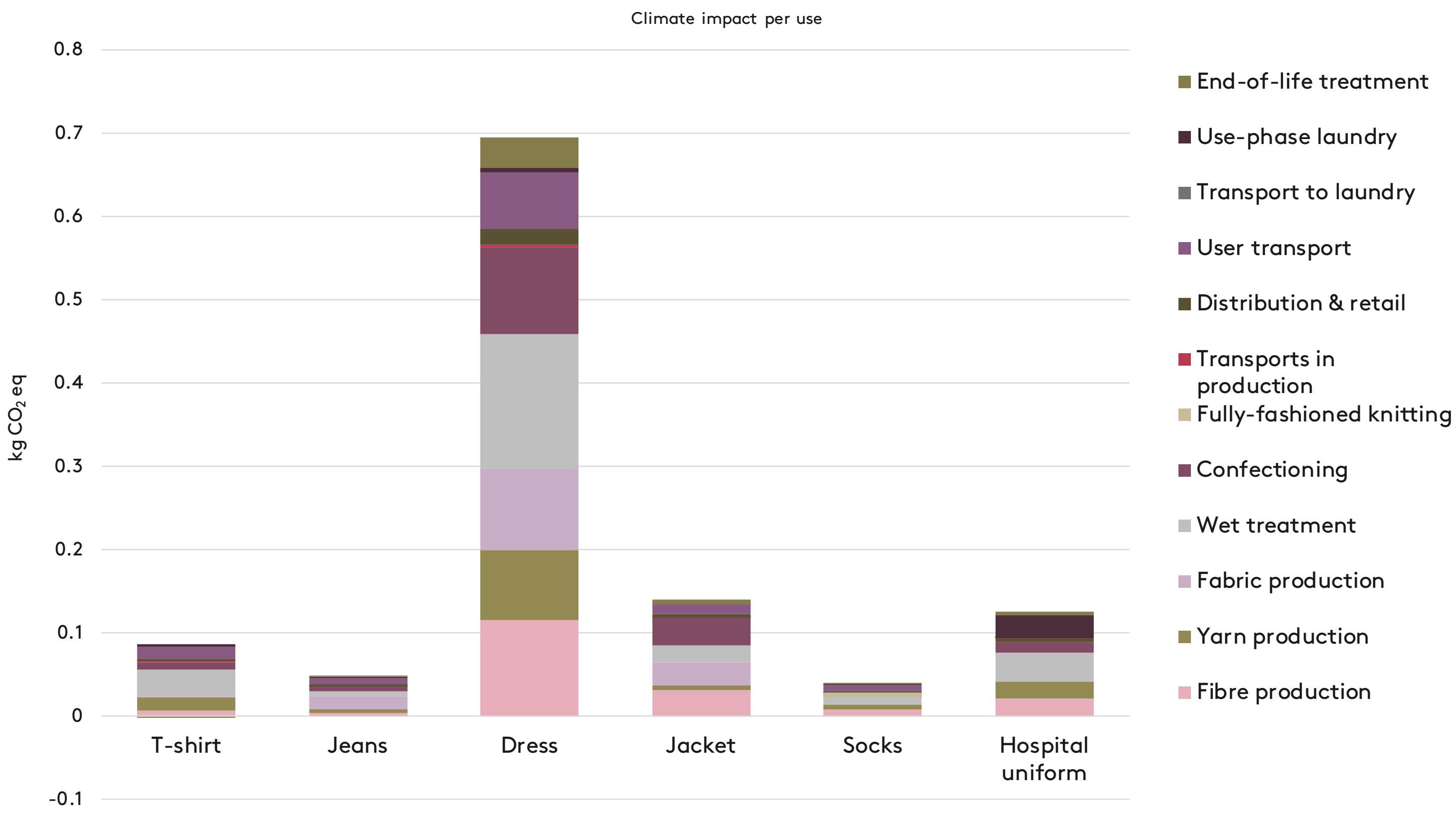


figure 4.2: Climate impact of the six garments, per garment use.

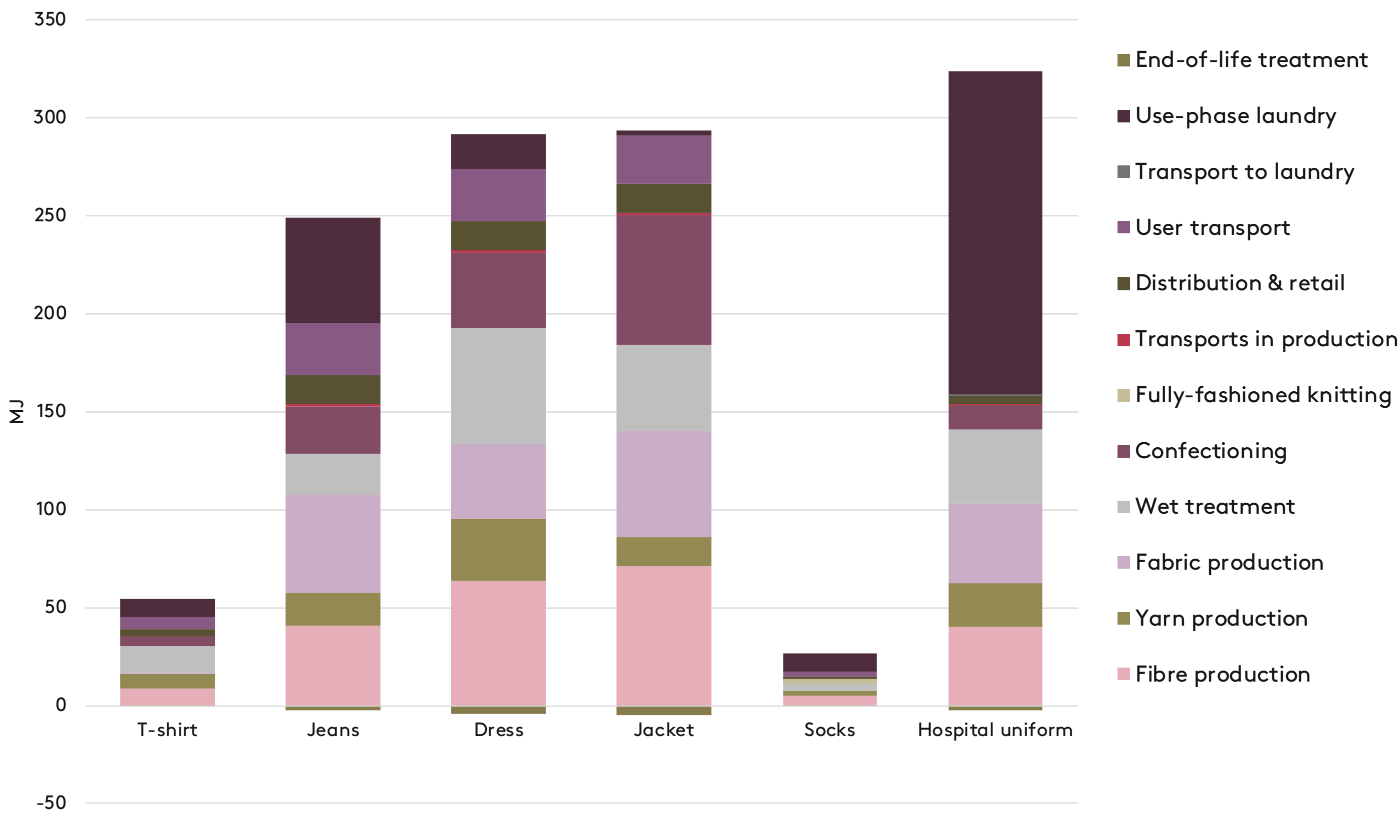


figure 4.3: Energy use of the six garments, per garment life cycle.

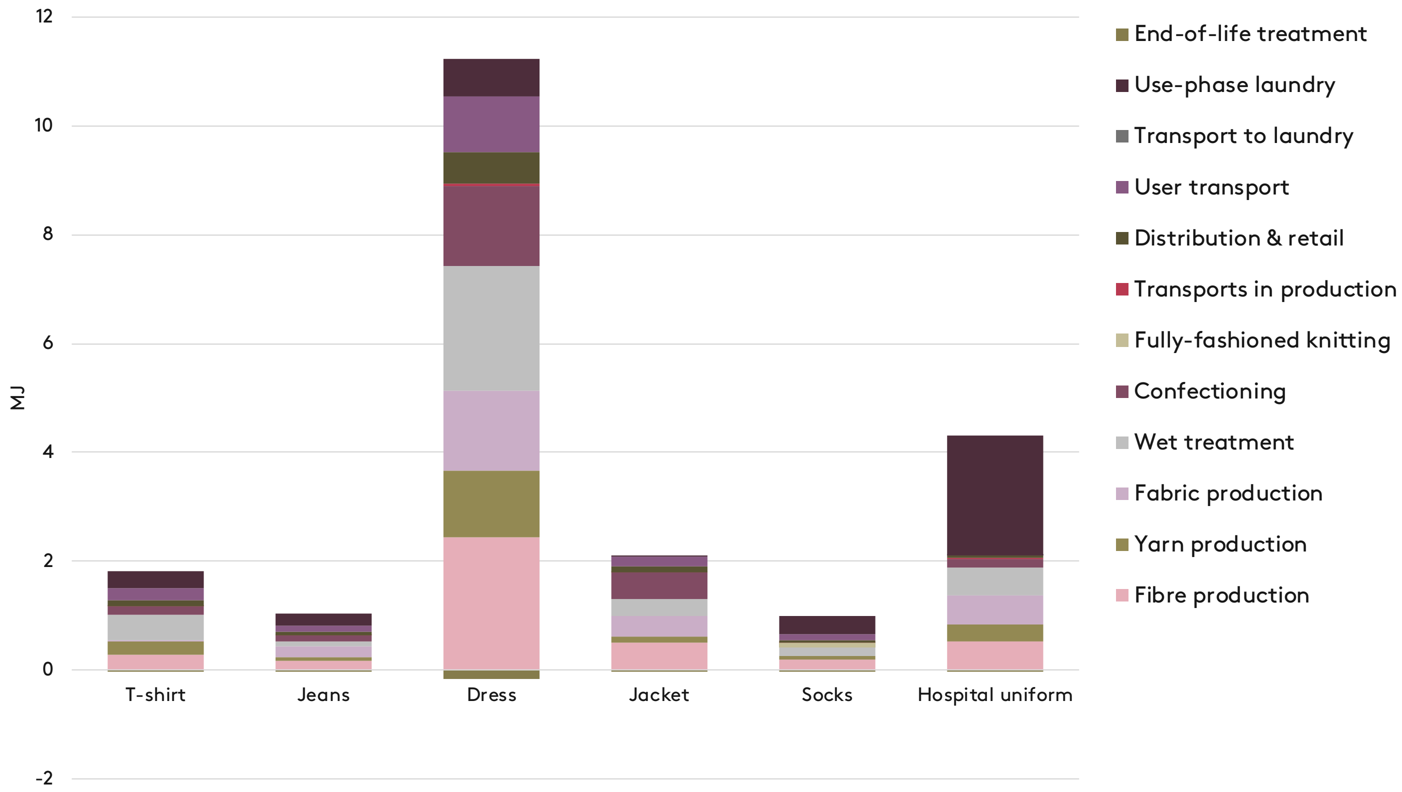


figure 4.4: Energy use of the six garments, per garment use.

Figure 4.5 and figure 4.6 below show results for water scarcity, per garment life cycle and per garment use, respectively. Only consumed water is accounted for – that is, water not being returned to the watershed it has been withdrawn from but lost through evaporation, included in product or waste, returned to a different watershed, etc. The consumed water is then multiplied with a water scarcity factor accounting for the availability of water and the demand for water for human and ecological needs in the respective country.

For garments consisting fully or partly of cotton, water consumed in the irrigation of cotton cultivation is a clear hotspot. Cotton cultivation being a water scarcity hotspot in the textile industry is consistent with previous reports (Chapagain et al. 2006, Quantis 2018). Per garment use, the dress shows rather high impact although it is not made of cotton – this is due to the fact it is used relatively few times per garment life cycle (26) in relation to the inputs in production. Notably, the water used in wet treatment contributes little towards the total impact, as is further discussed in Section 4.2.

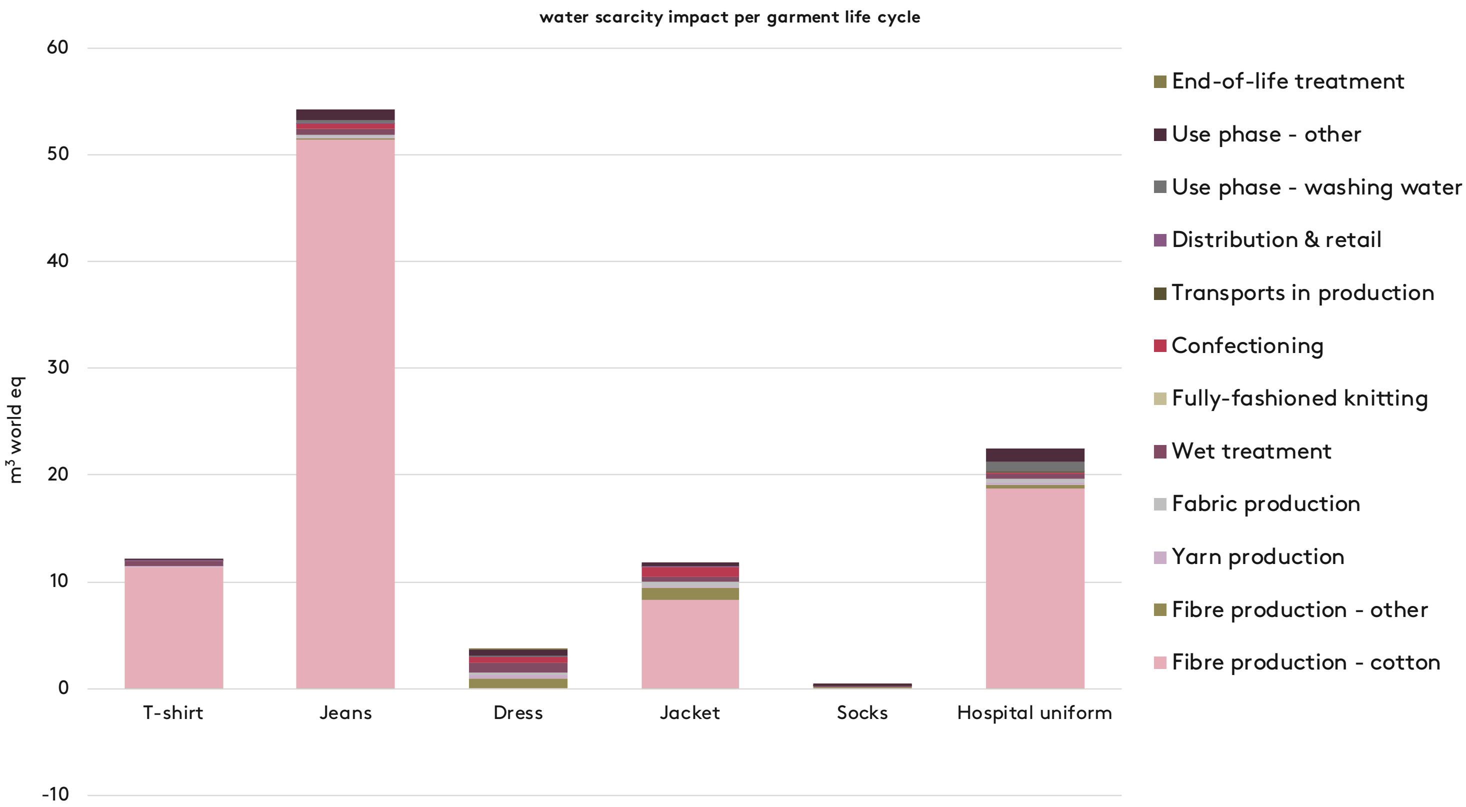


figure 4.5: Water scarcity impact of the six garments, per garment life cycle.

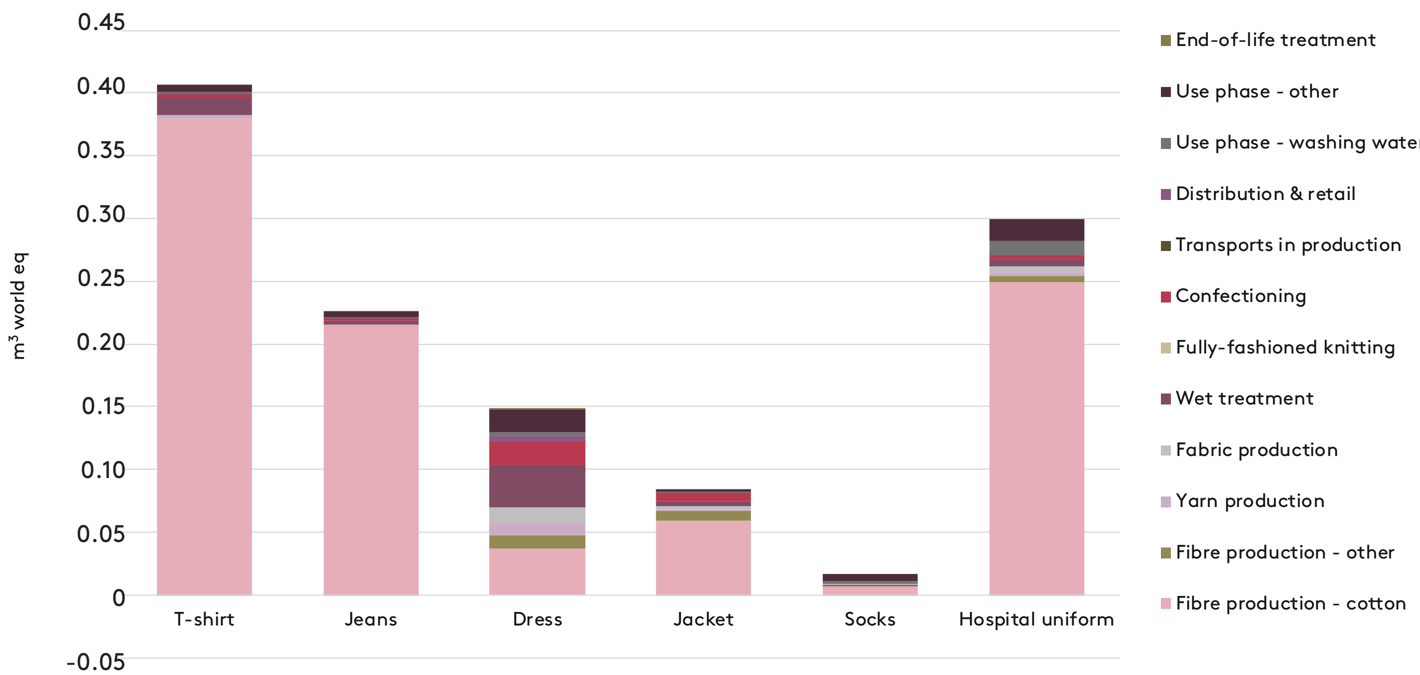


figure 4.6: Water scarcity impact of the six garments, per garment use.

Regarding toxicity, results are only shown for direct toxic emissions from the textile processes, see figures 4.7-4.12. Emissions of background processes were excluded as they totally dominated the overall impact, with direct emissions from textile processes never being more than 3.8% of total impact for a single garment and most often being in the order of 0.1% of total impact. Background emissions here relate to, for example, emissions from the mining of coal and burning of coal used to generate the power used in textile processes – and although these emissions are known to cause severe health-related issues, the order of magnitude of the underlying LCI data is associated with high uncertainty, for example the volumes and toxicity of long-term emissions. Due to these significant uncertainties, we deemed it to be meaningful to focus the presentation and analysis of results on the direct emissions from textile processes.

Results show that fibre (cotton) production dominate non-carcinogenic toxicity impact, followed by wet treatment, whereas wet treatment dominate for carcinogenic human toxicity and ecotoxicity. In the wet treatment, detergents, dyestuffs and the silicon-based durable water repellent (DWR) agents used for the jacket stand for the main contribution to all three categories: carcinogenic and non-carcinogenic human toxicity as well as freshwater ecotoxicity. Water emissions dominate over air emissions. However, this circumstance is driven by assumptions used in the model, in which all chemicals are emitted in much higher amount to water than to air.

The detergents used for pretreatment and washing stand for the major potential for non-carcinogenic human toxicity impacts in the wet treatment. There are various chemical mixtures in the model that according to the material safety data sheets (MSDS) includes for example surfactants, alcohols and oxirane compounds which are often also toxic to all three categories.

The freshwater ecotoxicity impacts are mainly caused by the large amount of chemicals emitted rather than use of highly toxic ones (based on the assumption of a waste water treatment plant efficiency of 90%). As an example, sodium hydroxide, hydrogen peroxide, sulfuric acid together with the optical brightener stands for 73% of the freshwater ecotoxicity impacts from the bleaching process for the t-shirt.

Besides the use of pesticides in the cotton cultivation, and water emissions from the wet treatment, a small contribution (<1%) comes from the yarn and fabric making. The spin finish and sizing agent used there are assumed to be a polyacrylic acid (PAA) copolymer (Bhuvenesh et al. 2004) which has a rather high potential for carcinogenic human toxicity impacts due to impurities of common breakdown products such as acrylamide and formaldehyde (Caulfield et al. 2002).

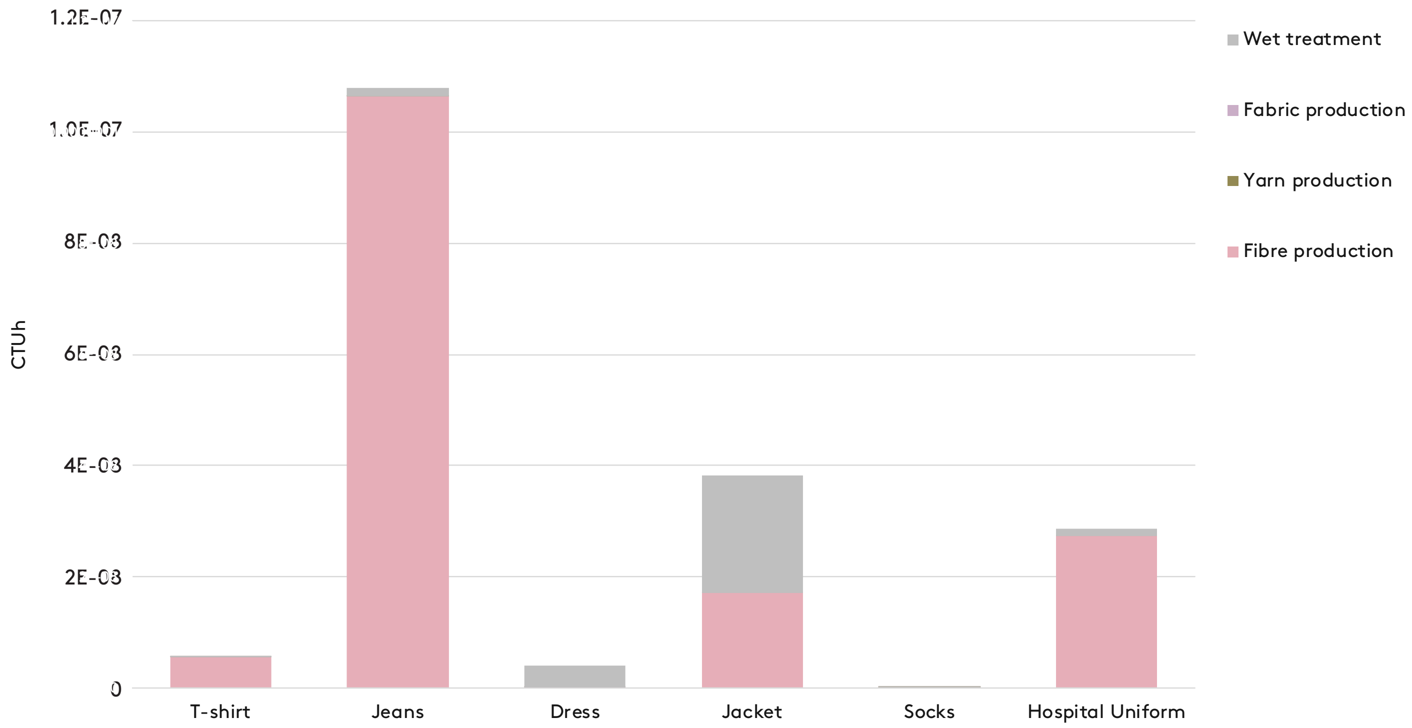


figure 4.7: Non-carcinogenic human toxicity impact of the six garments, per garment life cycle. Only direct emissions from textile processes.

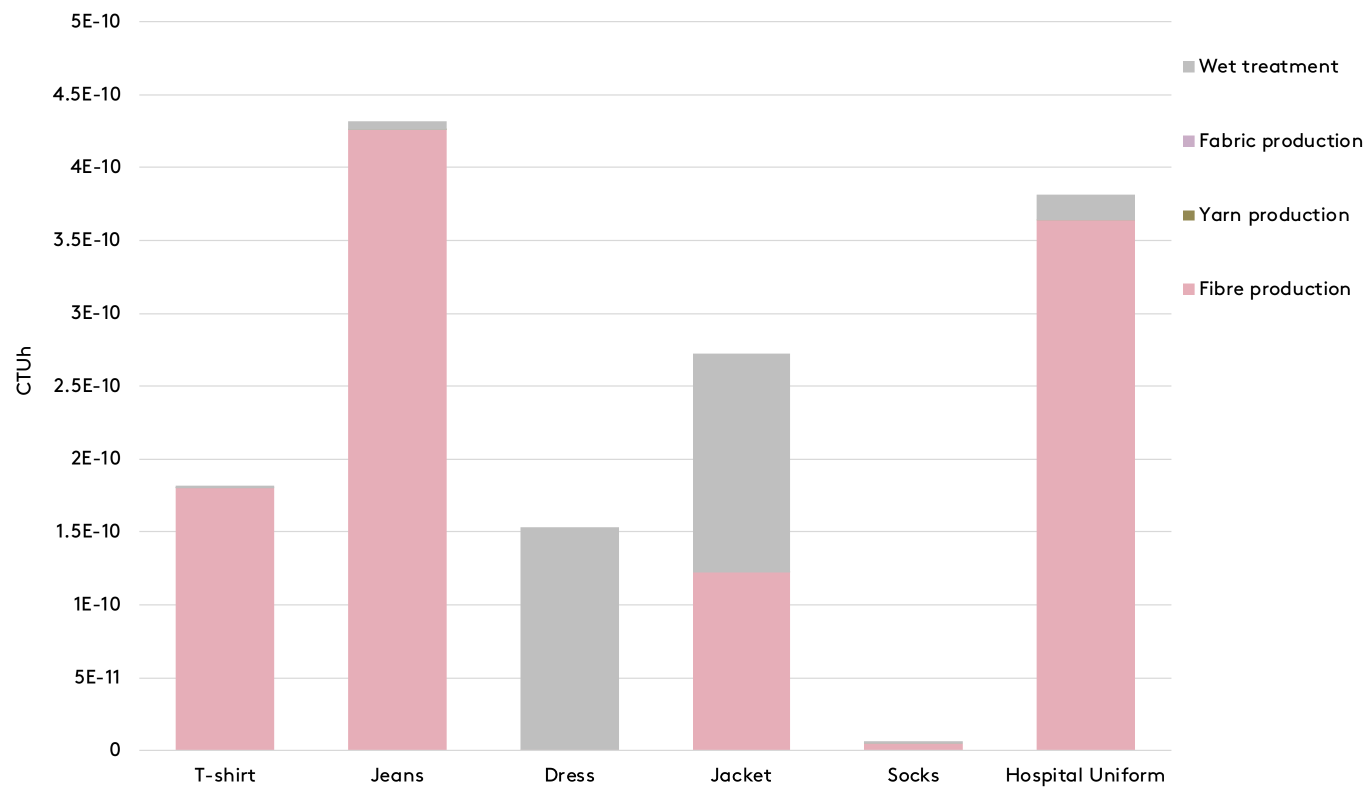


figure 4.8: Non-carcinogenic human toxicity impact of the six garments, per garment use. Only direct emissions from textile processes.

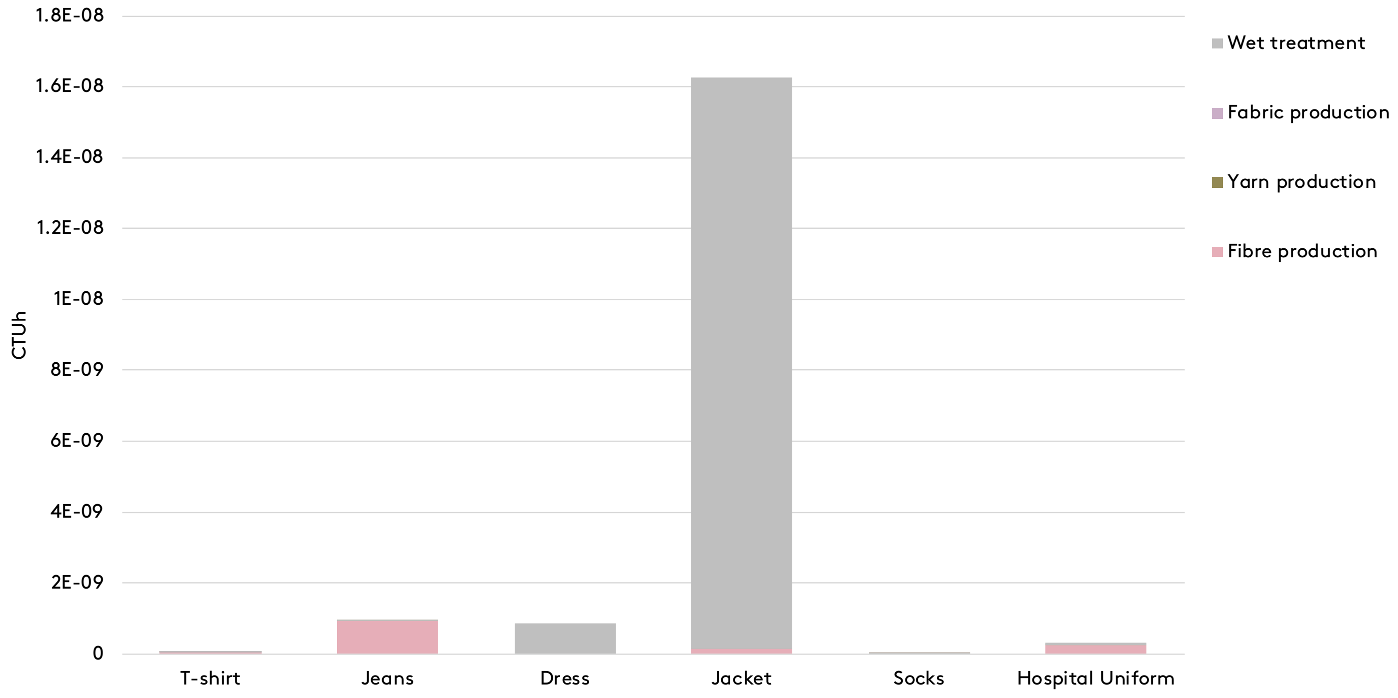


figure 4.9: Carcinogenic human toxicity impact of the six garments, per garment life cycle. Only direct emissions from textile processes.

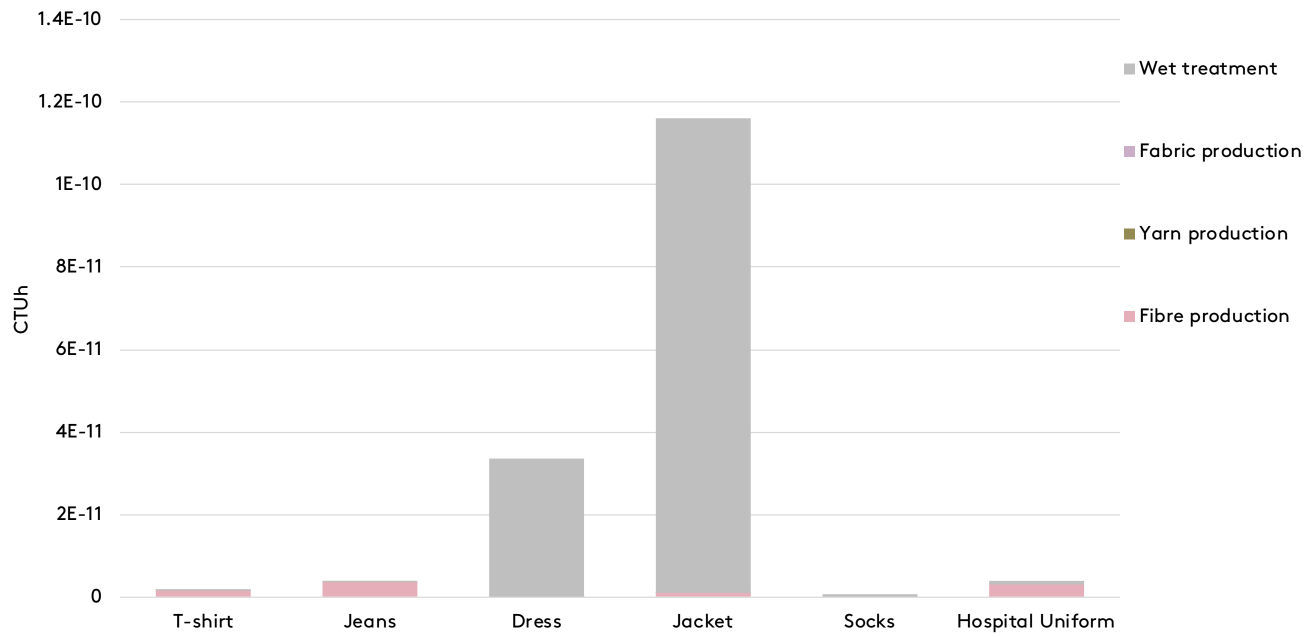


figure 4.10: Carcinogenic human toxicity impact of the six garments, per garment use. Only direct emissions from textile processes.

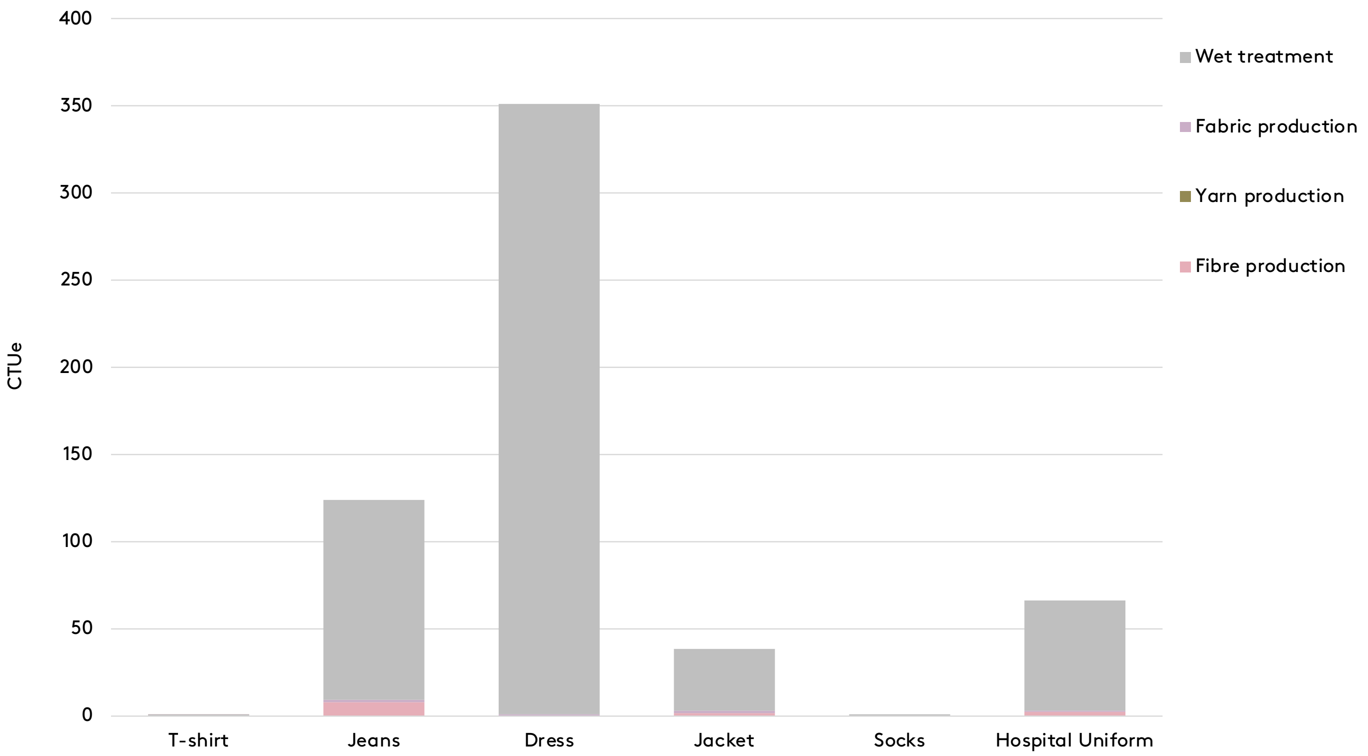


figure 4.11: Ecotoxicity impact of the six garments, per garment use. Only direct emissions from textile processes.

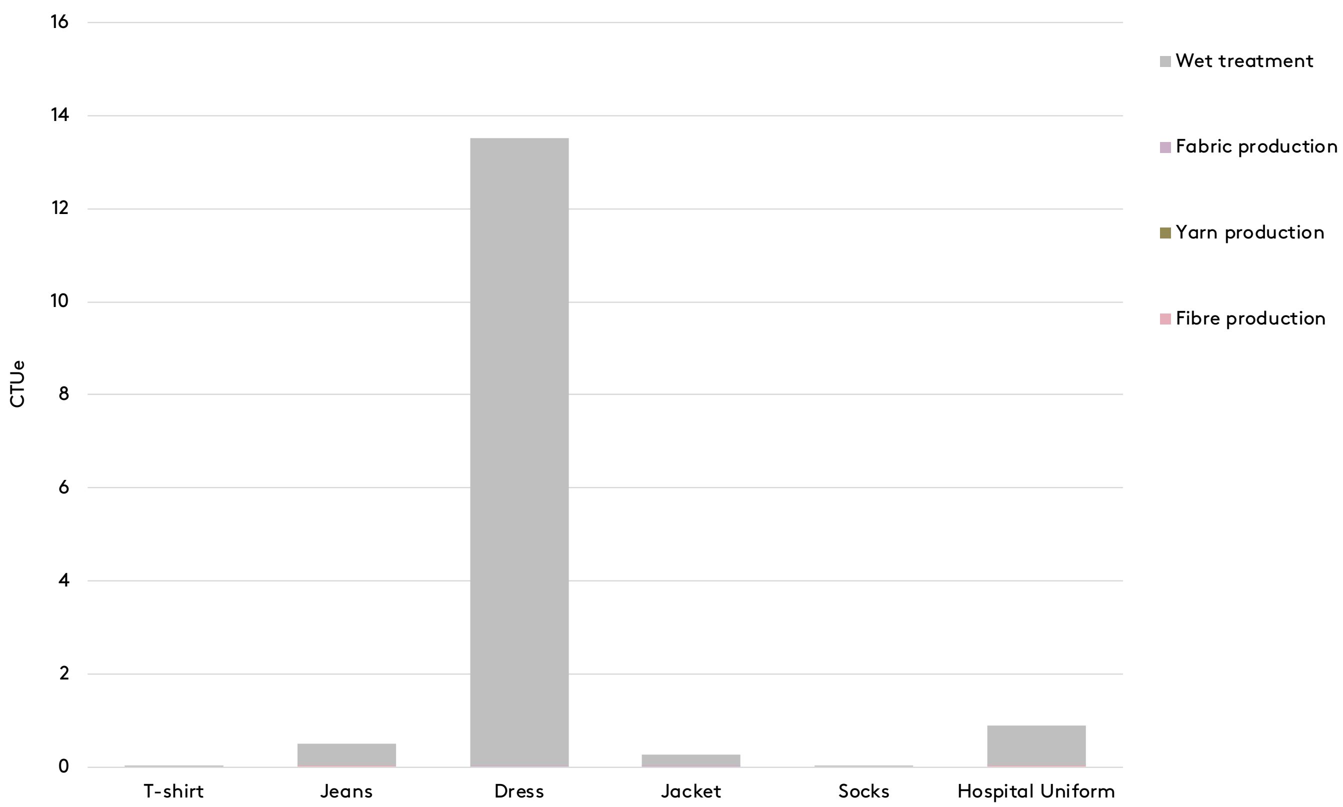


figure 4.12: Ecotoxicity impact of the six garments, per garment use. Only direct emissions from textile processes.

4.2 national-level impact

Above per-garment results were the basis for estimating the national-level impact of Swedish clothing consumption (the method for upscaling is described in Section 2.4). Table 4.1 summarises the results, which are presented at a more detailed level and discussed in below paragraphs. Results for toxicity and land use impact are not presented at the national level, due to shortcomings in LCI data and/or LCIA methods, as discussed in Sections 4.1 and 4.3. However, land use impacts are discussed qualitatively at the national level in Section 4.2.2.

table 4.1: Environmental impact of Swedish clothing consumption.

Impact category	National-level impact	Impact per capita
Climate change	3.27 million t CO2 eq	327 kg CO2 eq
Water scarcity	6.13 billion m^3 world eq.	613 m^3 world eq
Energy resources	600 million MJ	6000 MJ

The total climate impact of Swedish clothing consumption is about 3.3 million tonnes of CO2 eq. per year, which is 327 kg CO2 eq. per capita or about 3% of the consumption-based carbon footprint of an average Swede (Dawkins et al. 2019). This might seem low, but as the 2-degree goal stipulates that climate impact must be close to zero by mid-century, there will be little or no room for any greenhouse gas emissions arising from the production, transportation and laundering of clothes.

The above carbon footprint can be compared with the carbon footprint of the clothing consumption by an average European estimated by Quantis (2018) in their "Measuring fashion" report, which was almost four times higher: 1 210 kg CO2 eq. There are some large differences between our estimate and theirs, among others they neither include the user's transport back and forth from the store or the user laundry. If they would have included this, it would have further increased the difference between our estimate and theirs. In an attempt to find out why there is such a large difference between the two estimates, it appeared that Quantis have assumed unusually high greenhouse gas emissions per unit of energy used in production – this has however not been possible to confirm.

Ivanova et al. (2017) estimated the per-capita carbon footprints of clothing consumption in 18 European countries, spanning from less than 200 kg CO2 eq. in Bulgaria and Hungary to about 800 kg CO2 eq. in parts of UK. In average, they conclude that clothing contributes with about 4% of EU household emissions, which is about the same as in our scenario with the European electricity mix, see Section 4.2.1.

Finally, Beton et al. (2014) found the per-capita carbon footprint of European textile consumption to be about 824 kg CO2 eq. (412 Mt CO^2 eq. divided by an EU-27 population of 500 million). Textiles here include apparel, home textiles and technical textiles. Carlsson et al. (2011) conclude that home textiles such as bed linen, curtains and towels correspond to 40% of the consumption of apparel textiles in Sweden, and globally technical textiles constitute 4% of textile fibres (Quantis 2018). Assuming these figures, the Beton et al. (2014) carbon footprint of clothing consumption would be 565 CO^2 eq.

As further discussed in Section 4.2.1, this is based on unrealistically high numbers of washes per garment. If their laundry impact is reduced by 50% – a more realistic estimate in our opinion – their per-capita carbon footprint of European clothing consumption would instead be 473 kg CO2 eq. This is about 40% higher than our rough proxy of a European average (see Section 4.2.1), excluding the transport back and forth from the store (which Beton and colleagues exclude), but still in the same order of magnitude.

Overall, the comparison with the results of Ivanova et al. (2017) and Beton et al. (2014) indicate the Swedish and European carbon footprint estimates of the present study are reasonable, but more likely under- than overestimates. Figure 4.13 and figure 4.14 show the climate impact and energy use, respectively, per life-cycle phase. In these and the following figures of this section, fully-fashioned knitting of the socks has been sorted under fabric production. The figures show the clear dominance of production, totalling 80% of climate impact and 71% of energy use. Among production processes, wet treatment (mainly fossil energy used for heating water) dominates with almost one fourth of the climate impact. The climate impact of the long-distance transport from the production countries is sometimes thought of as a large contributor to climate impact. Although these transports dominate the climate impact from distribution and retail (about 80% of this impact), they contribute with no more than 3% of the total life-cycle climate impact.

Further, it is noteworthy that the use-phase transport, i.e. mainly the user's transport back and forth from the store[9], contributes about 11% of climate impact[10] and 9% of energy use. This is an often-neglected part of the apparel product system, seldom included in studies of the environmental impact of clothing, which can be influenced for example by the location of stores (locations in central areas and/or close to public transport are preferable, rather than external shopping malls). Half of the use-phase transports were assumed to be made by car, using an Ecoinvent dataset representing the average of the European car fleet, with well-to-wheel greenhouse gas emissions of 326 g CO2 eq. per km. Well-to-wheel greenhouse gas emissions in Europe are, however, decreasing: for average cars sold in 2017 they were 258 g CO2 eq. per km (ICCT 2018), i.e. 21% lower than the fleet-average. Assuming everything else equal, the relative contribution from the use-phase transport can thus be expected to decrease in the coming years.

The main differences between climate impact and energy use, in terms of the contributing life-cycle phases, is the lower climate contribution from use-phase laundry, due to the relatively low-carbon Swedish electricity mix, and the negative energy contribution from the end-of-life treatment, due to the incineration with energy recovery.

[9] The hospital uniform does not have a user transport, instead the use-phase transport consists of the truck transport to the laundry and back, a negligible contribution.

[10] Eleven percent is considerably lower than the estimate of the previous report of this report, Roos et al. (2015), which was 23% - this number has been found to be erroneous, an error originating from the from the scaling-up to the national level, in which the user transport of the dress was considerably overestimated (the other results of the dress in Roos et al. 2015, are, however, correct).

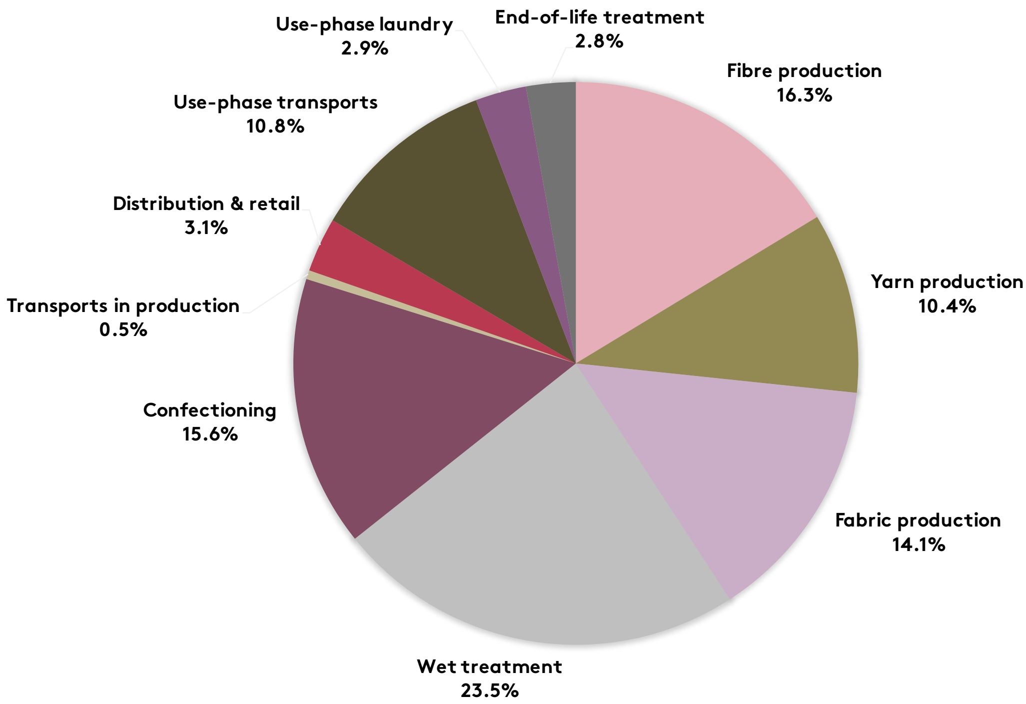


figure 4.13: Climate impact of Swedish clothing consumption, contribution of life-cycle phases.

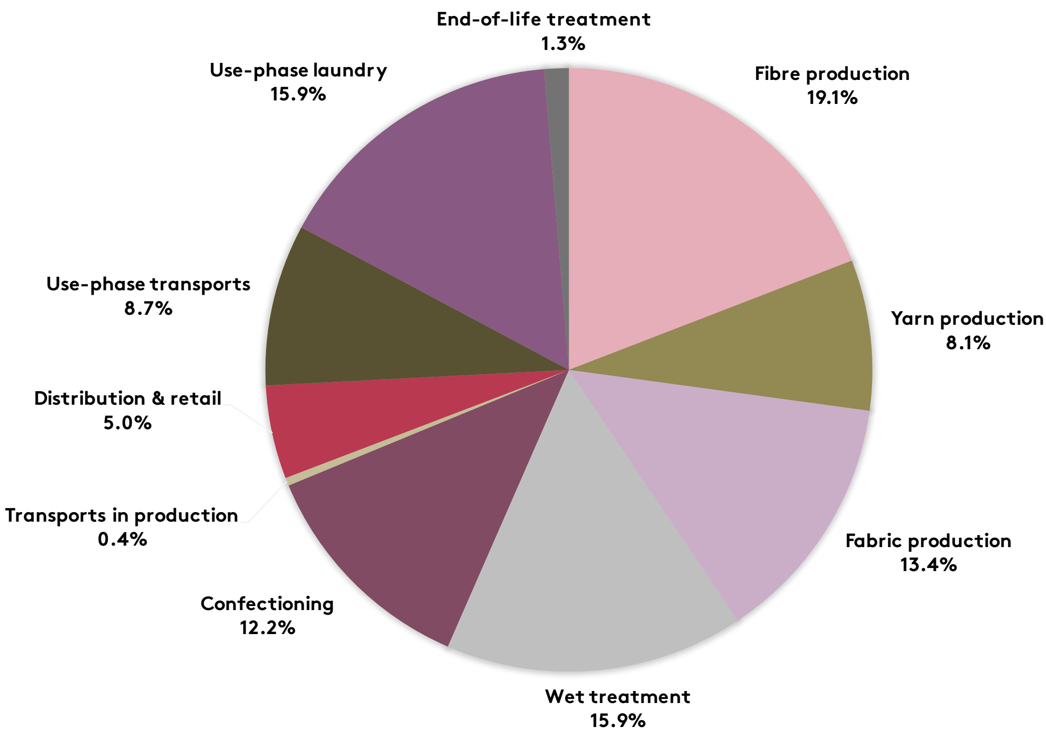


figure 4.14: Energy use of Swedish clothing consumption, contribution of life-cycle phases.

Figure 4.15 shows the water scarcity impact of Swedish clothing consumption, per life-cycle phase. As for the results shown above per garment, the dominance of water consumed in cotton cultivation is striking, totalling about 87% of impact. Notably, the water use in wet treatment contributes little towards the total impact, about 3%. The small contribution to water scarcity is due to not much water being consumed (polluting water does not count as consuming water here) compared to what is consumed in cotton cultivation. Water pollution is instead accounted for in the freshwater ecotoxicity calculation where wet treatment stands out as the process with highest impact.

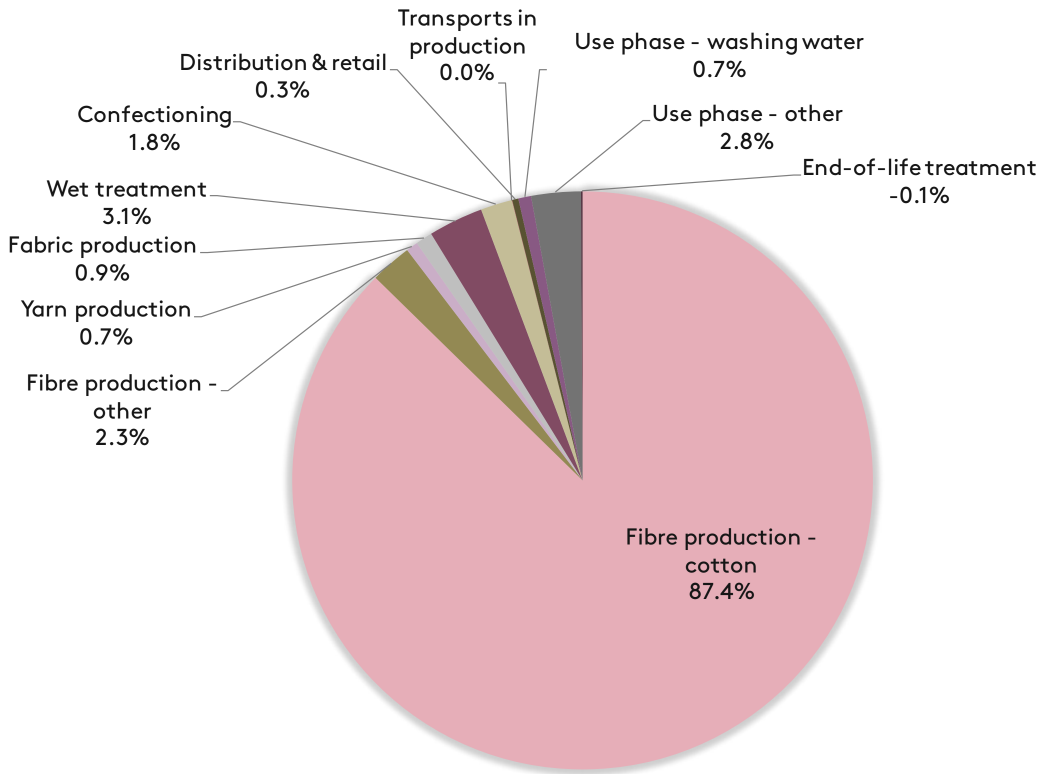


figure 4.15: Water scarcity impact of Swedish clothing consumption, contribution of life-cycle phases.

4.2.1 sensitivity analysis

A sensitivity analysis tested the influence of assuming the European electricity market mix instead of the Swedish one for all electricity-demanding processes located in Sweden (i.e. power used in the retail store, the use-phase laundry, and the end-of-life credit from power generation). We used the Swedish electricity market mix as the baseline assumption because this reflects the electricity supply where the end-users are located (the electricity generated within Sweden plus imported electricity). However, there are also reasonable arguments for assuming the European mix, as the European electricity market is integrated and deregulated. It was thus deemed relevant to set up a scenario with the European electricity market mix. The result of this scenario is only presented for the impact category of climate change, as this is the impact category mainly influenced by the choice of electricity mix. The per-capita carbon footprint of this scenario is about 365 kg CO2 eq., 12% above the baseline scenario. See figure 4.16 for results per life-cycle phase.

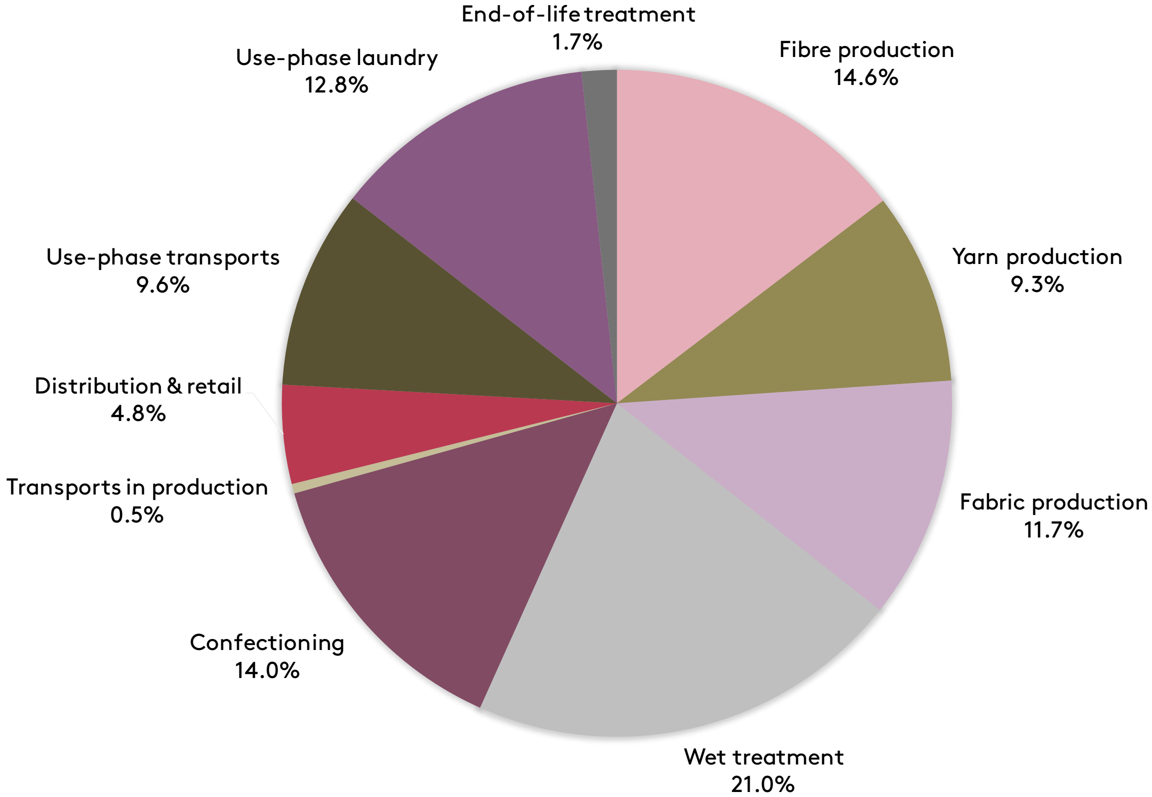


figure 4.16: Sensitivity analysis of the climate impact of Swedish clothing consumption, contribution of life cycle phases. Scenario with European electricity mix assumed for retail, use and end-of-life processes located in Sweden.

By assuming the European electricity mix, the sensitivity analysis also functions as a rough proxy of the environmental impact of European clothing consumption. The results of figure 4.16 can be contrasted to Beton et al. (2014), which estimated the environmental impact of European textile consumption, and found that 52% of climate impact comes from production, 45% from laundry, and 5% from transports (including transport in production and distribution, but excluding the user's transport back and forth from the store). The main difference between this and the present study is the high contribution from use-phase laundry. This difference is mainly because Beton and colleagues have assumed much more washes per garment: 50 washes per T-shirt (15 was assumed in the present study), 15 washes per dress (8.7 in the present study), 92 washes per denim trousers (24 in the present study).

Our assumptions were based on net import statistics combined with surveys of user behavior whereas the assumptions of Beton and colleagues seem to be based on the expected technical performance of a garment, i.e. theoretical life length and washing frequency (their own estimates or estimates done in secondary sources). As such, we find our estimate of the contribution from the user's laundry to be more accurate[11]. Furthermore, Beton and colleagues have excluded the user's transport back and forth from the store, which is another difference between the two studies.

[11] For a summary of use-phase parameters of difference LCA studies of apparel, see Roos et al. (2017).

4.2.2 land use impact

As described in Section 2.3.4, results for land use impact using LANCA 2.3 were calculated but are not shown due to large uncertainties. Below, these results are briefly discussed, as they point out areas of potential interest in future studies.

The national-level scale up showed that two processes dominate the four midpoint indicators for land use impact: cotton cultivation (up to 68% of impact) and the laundering of the hospital uniform (up to 40% of impact), the latter because of growing the trees for producing the pellets used to fuel the drying process. The dominance of cotton cultivation in land use impact is not surprising and was seen in the previous version of this report as well (Roos et al. 2015), in which an inventory-level indicator for agricultural land occupation (including forestry) was used as a proxy for land use impact.

The importance of the pellets in the hospital uniform product system is more surprising and was also seen in the hospital uniform results of the previous report (these results were not, however, analysed at a national level). The main contributing flow to cotton cultivation was a non-regionalized flow of arable land use, and for the production of pellets it was a non-regionalised flow of intensive forest land use. For the four indicators, the differences between regionalised characterisation factors are very large, indicating that non-regionalised flows are associated with large uncertainties. Moreover, although some indicators, such as erosion potential, has country-specific characterisation factors available in the LCA software, others, such as the infiltration reduction potential, have three generic factors, each representing many countries, indicating a very coarse regionalisation. This means that although it would be possible to manually regionalise the major flows of the product systems, the uncertainties would still be very large. Therefore, land use impact results are not shown or further discussed in the present study. Instead future studies are warranted to look further into issues of land use, with a particular focus on agricultural feedstock (specifically cotton) and any bioenergy used for heat or power. Such studies would be made feasible when more regionalised and fine-grained LCI data is implemented in LCA software, allowing a more regionalised assessment of land use impact.

4.3 t-shirt

For each garment, results are provided at a more detailed level in which life-cycle phases are divided into processes. For toxicity, results for direct emissions in textile processes were presented at the level of the processes in the cross-garment comparison of Section 4.1, thus toxicity is not shown here.

Figure 4.17 shows the climate impact of the T-shirt, revealing the importance of wet treatment (36%), especially the bleaching process (29%) due to high heat use (30 MJ/kg bleached fabric) provided by fossil fuels. Yarn production (19%) and confectioning (12%) are also important contributors, mainly due to relatively high electricity use combined with the carbon-intensive electricity mix of the production countries. Further, 20% of climate impact is due to the user's transport back and forth from the store – this is based on statistics outlining an average distance to the store of 8.5 km travelled 50% by car, 50% by bus. This contribution can be much larger for users who travel longer distances and/or to a larger extent use a car, whereas it can be almost non-existent for users that mostly walk, bike or take public transportation to stores.

The user transport was emphasised as a climate hotspot also in the previous version of this report (Roos et al. 2015) but is generally overlooked in other studies of the environmental impact of clothing (usually it is omitted altogether). Furthermore, other transports contribute with slightly less than 5% each and the user's laundry (washing, drying, ironing) with about 3%, and processes such as production and disposal of packaging, energy use in stores, the travelling of staff involved in distribution and retail, are insignificant.

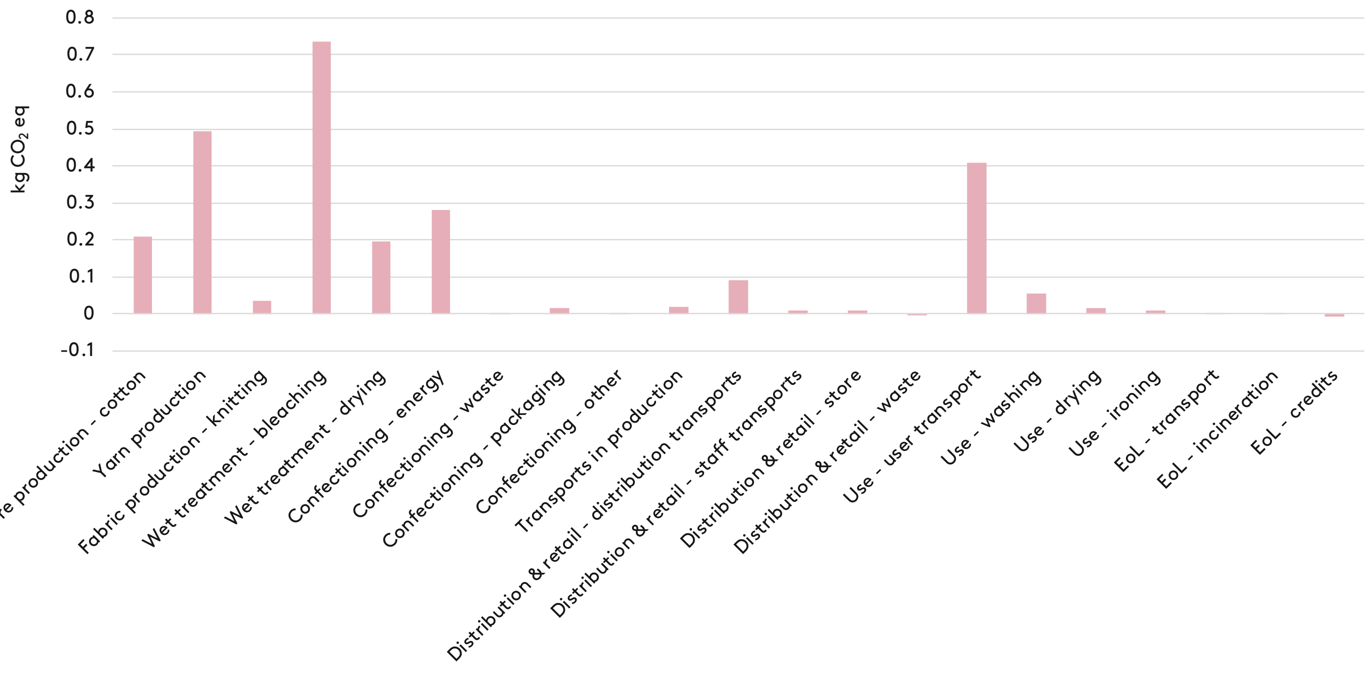


figure 4.17: Climate impact of T-shirt, per garment service life (30 uses).

Figure 4.18 shows the energy use of the T-shirt. The pattern is similar as for climate impact, with two main exceptions: (i) fibre production is more important due to inputs of renewable energy, (ii) use-phase laundry is more important as the benefit of having a relatively low-carbon energy supply is not shown here. The large share of non-renewables used in laundry are not due to fossil resources – as this would have translated to high climate impact – but due to the primary energy content of uranium used for nuclear power (~40% of Swedish electricity supply), which is 93% of the non-renewable primary energy demand of the Swedish electricity mix. These results suggest that more energy-efficient laundering, for example by washing in lower temperatures or hang-drying, does not translate to a significant climate benefit – but it is important for handling concerns related to the equitable sharing of energy resources.

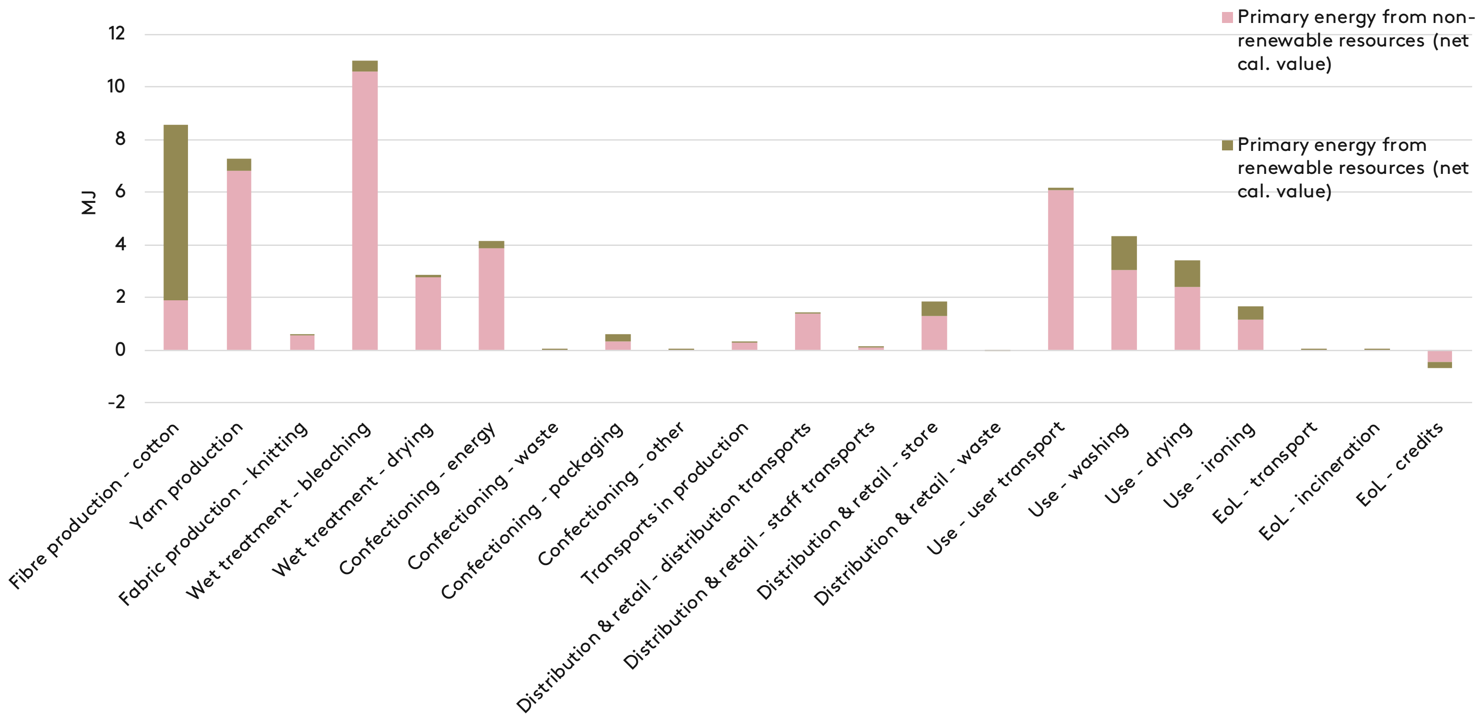


figure 4.18: Energy use of T-shirt, per garment service life (30 uses).

The result for water scarcity in figure 4.19 shows that water consumed in the irrigation of cotton farms is by far the most important hotspot for a cotton T-shirt (92% of total impact).

Note that the results of the land use impact of figure 4.20 four part diagrams, are highly uncertain compared to the results of other impact categories, and that land use impact results are thus not shown for the other garments – see discussions in Sections 2.3.4 and 4.2.2. The results are included for the T-shirt to provide an example of how cotton cultivation dominates land use for a simple cotton garment, and as an example of the kind of impact categories we will see more of as regionalisation of land activities improves. The land use impact results of figure 4.20 resemble the water depletion results – once again cotton cultivation is the main contributor. This is because agriculture is the main driver of these impacts and cotton cultivation is the main agricultural activity of the

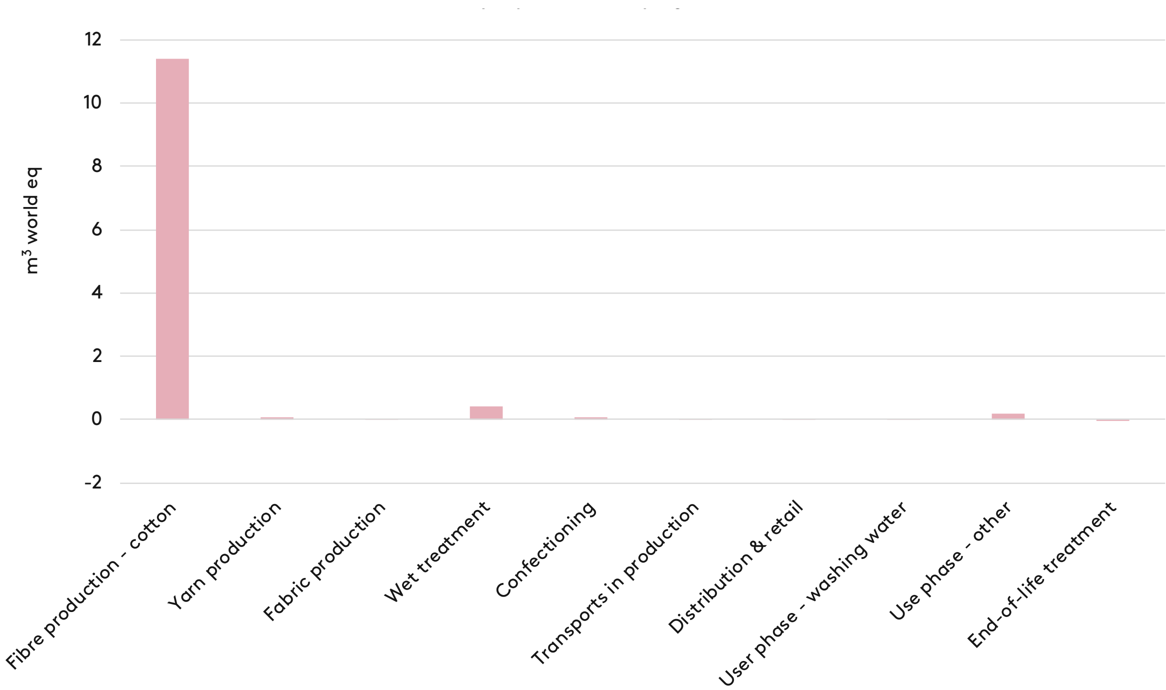
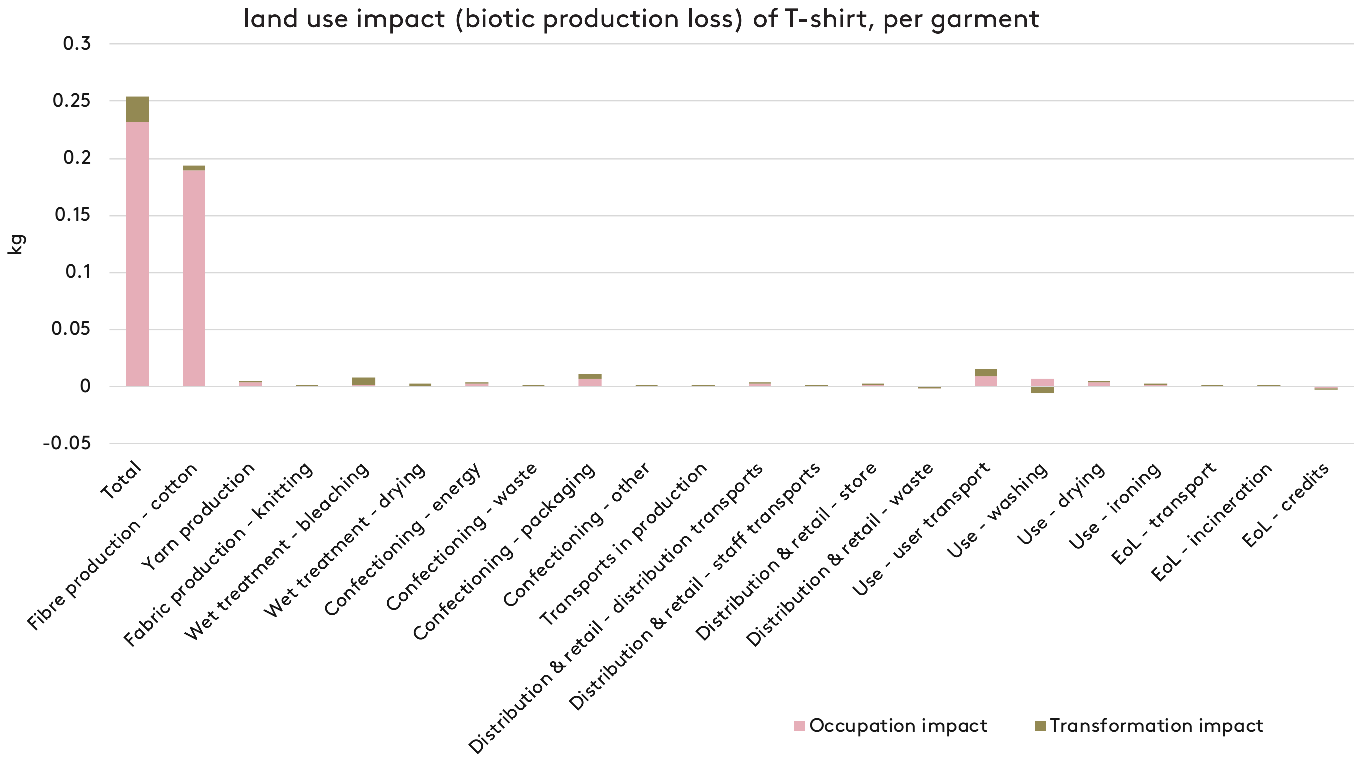


figure 4.19: Water scarcity impact of T-shirt, per garment service life (30 uses).

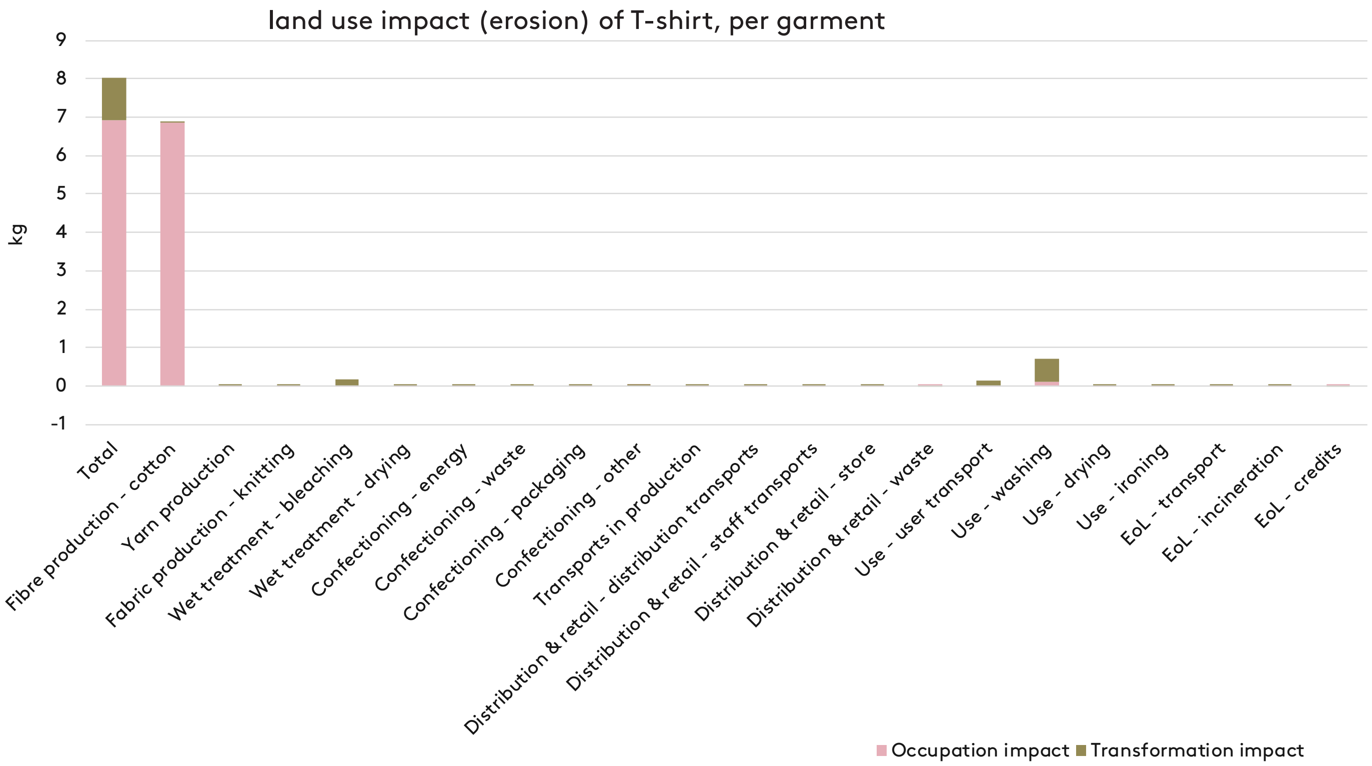
T-shirt product system. Elsewhere in the product system some agricultural land is used for bioenergy and packaging feedstock, but the area is small compared to cotton cultivation, as was shown in the results of the previous version of this report, when the area of occupied agricultural land was used as an indicator (Roos et al. 2015).

In a possible future study, when SQI (which is an aggregated indicator for land use impact, see Appendix D) is available in LCA software, one will be able to see how much each of the land use impact indicators in figure 4.20 contributes to the aggregated impact of land use in the T-shirt product system. A preliminary indication was given by applying weighting factors derived from de Laurentiis et al. (2019)[12] , which suggested (mechanical) infiltration reduction is most important (40% of aggregated impact), followed by bioproduction loss (30%), erosion (21%) and groundwater regeneration reduction (9%).

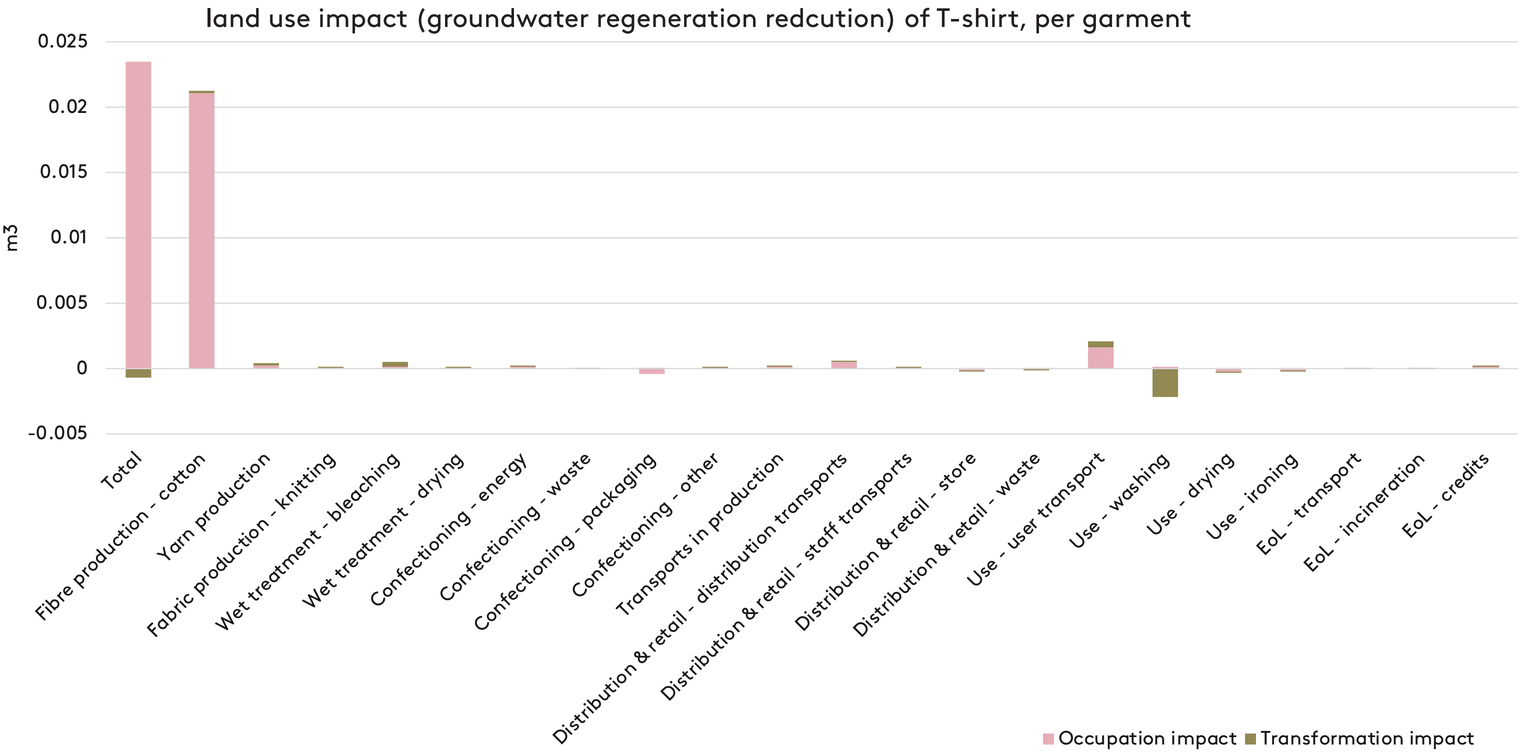
[12] For more on why these were not used in the present study, see Appendix D.



land use impact (biotic production loss) of T-shirt, per garment
kg
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Total
Fibre production - cotton
Yarn production
Fabric production - knitting
Wet treatment - bleaching
Wet treatment - drying
Confectioning - energy
Confectioning - waste
Confectioning - packaging
Confectioning - other
Transports in production
Distribution & retail - distribution transports
Distribution & retail - staff transports
Distribution & retail - store
Distribution & retail - waste
Use - user transport
Use - washing
Use - drying
Use - ironing
EoL - transport
EoL - incineration
EoL - credits
Occupation impact
Transformation impact



land use impact (erosion) of T-shirt, per garment
kg
9
8
7
6
5
4
3
2
1
0
-1
Total
Fibre production - cotton
Yarn production
Fabric production - knitting
Wet treatment - bleaching
Wet treatment - drying
Confectioning - energy
Confectioning - waste
Confectioning - packaging
Confectioning - other
Transports in production
Distribution & retail - distribution transports
Distribution & retail - staff transports
Distribution & retail - store
Distribution & retail - waste
Use - user transport
Use - washing
Use - drying
Use - ironing
EoL - transport
EoL - incineration
EoL - credits
Occupation impact
Transformation impact



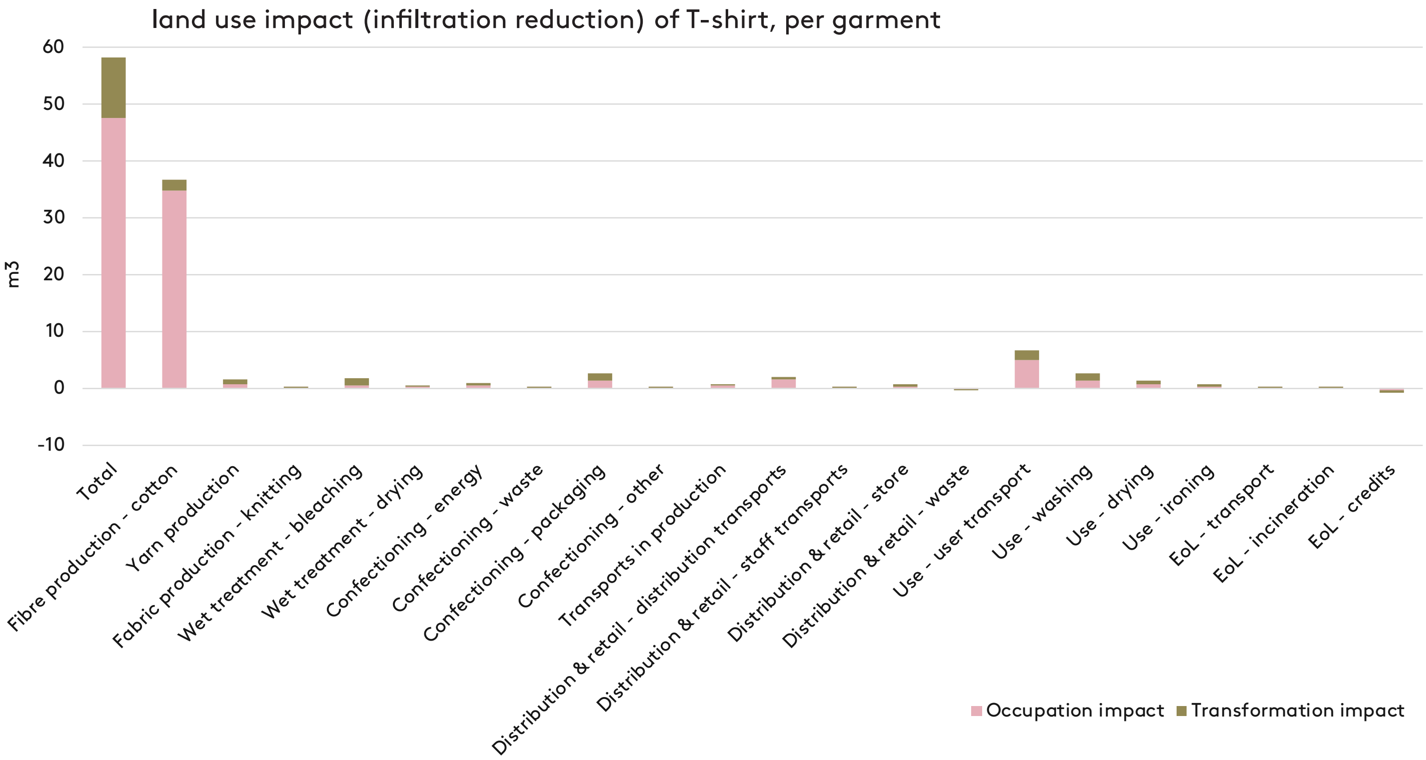


figure 4.20: Four part figure depicting land use impact of T-shirt, per garment service life (30 uses).

4.4 jeans

Figure 4.21 shows the climate impact of the jeans, revealing the importance of wet treatment (32%), largely due to the high amount of fossil fuel-provided heat used in bleaching and dyeing (30 MJ/kg fabric). As for the T-shirt, yarn production (10%) and confectioning (12%) are also important, but here also fabric production (weaving) is important (12%) – these contributions are mainly driven by relatively high electricity use combined with the carbon-intensive electricity mix of the production countries.

Fibre production contributes with about 9% of impact, whereof cotton (98% in mass) contributes with 94% and elastane (2% of mass) with 6%, i.e. on mass basis elastane is about three times as carbon intensive as cotton. The user's transport back and forth from the store also matters (16%) (see discussion for T-shirt results in Section 0). Other transport and the user's laundry contribute about 5% each. Processes such as production and disposal of packaging, energy use in stores, and the travelling of staff involved in distribution and retail, are insignificant.

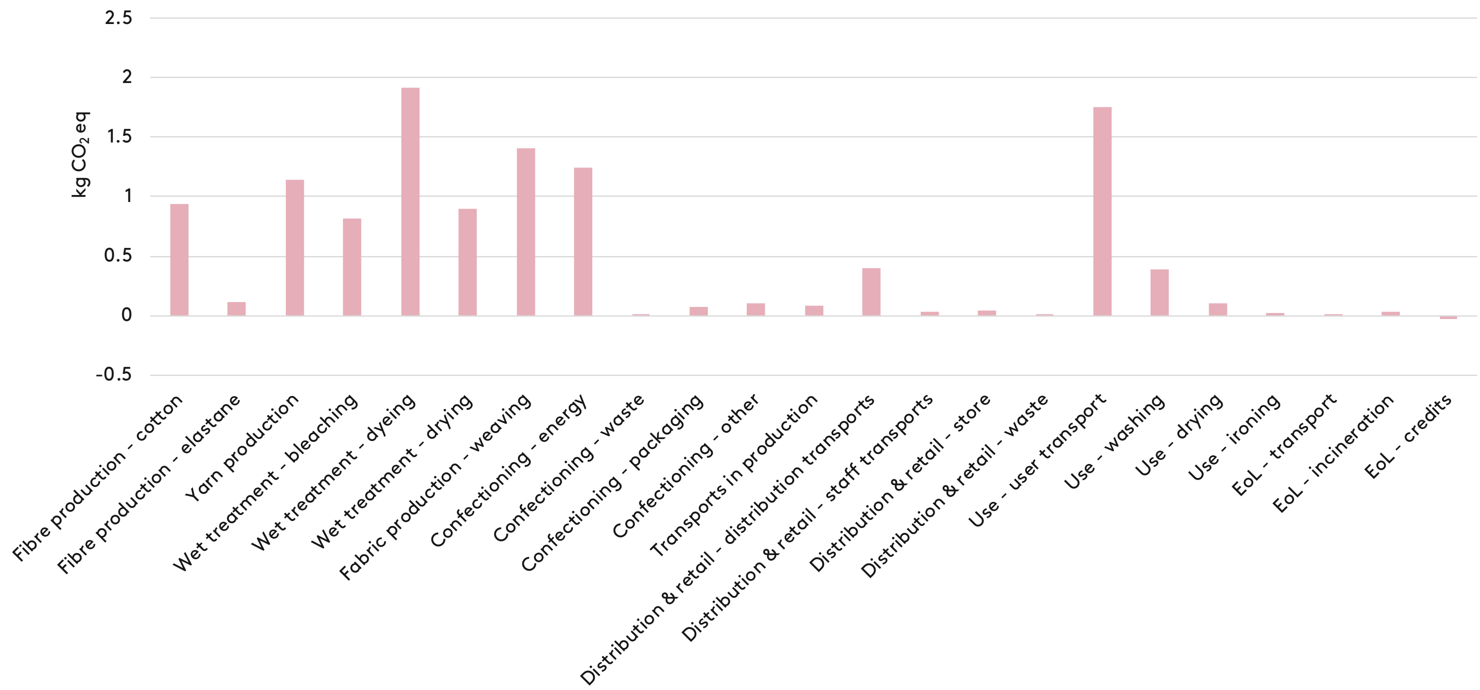


figure 4.21: Climate impact of jeans, per garment service life (240 uses).

The energy use of the jeans is shown in figure 4.22. The pattern is similar as for the T-shirt, except from fabric production being a major contributor as weaving is a much more energy-demanding process than knitting. Noteworthy is that laundry (washing, drying, ironing) is a relatively important process for the jeans compared to the T-shirt – for example, washing uses more energy than the the user transport – this is because the user transports is divided between more uses (240 compared to 30 for the T-shirt), whereas laundry scales with the number of uses (regardless of whether a garment is used 100 or 200 times, it is washed with the same frequency). The dominance of laundry is to some extent offset by the low frequency of washing of jeans (after every tenth use vs. every second use for the T-shirt).

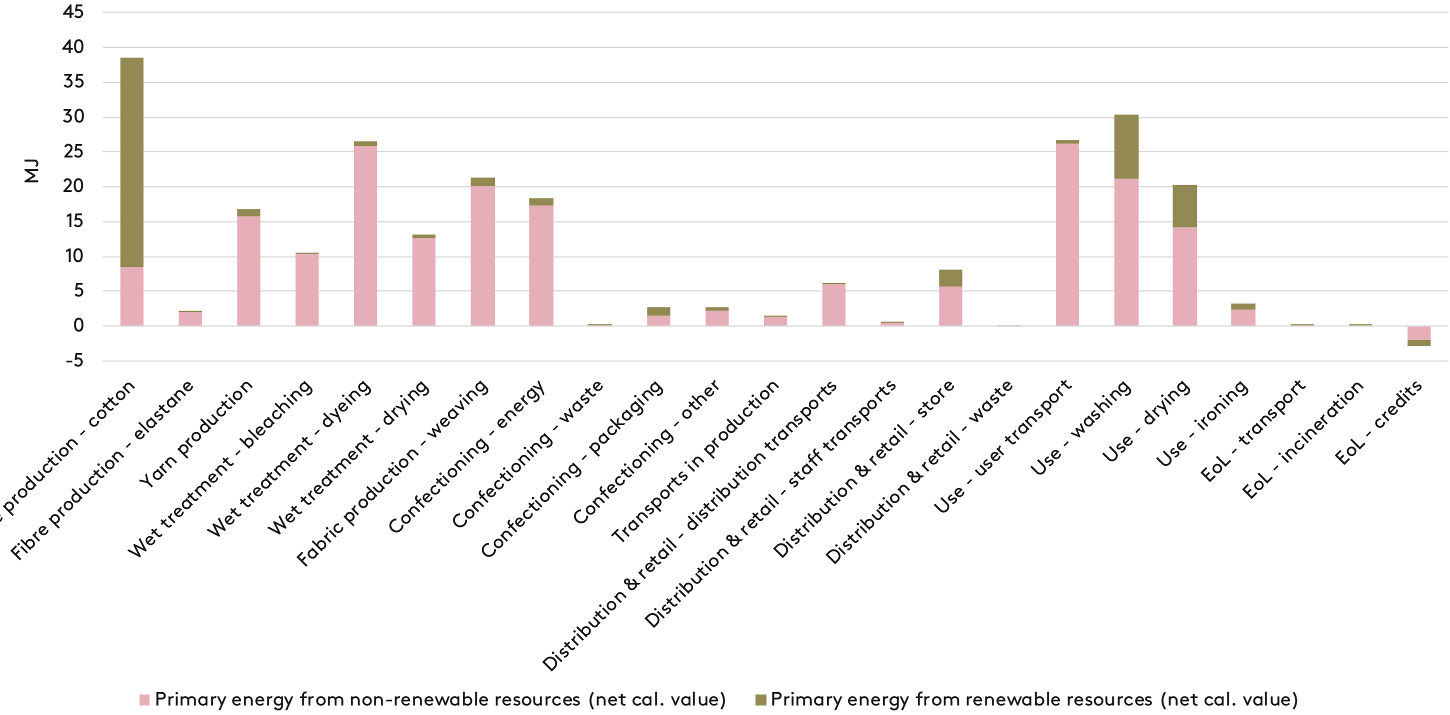


figure 4.22: Energy use of jeans, per garment service life (240 uses).

The result for water scarcity in figure 4.23 shows that water consumed in the irrigation of cotton farms is by far the most important water scarcity hotspot (93% of total impact) for a pair of cotton/elastane jeans.

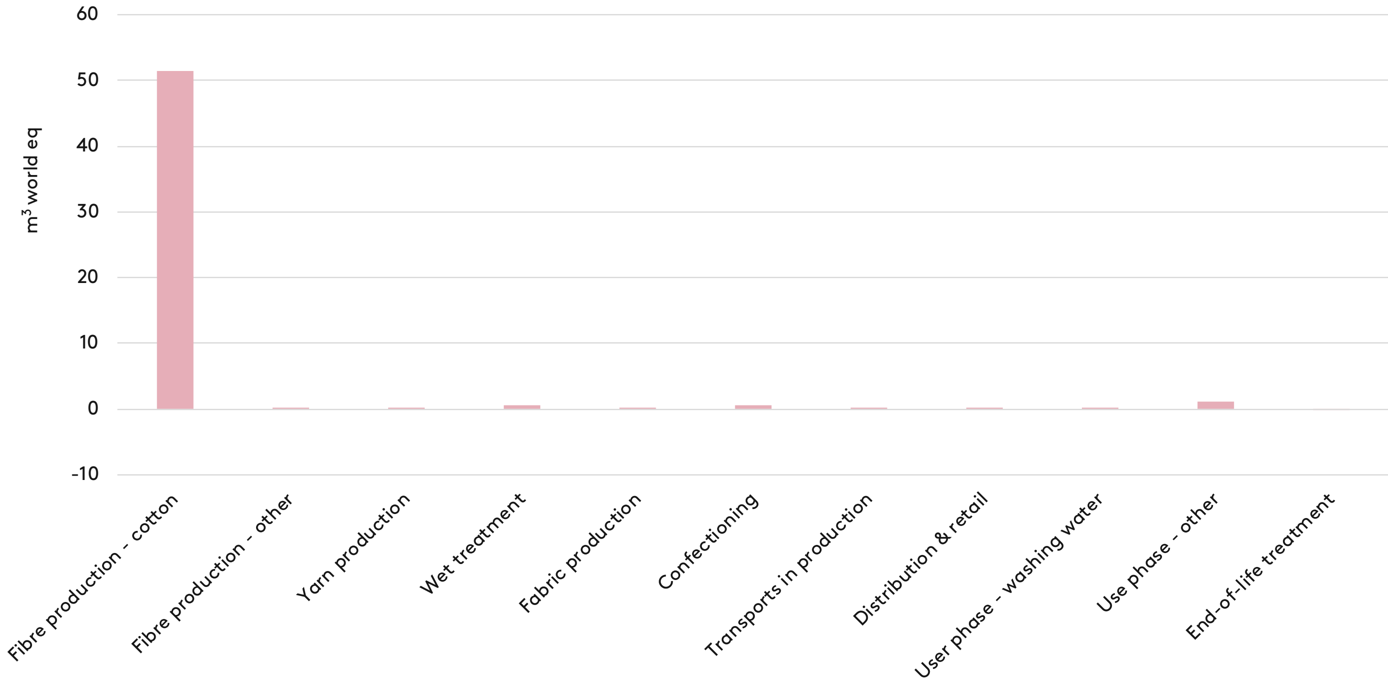


figure 4.23: Water scarcity impact of jeans, per garment service life (240 uses).

4.5 dress

Figure 4.24 shows the climate impact of the dress, revealing the importance of wet treatment (22%), largely due to the high amount of fossil fuel-provided heat used in dyeing (7%), pretreatment (6%) and drying (5%). Yarn production (11%), confectioning (12%) and weaving (12%) are also important – these contributions are mainly driven by relatively high electricity use combined with the carbon-intensive electricity mix of the production countries. Fibre production contributes with about 16% of impact. The user's transport back and forth from the store also matters (9%) (see discussion for T-shirt results in Section 0). Other transports contribute with about 2.5% and the user's laundry with about 5%. Processes such as production and disposal of packaging, energy use in stores, and the travelling of staff involved in distribution and retail, are insignificant.

The energy use of the dress is shown in figure 4.25. The results are very similar as the climate impact results, as energy use is heavily dominated by fossil energy.

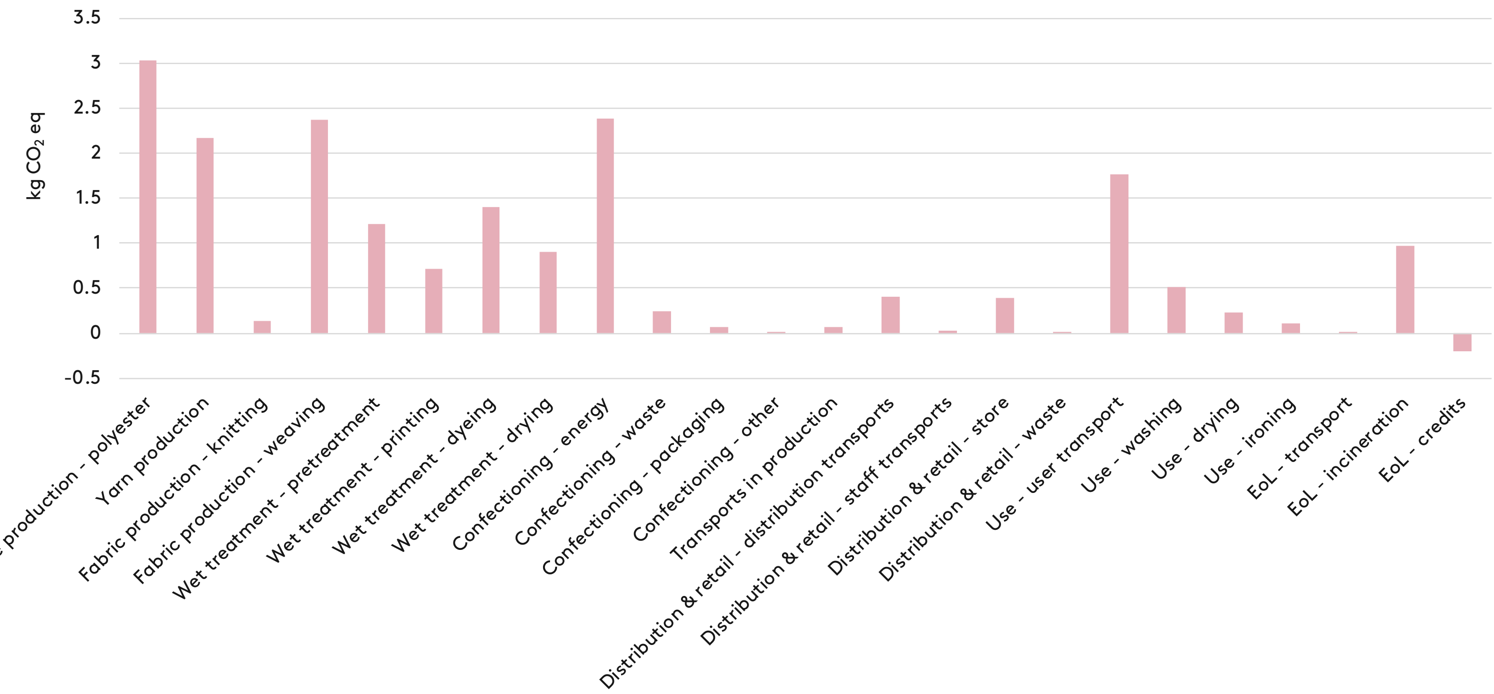


figure 4.24: Climate impact of dress, per garment service life (26 uses).

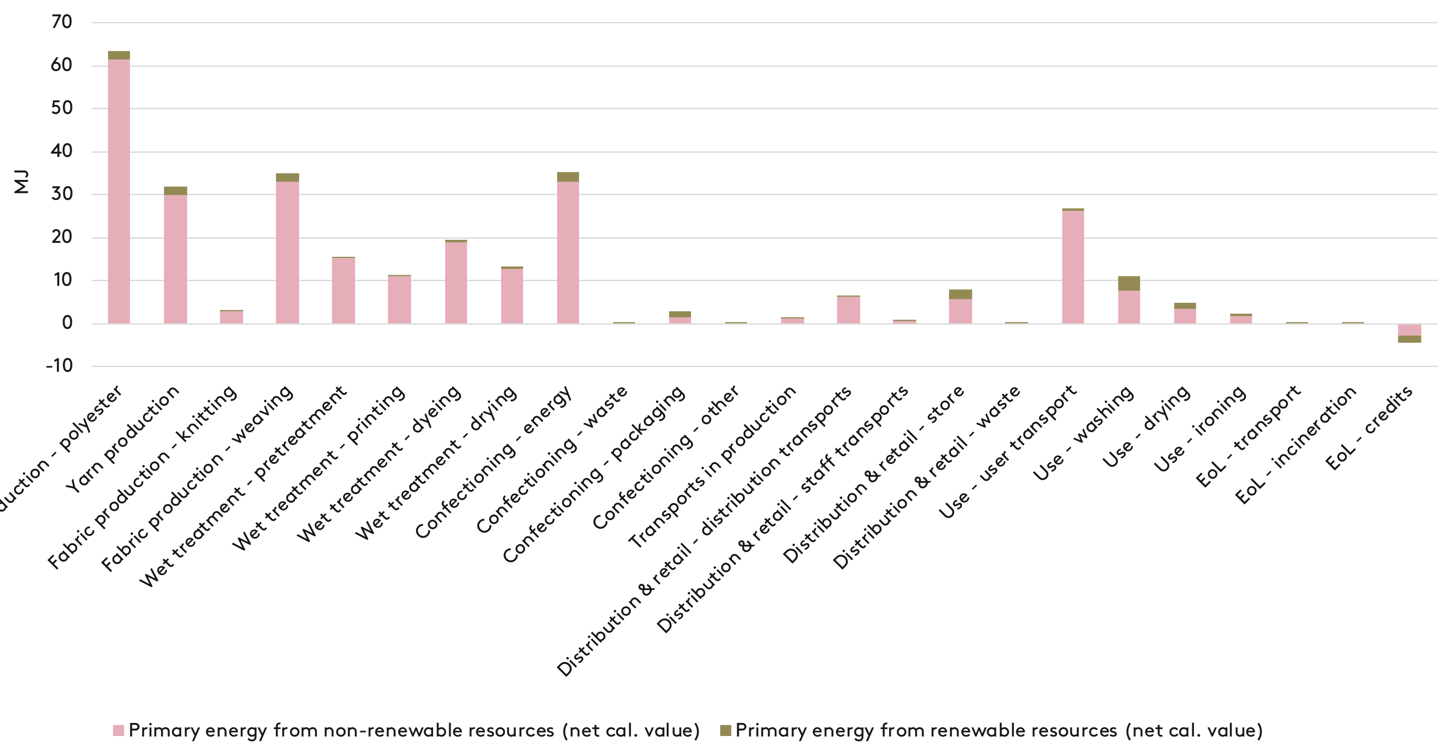


figure 4.25: Energy use of dress, per garment service life (26 uses).

The result for water scarcity in figure 4.26 shows a very different pattern compared the T-shirt and the jeans, as there is no production of cotton overshadowing the other contributions – which obviously means that the importance of the water scarcity issue is much lower for a polyester dress than for a pair of jeans or a cotton T-shirt. Here, the main contributions come from wet treatment and the background processes of polyester production (water used to produce input energy and chemicals).

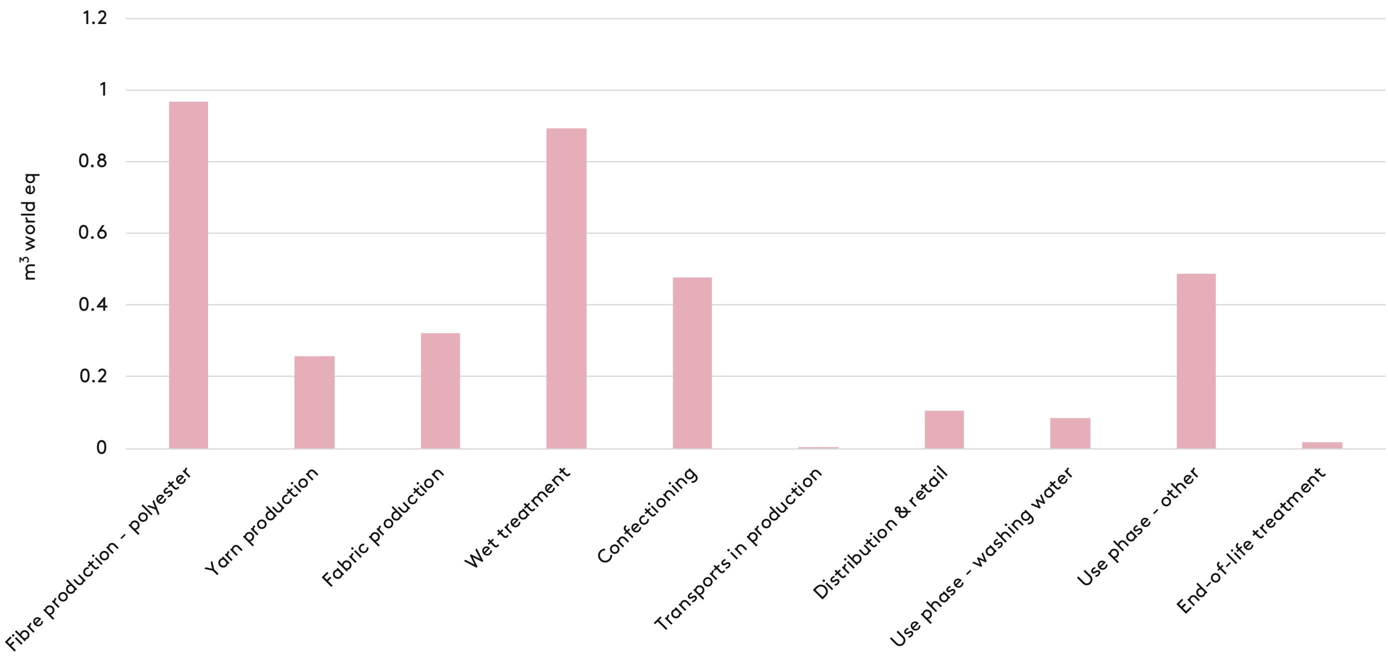


figure 4.26: Water scarcity impact of dress, per garment service life (26 uses).

4.6 jacket

Figure 4.27 and figure 4.28 show the jacket's climate impact and energy use, respectively. The two indicators display very similar pattern, as most energy use is associated with high climate impact. The following discussion focusses on the climate impact. The production of polyamide is a climate hotspot (15%), although it is just 46% of the fibre content of the jacket. Some other energy-consuming processes are also important climate-wise: confectioning (20%), weaving (15%) and dyeing (12%).

Confectioning contributes more than for the other garments, which is because a jacket is a relatively complex garment with a long sewing time (135 min). The user's transport back and forth from the store also matters (8%) (see discussion for T-shirt results in Section 4.3), whereas the user's laundry is negligible as the jacket is assumed to be washed just once in its service life. Transports between production facilities and distribution transports contribute with about 2.5%, and processes such as production and disposal of packaging, energy use in stores, and the travelling of staff involved in distribution and retail, are insignificant.

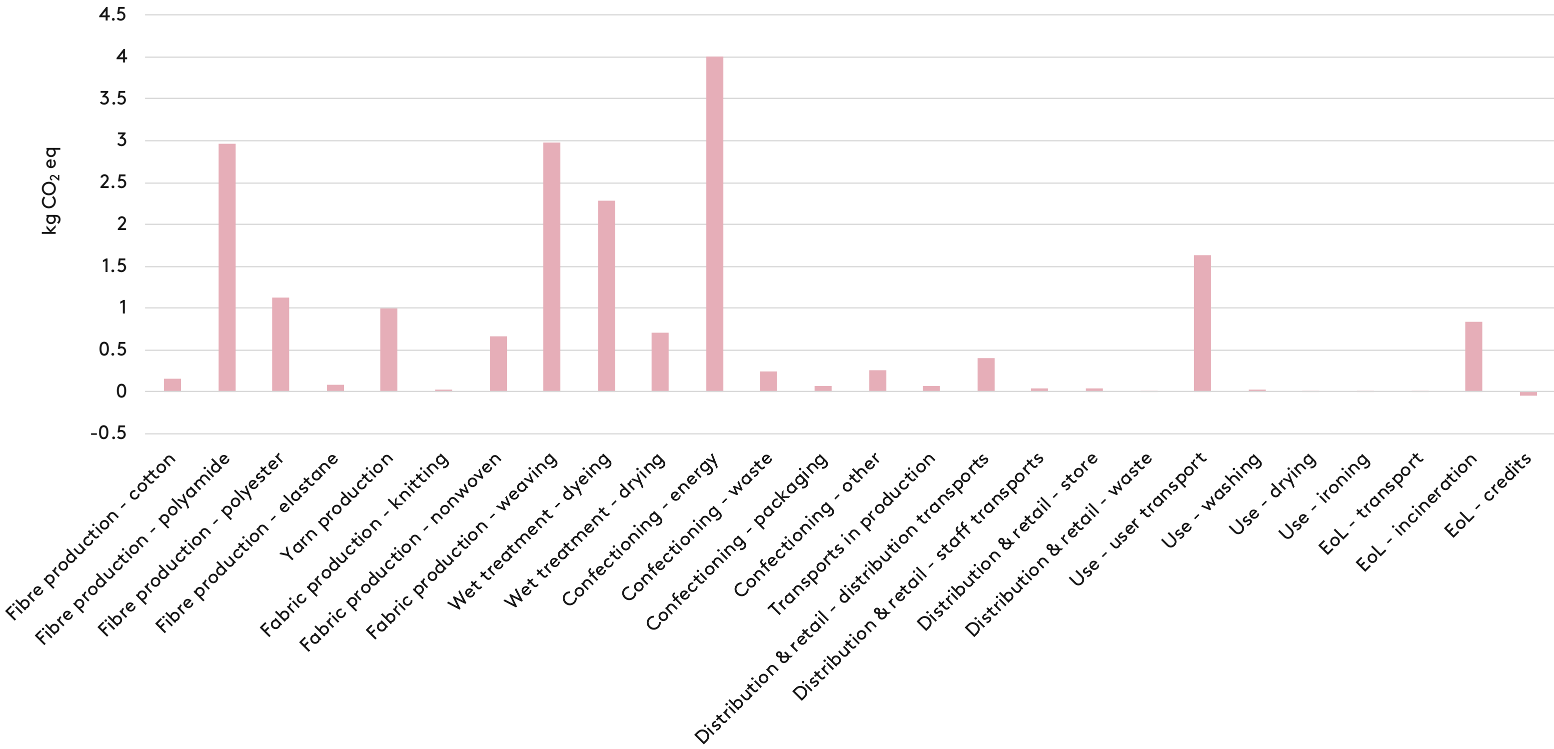


figure 4.27: Climate impact of jacket, per garment service life (140 uses).

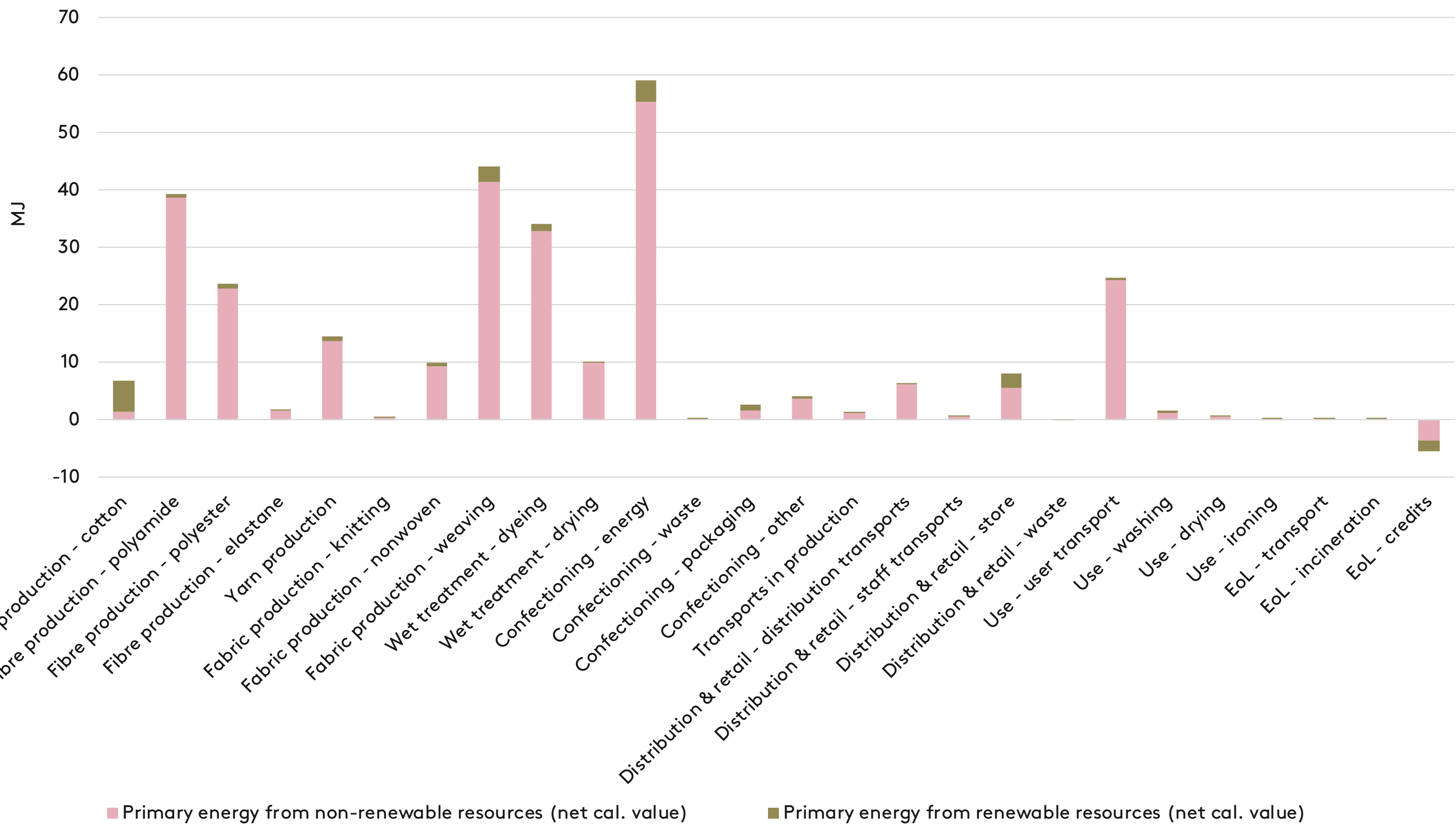


figure 4.28: Energy use of jacket, per garment service life (140 uses).

The result for water scarcity in figure 4.29 shows that water consumed in the irrigation of cotton farms is the most important water scarcity hotspot (70% of total impact) for a jacket with a cotton content of not more than 17%.

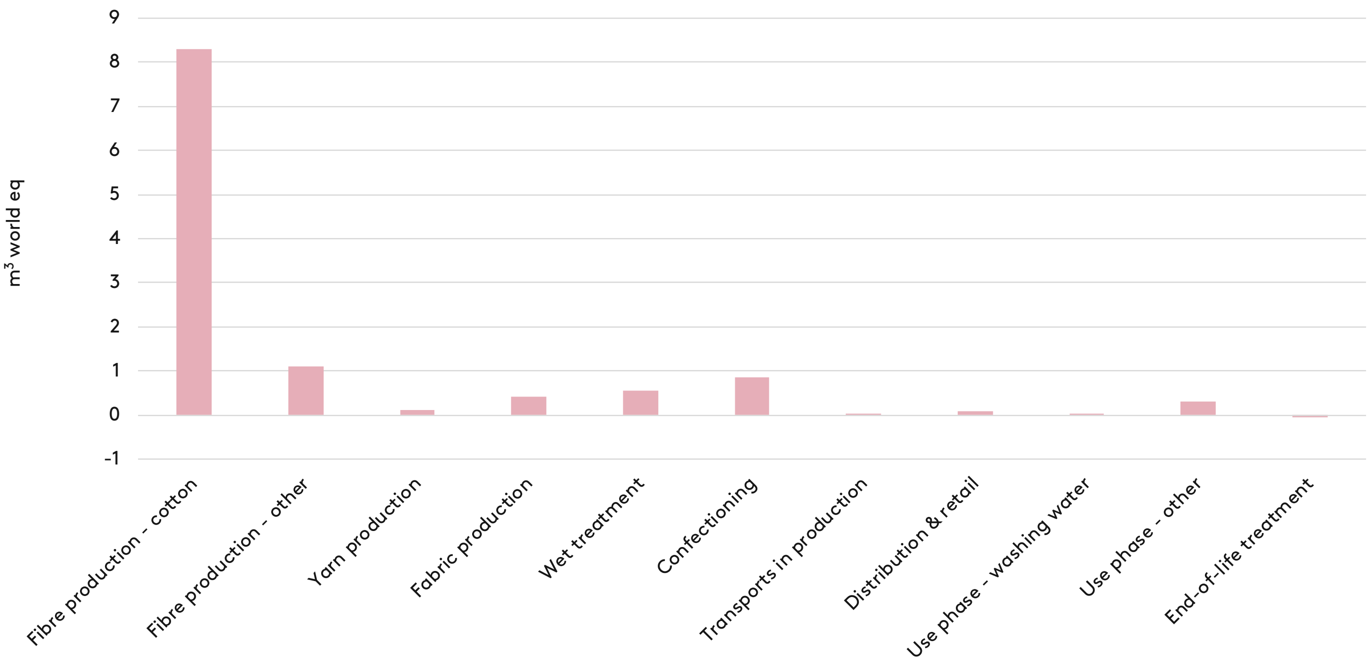


figure 4.29: Water scarcity impact of jacket, per garment service life (140 uses).

4.7 socks

Figure 4.30 shows the climate impact of a pair of socks, revealing the following climate hotspots: production of polyamide fibres (12% of impact, with 27% of fibre content), production of viscose fibres (10% of impact, with 72% of fibre content, i.e. the climate impact per kg fibres is about one third that of polyamide), yarn production (12%), wet treatment (14%), fully-fashioned knitting (15%), the user's transport back and forth from the store (5%) and the user's laundry (6%). Other transport contributes with about 4% and processes such as production and disposal of packaging, energy use in stores, and the travelling of staff involved in distribution and retail, are insignificant. The fact that many production processes contribute roughly equal parts to the total climate impact, suggest that one needs to involve more or less the entire production chain for reducing the climate impact of socks production.

The pattern of the energy use results resembles that of climate impact, with two exceptions: the renewable energy used for viscose production is clearly visible, as is the increased importance of the use-phase laundry – powered by the relatively low-carbon electricity mix of Sweden, largely relying on nuclear and hydro power. The importance of laundry is a result of socks being assumed to be washed after every use.

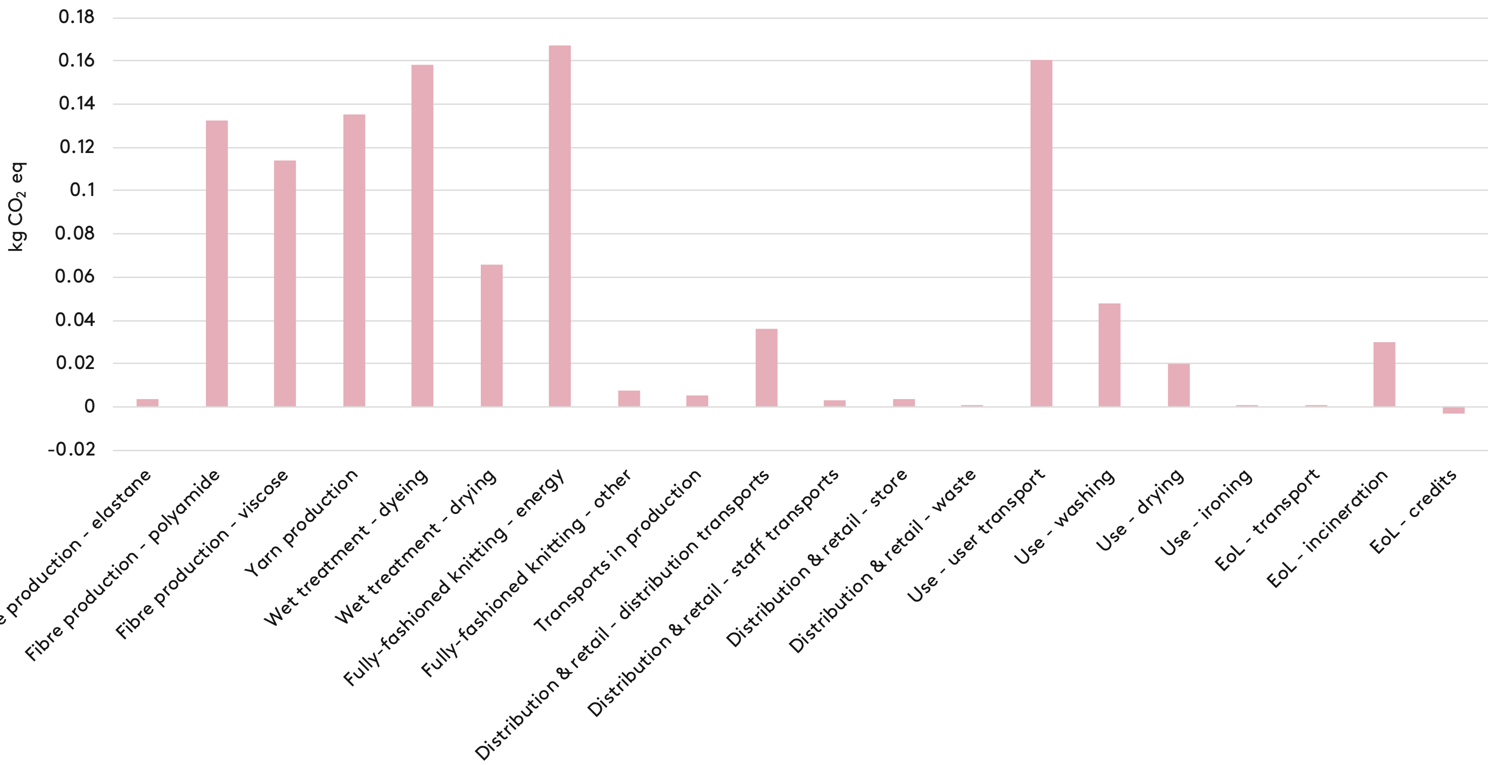


figure 4.30: Climate impact of socks, per garment service life (27 uses).

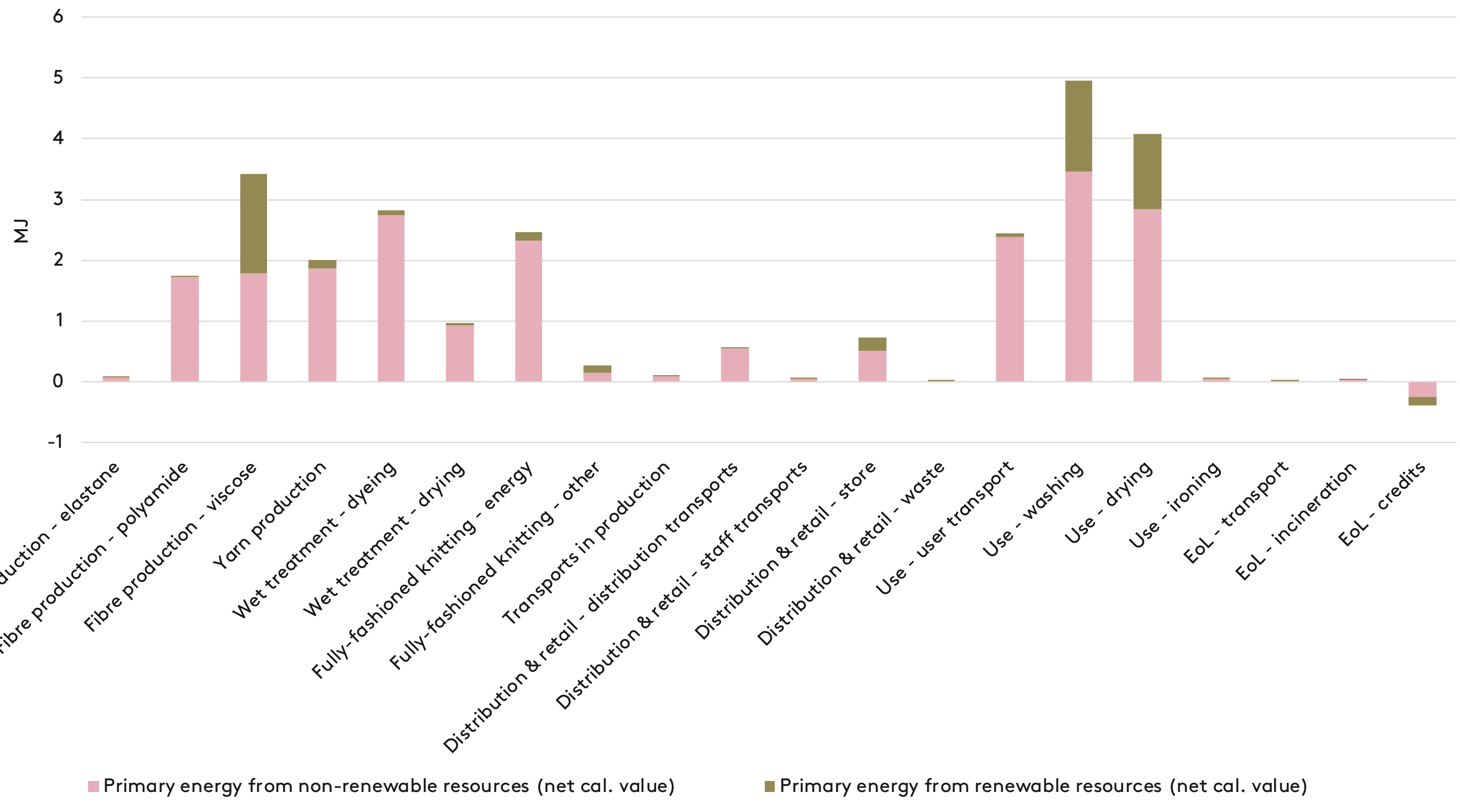


figure 4.31: Energy use of socks, per garment service life (27 uses).

The result for water scarcity in figure 4.32 shows that just as for the dress the pattern is very different from those garments made by cotton – and the importance of the water scarcity issue is much lower for a pair of viscose/polyamide/elastane socks than it is for cotton garments. Here, the main contributions – although minor in absolute terms – comes from viscose production and background processes in the use phase (electricity generation, detergent production, etc.).

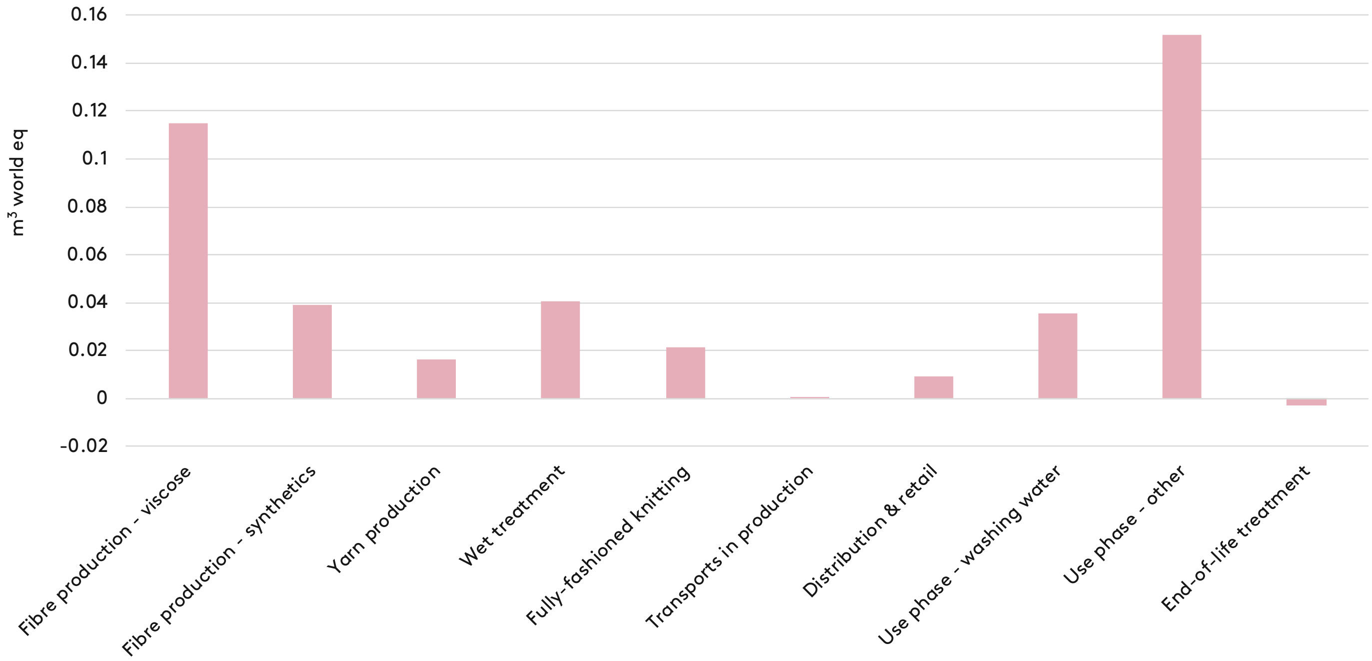


figure 4.32: Water scarcity impact of socks, per garment service life (27 uses).

4.8 hospital uniform

Figure 4.33 shows the climate impact of the hospital uniform, revealing the following climate hotspots: production of polyester fibres (12% of impact, with 50% of fibre content), yarn production (13%), weaving (23%), wet treatment (21%, whereof dyeing 16%), confectioning (6%), and the industrial laundry (17%). Transport contributes slightly less than 3%.

Figure 4.34 shows the energy use hospital uniform, revealing industrial laundry as the main energy culprit. This is because it is used many times during its service life (75 times; the relative importance of production diminishes when number of uses increase) and washed after each in rather high temperature (70-90°C).

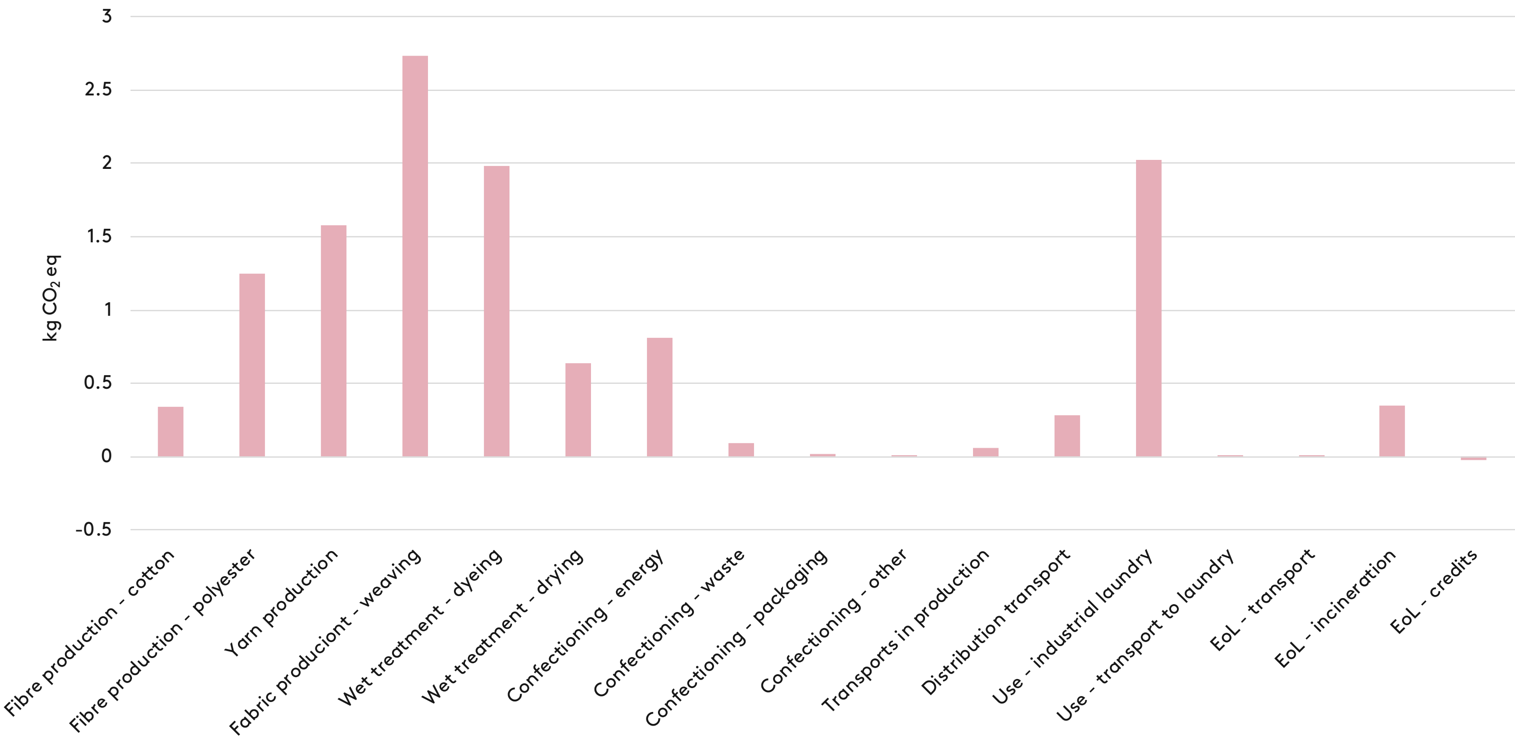


figure 4.33: Climate impact of hospital uniform, per garment service life (75 uses).

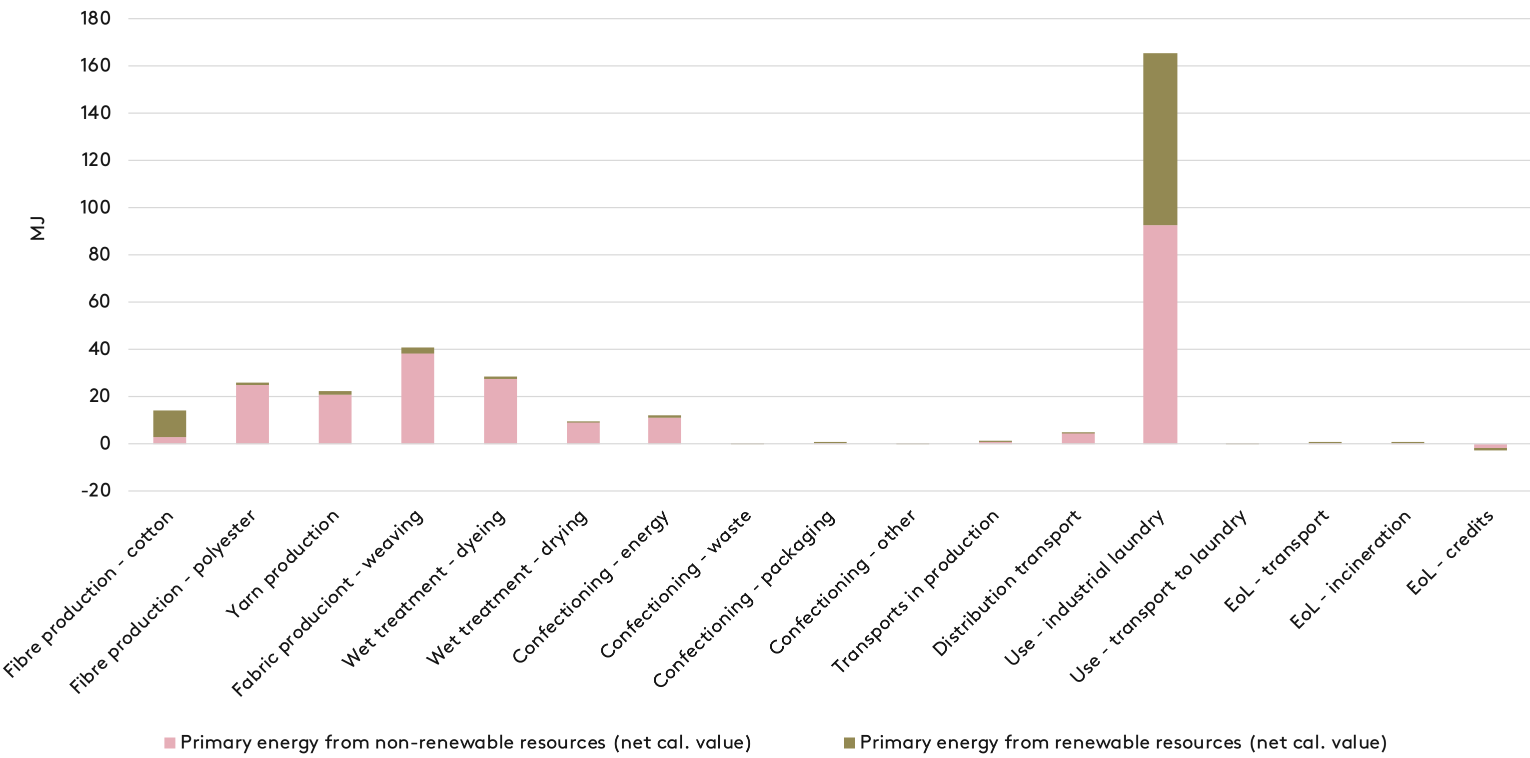


figure 4.34: Energy use of hospital uniform, per garment service life (75 uses).

The result for water scarcity in figure 4.35 reveals, as for the other cotton-containing garments, the importance of irrigation of cotton farms – in this case its contribution is 83% of total impact.

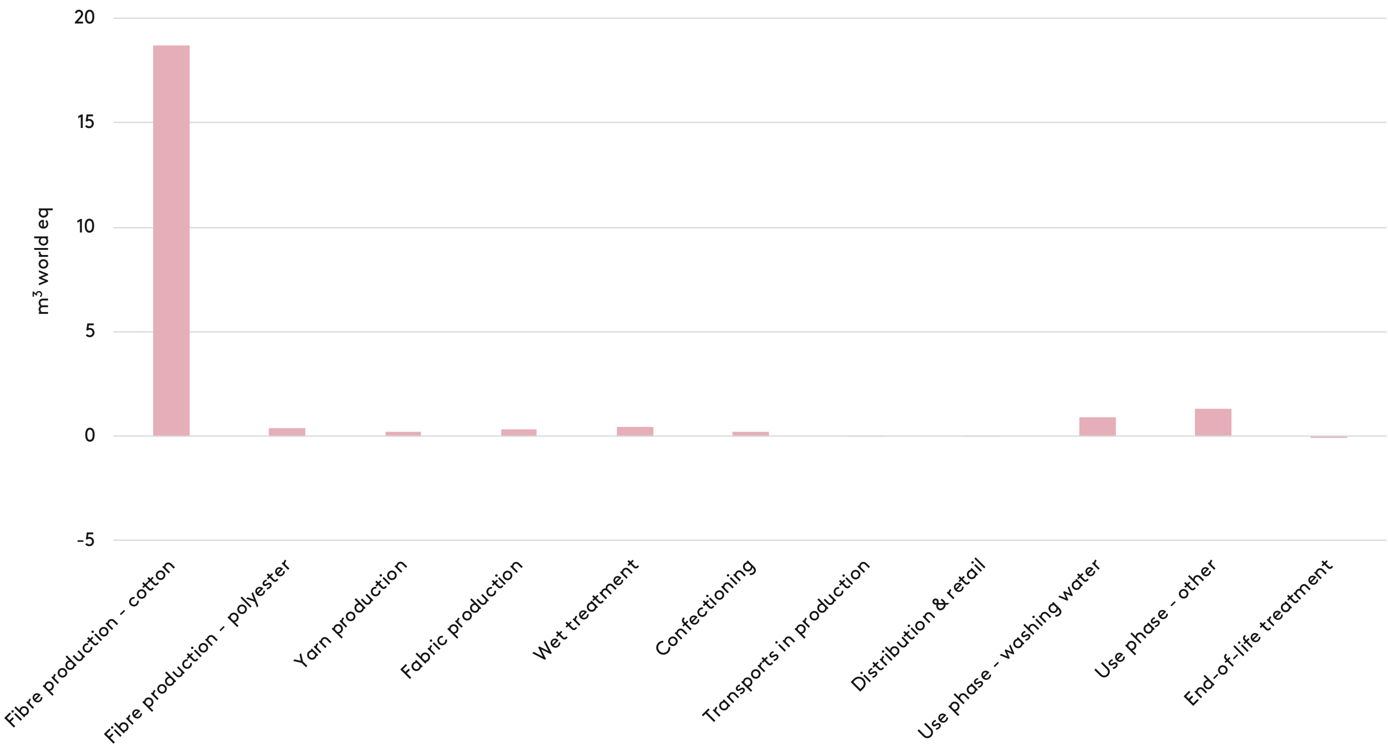


figure 4.35: Water scarcity impact of hospital uniform, per garment service life (75 uses).

4.9 reducing the environmental impact of clothing

Below we provide a few examples of how interventions can reduce the environmental impact of clothing – per garment use, per garment life cycle and at the level of Swedish clothing consumption. Further examples are given in Chapter 5, the summary of previous LCA studies carried out in Mistra Future Fashion.

4.9.1 prolonging the life of clothing

Figure 4.36 and figure 4.37 give two examples of the effects of prolonging the service life of garments. The first figure shows the climate benefits of using a T-shirt three times as often during its life as the average T-shirt modelled in the present study, i.e. it can be said to reflect the environmental profile of a favourite T-shirt of yours. The pattern would be identical for the other garments and impact categories: per garment use, all processes except the user's laundering (washing, drying and ironing) scale down with increasing uses. In total, the per-use impact of your favourite T-shirt is 65% lower than the average one.

The second figure show the national-level gains if all garments are used twice as long before disposal, which can be said to reflect a future scenario in which the quality of the average garments has improved, the shopping habits of consumers have changed, and/or collaborative business models (second hand, renting, swapping, borrowing, etc.) have become more widespread – in other words, the sharing economy has boomed. Overall, using clothes longer is an effective way of reducing all kinds of impact throughout (almost) the entire life cycle. Also, it is an intervention that can be combined with most other interventions, which are further explored in the following sections.

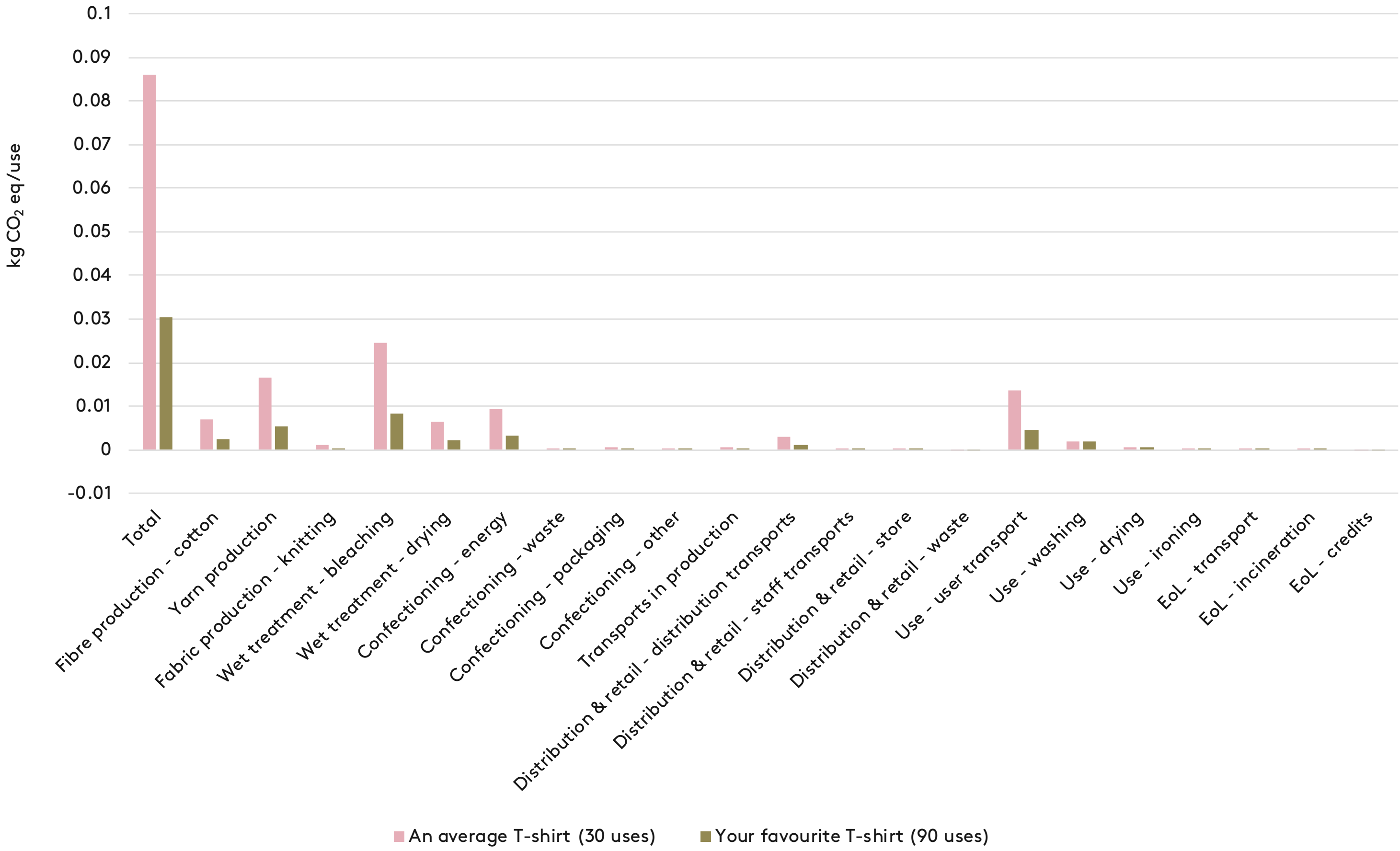


figure 4.36: Climate impact of your favourite T-shirt compared the average one, per use.

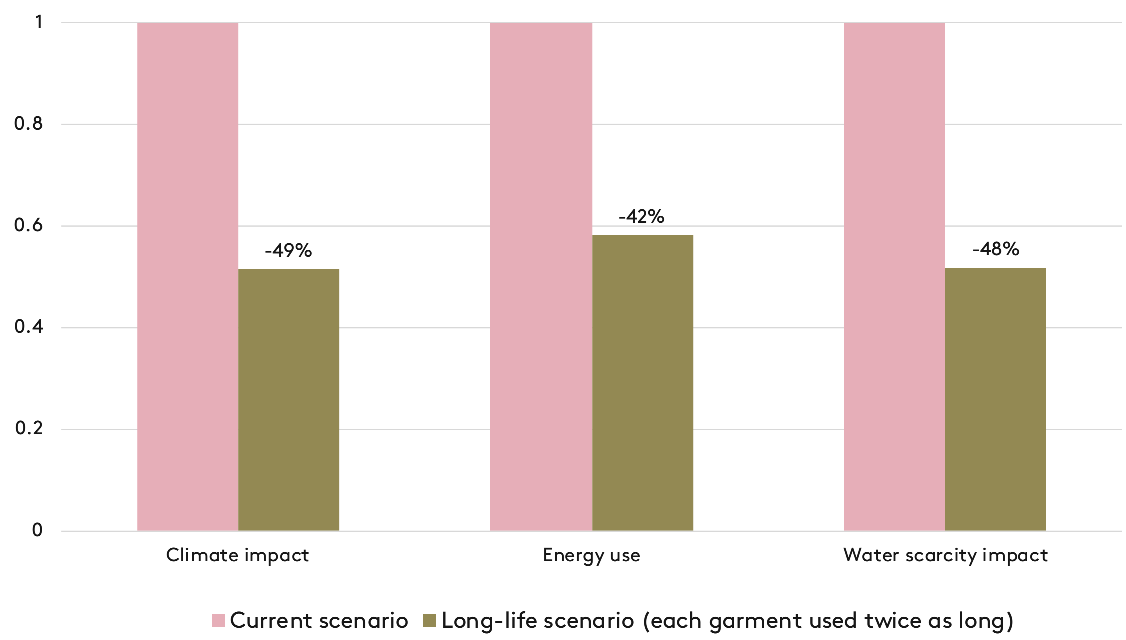


figure 4.37: Environmental impact reductions if each garment of the national-level model is used twice as long.

4.9.2 cleaner production

The results show that energy use is a major cause of much of the environmental impact of production. One potentially effective intervention would be to shift to renewable energy.

Figure 4.38 explores the impact-reduction potential of shifting the electricity use in yarn production, fabric production, wet treatment and confectioning from the current electricity mix of the production countries, with a carbon footprint of 929 g CO2 eq/kWh, to solar-powered electricity, with a carbon footprint of 47 g CO2 eq/kWh[13]. This reduces impact per garment life cycle by between 27 and 44%. There would be further gains if other energy sources were also swapped for renewables, such as the light fuel oil and natural gas used for heat in production (mainly for wet treatment) and the fuel used for the user's transport. These are energy-demanding processes which are under direct control by producers and users, but there are other which are more difficult to influence/ control: the energy use of backgrounds processes, such as the production of input chemicals.

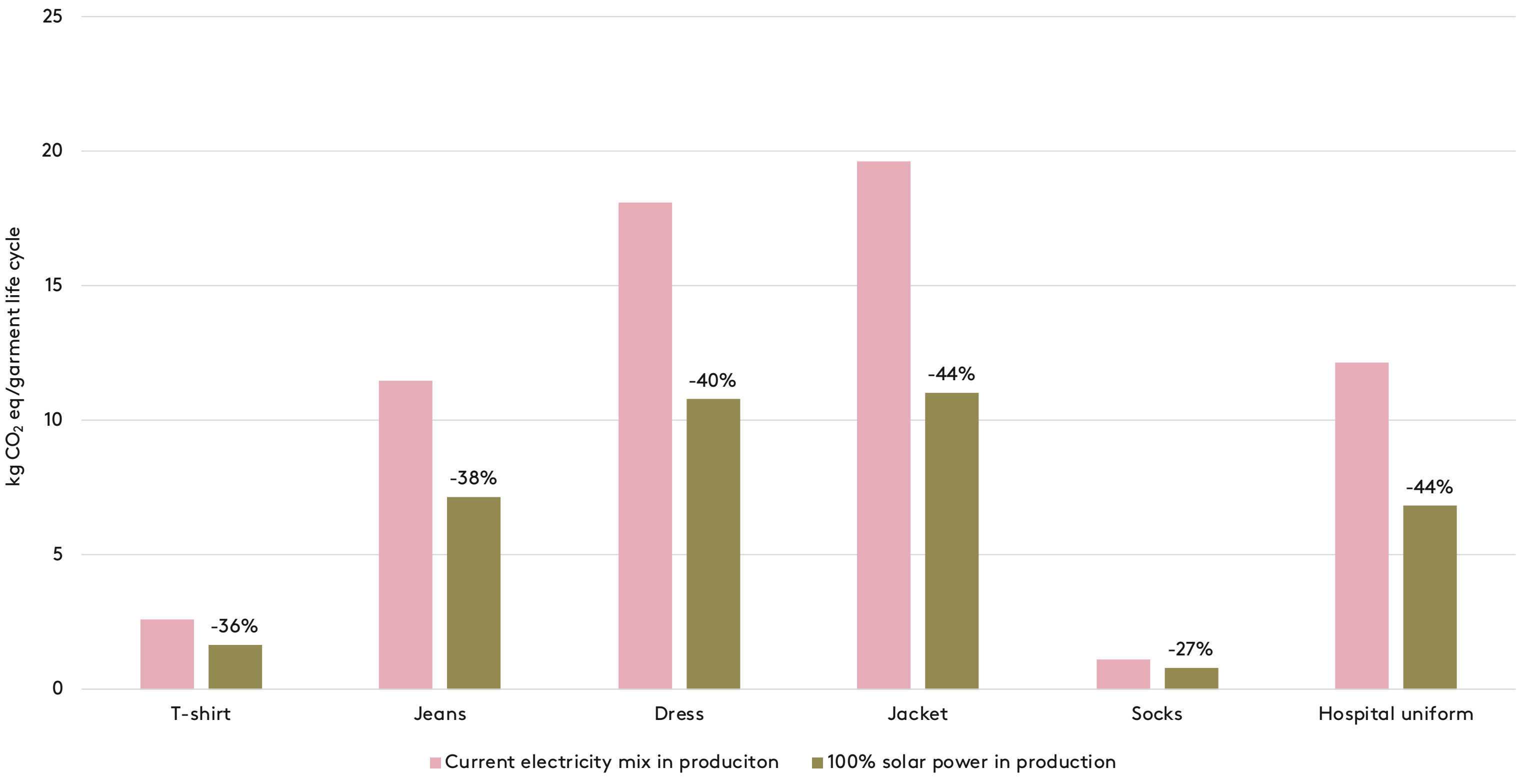


figure 4.38: Climate benefits of shifting to solar power in production.

[13] Assuming the Ecoinvent 3.5 dataset "RoW: electricity production, solar tower power plant, 20 MW". Other types of solar power has similar climate impact per kWh and would thus yield similar results.

Figure 4.39 shows the effects on climate and water scarcity impact obtained by shifting the fibre content of the T-shirt from cotton to viscose. The viscose dataset chosen here is the same as used for the socks (i.e., an Ecoinvent 3.5 dataset reflecting global average production). Note that only the fibre production process was assumed to be influenced, although a change of fibre may also impose slight changes on other processes. The figure clearly shows that avoiding cotton in general reduces water scarcity impact, whereas climate impact is slightly increased by such a change.

This is an example of a potential trade-off between different impact categories. However, it should be emphasised that the difference in climate impact between the two fibre types is smaller than the differences often seen among alternative data sets for these two fibre types (Sandin et al. 2019). Likewise, it should be emphasised that the di fferences between different datasets of cotton cultivation are also very large, as some farms use no "blue water" (irrigation) and are located in areas without water stress – so the potential water scarcity gains of shifting from cotton to a regenerated cellulose fibre can also be achieved by shifting from average cotton to cotton grown on farms with more sustainable water management practices.

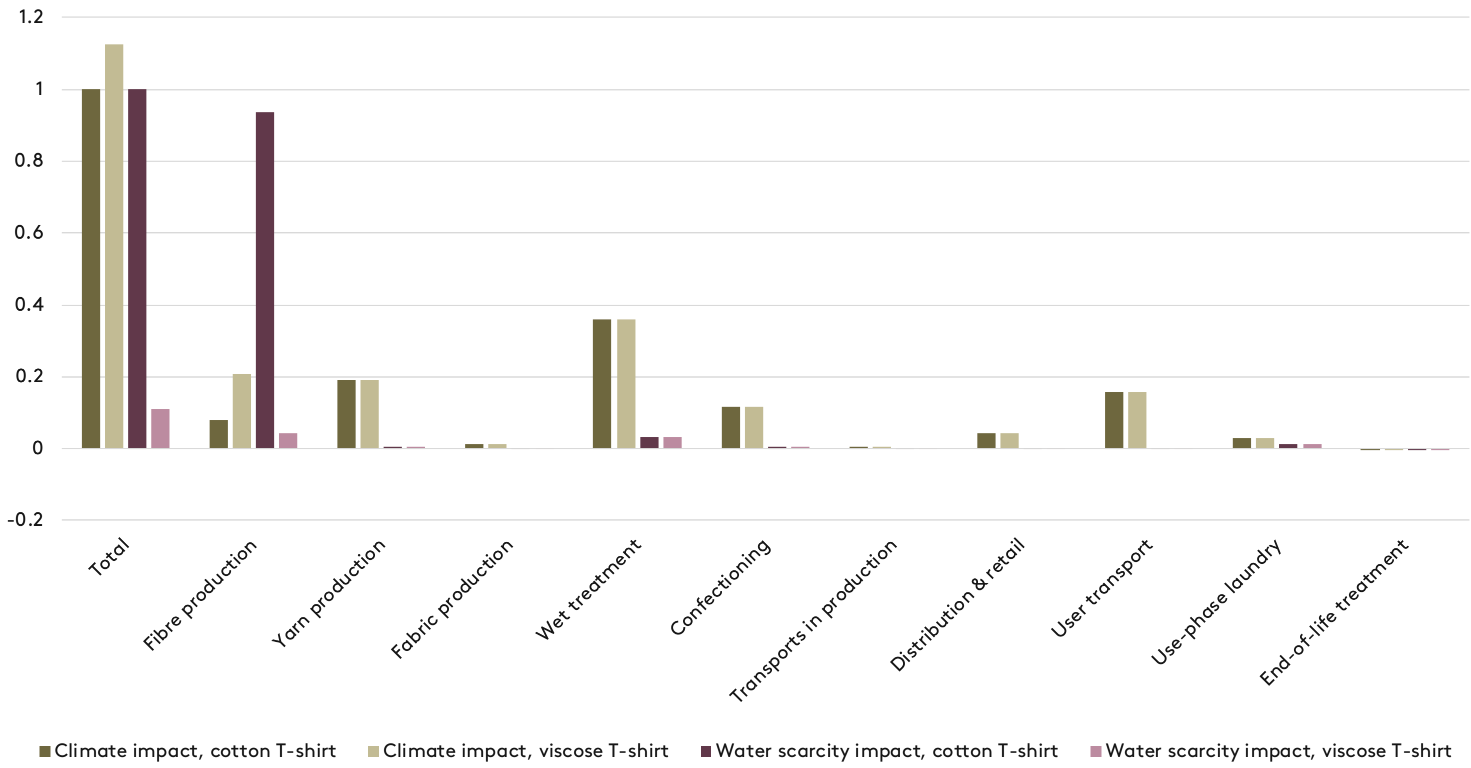


figure 4.39: Climate and water scarcity impact of a cotton T-shirt compared to a viscose T-shirt. Results are normalised to the impact of the cotton T-shirt.

Figures 4.40-4.42 show the benefits of interventions that reduce the toxicity of the life cycle of the dress, in terms of the relative importance of improving the environmental performance of the wet treatment process and chemistry separately. The first scenario reflects the baseline of the study (average chemicals and process conditions, see Appendix B, table B 3). In scenario 2 and 3, the process stays the same but in scenario 2, BAT chemicals are used and in scenario 3, worst-case chemicals are used (recipes from Roos et al. (2018)). In scenario 4, average chemicals are again used while the waste water treatment plant (WWTP) is modelled with its ability to remove chemicals improved from 90% to 99%. In scenario 5, there is no WWTP, and average chemicals are used. The scenarios can of course also be combined.

Figure 4.40 shows the results for human toxicity (carcinogenic) impacts, where the difference between the scenario 1 and scenario 3 is three orders of magnitude. Chemicals classified as carcinogenic are rarely used which explains why the worst-case model is so dominant. The figure also shows how the improvement made via better waste water treatment is considerably lower than that of selecting less hazardous chemicals, underlining the conclusions that reducing the use of the most hazardous chemicals is the most important intervention for reducing the toxicity impact of textile processes.

For human toxicity (non-carcinogenic) and freshwater ecotoxicity impacts, also average chemicals contribute to the environmental load. Therefore, the difference between selecting average and worst-case chemicals is not as large as it is for carcinogenic impact, about one order of magnitude. For these impact categories the selection of chemicals is of equal importance to the implementation of waste water treatment (scenarios 3 and 5 in figure 4.41 and figure 4.42 are the same order of magnitude).

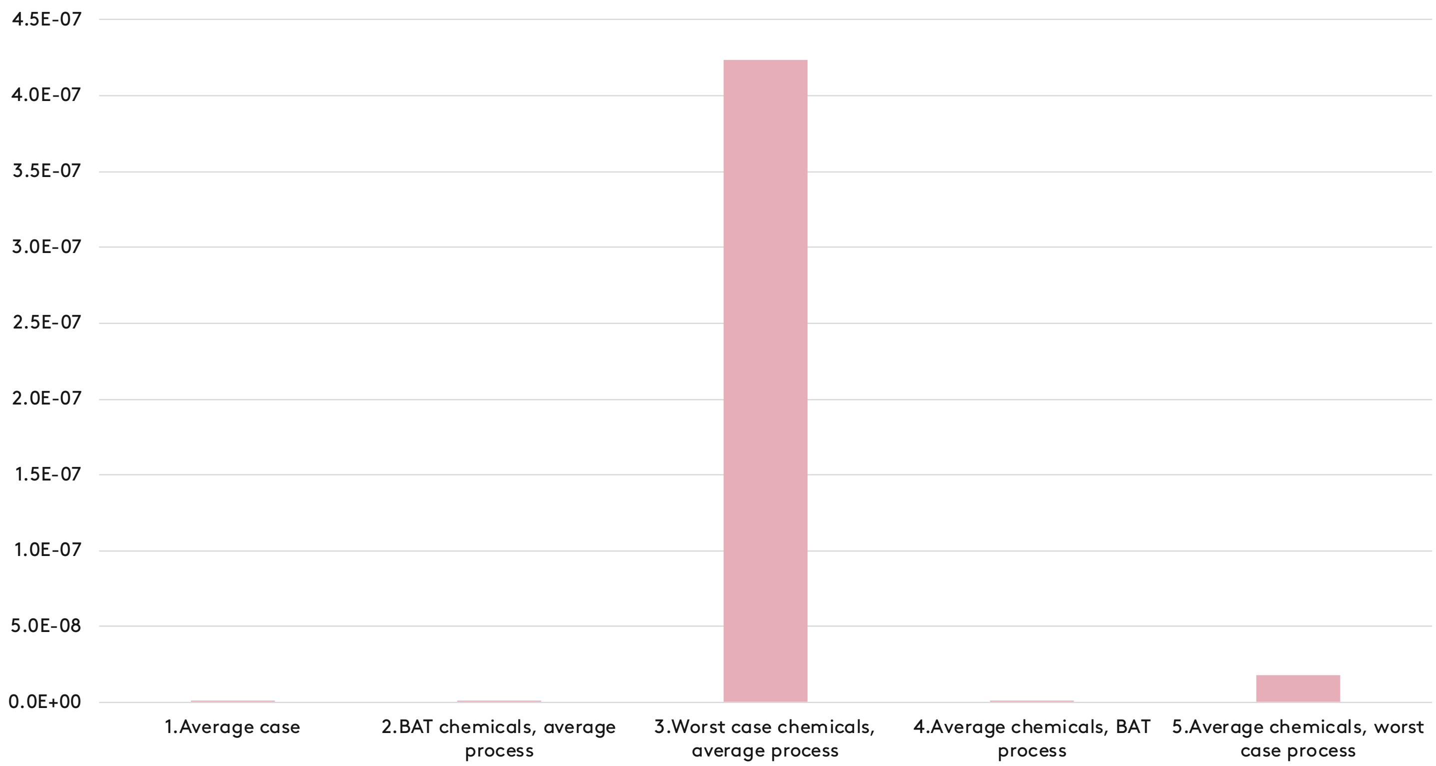


figure 4.40: Influence on human toxicity (carc.) impact of dress of better or worse chemicals selection respective process performance. Only direct emissions from textile processes.

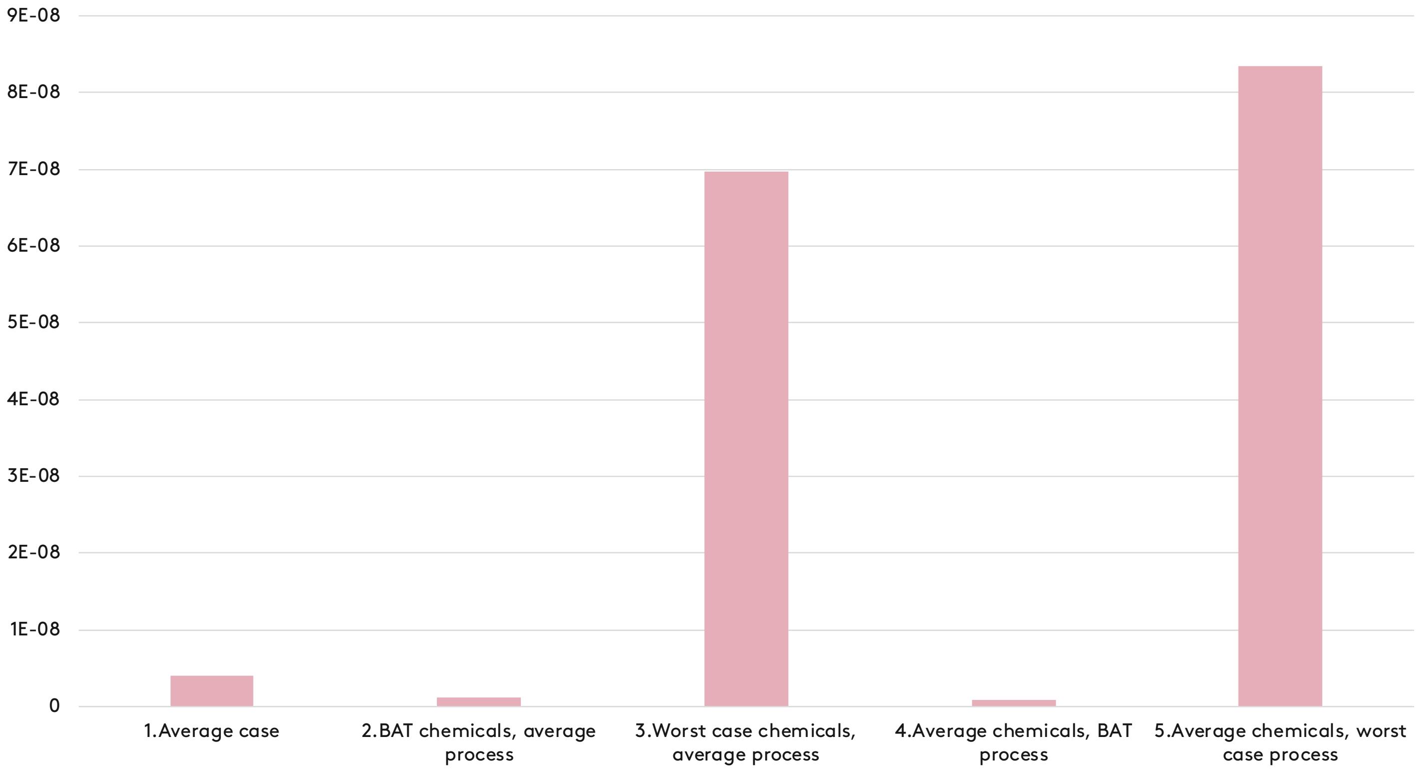


figure 4.41: Influence on human toxicity (non-carc.) impact of dress of better or worse chemicals selection respective process performance. Only direct emissions from textile processes.

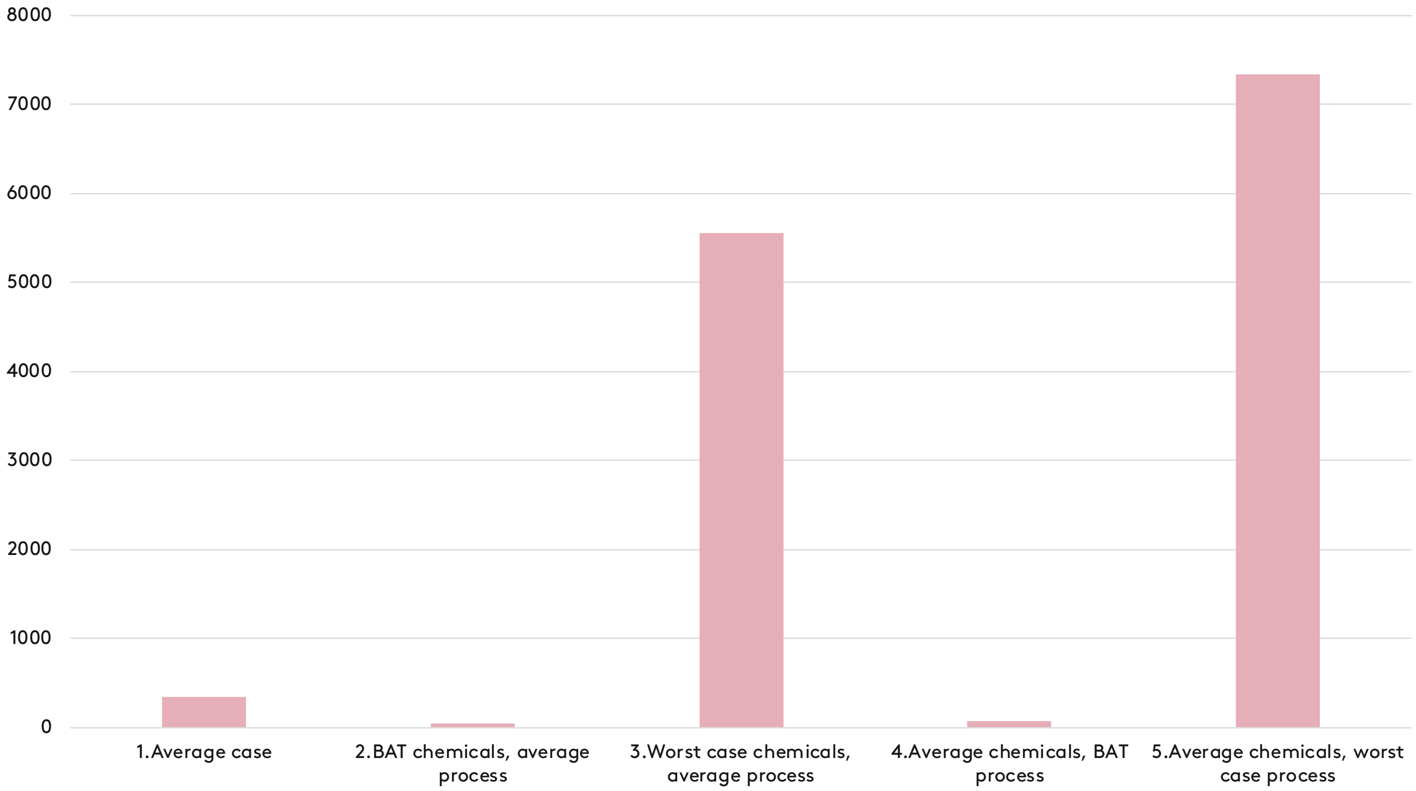


figure 4.42: Influence on freshwater ecotoxicity impact of dress of better or worse chemicals selection respective process performance. Only direct emissions from textile processes.

4.9.3 changed user behavior

The above scenarios with prolonged life length of clothing are examples of changed user behavior. Other examples other means of transporting oneself back and forth from the store or washing in lower temperature – the effects of these two interventions are shown in below figures. Here the focus is on the everyday garments, whereas the hospital uniform is excluded as it is less influenced by user behaviour.

Figure 4.43 shows the effect of walking or driving with a car back and forth form the store, instead of the current average user transport assumed in the present study (50/50 mix of driving and taking a bus). How you decide to travel to the store can significantly reduce or increase the environmental impact of clothing. For an average distance, the choice between walking or taking the car determines 12-24% of the climate impact of the clothing purchase and use – for longer distances and/or if you buy fewer garments per trip (1 kg/17 km was assumed in the present study), the choice is even more important.

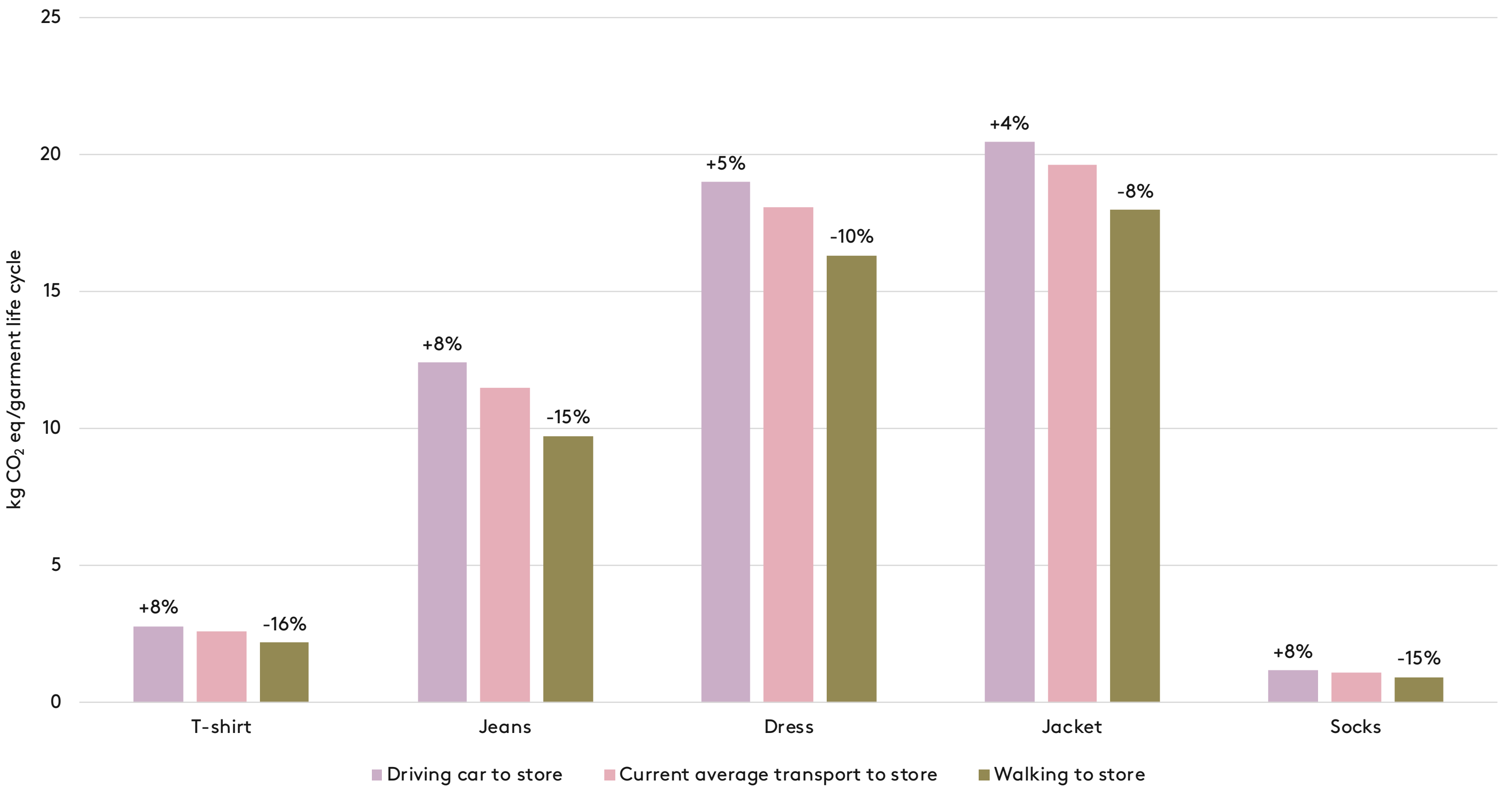


figure 4.43: Climate benefits and drawbacks of different means of transportation back and forth from the store.

Figure 4.44 shows the effect of reducing the washing temperatures, from 40 to 30°C for the T-shirt, the jeans, the dress and the jacket, and from 60 to 40°C for the socks. The direct benefits in Sweden are negligible – lower than 1% even for the socks, a garment assumed to be washed after every use. The low climate benefit of lowering the washing temperature is mainly due to the relatively low-carbon electricity mix of Sweden (44.6 g CO2 eq/kWh), the benefits will be considerably larger for many other countries. The benefit is also smaller than shown elsewhere due to lower number of uses per garment of the present report (a number based on actual user behavior, not theoretical/ideal life lengths) compared to many other reports.

The more uses and washes there are during a garment's service life, the more important various laundering parameters are in relation to the parameters for production. Notice that the climate benefit of lower washing temperature is, depending on garment, between one and three order of magnitudes smaller than that of not taking the car when travelling to the store – a parameter given much less attention in discussions on sustainable fashion. There may, however, be climate (and other environmental) benefits of low washing temperatures than those captured here, for example if a low temperature is gentler towards the fabric and thereby extend its technical, and hopefully its practical, service life. Nor does this analysis address the question of whether implementing fewer washes per use reduces the impact of production per use via extending garment technical lifespans.

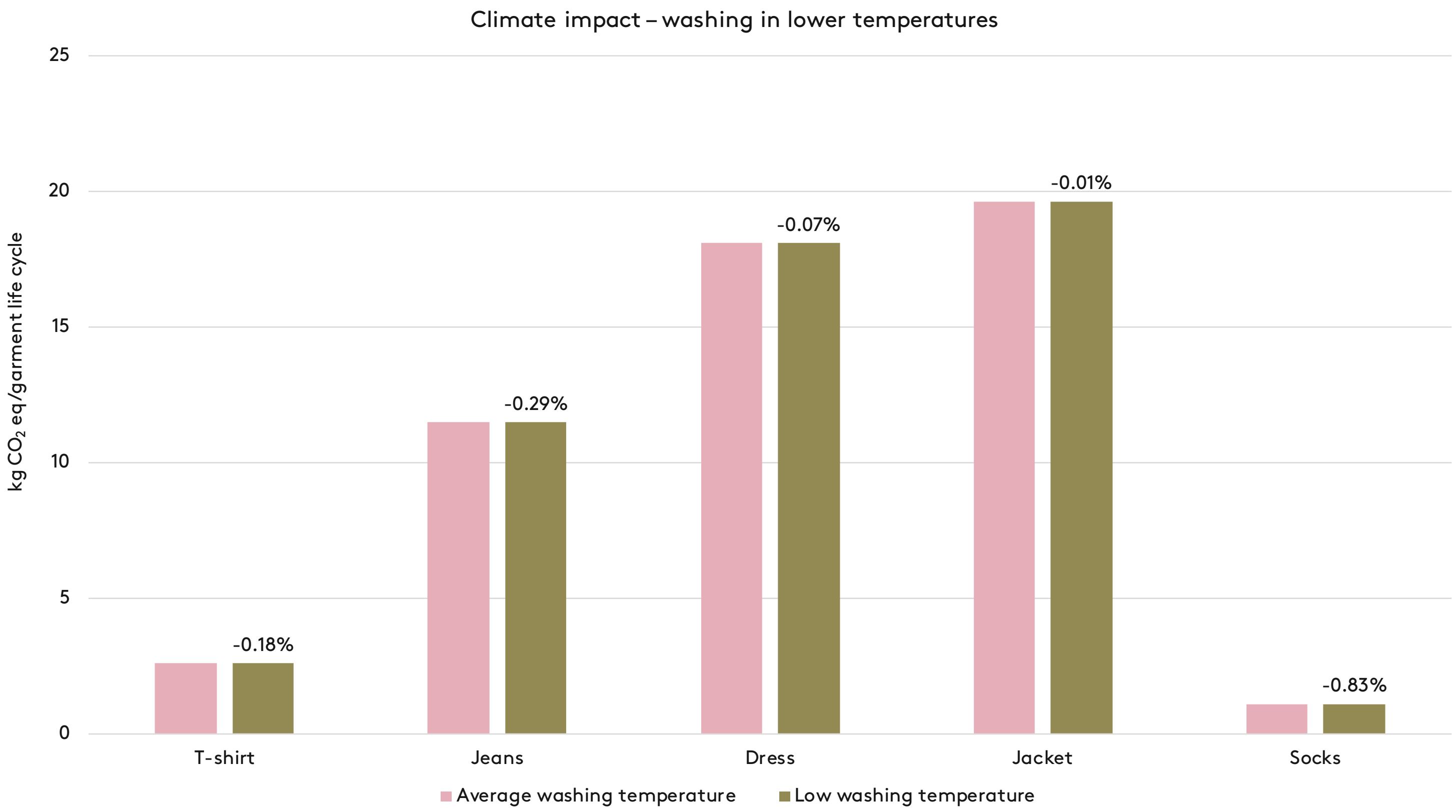


figure 4.44: Climate benefits of washing in lower temperatures.

4.9.4 combining interventions

Figure 4.45 shows the aggregated climate benefits at a national-level in case of massive penetration of three of the interventions: more uses of each garment (on average twice as many uses per garment service life), solar-powered production, and users walking to the store by foot or some other means of transportation with negligible climate impact. In total, these interventions can mitigate 78% of the climate impact of Swedish clothing consumption, or 2.5 million tonnes of CO2 eq. per year. These are examples of complementary interventions. Other interventions are not complementary, for example changing to natural fibres cannot be combined with waterless dyeing techniques, such as spin dyeing, as these are only applicable for synthetics.

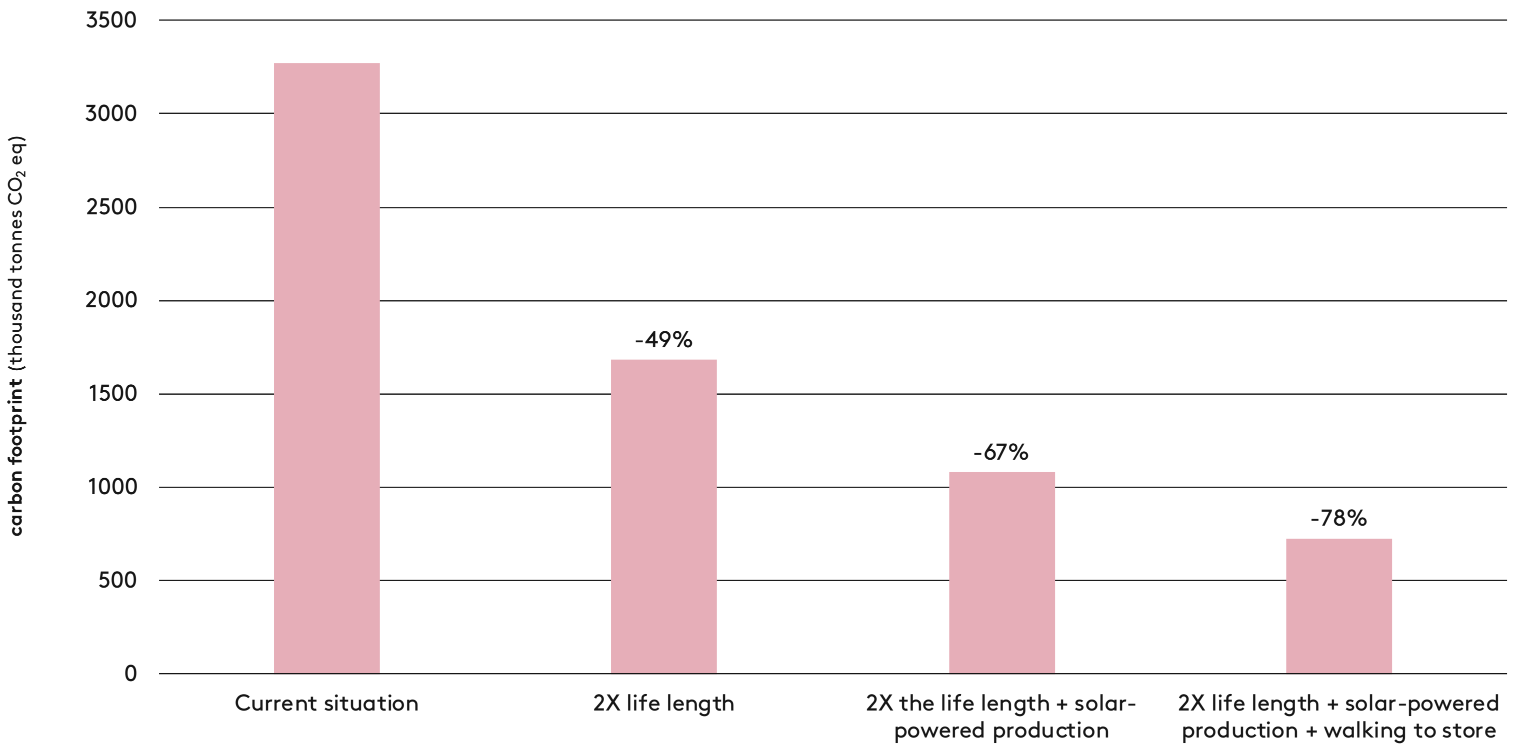


figure 4.45: National-level climate benefits of combining several intervention scenarios: doubled life lengths of clothing, solar-powered production and walking to the store.

4.10 discussion of uncertainties

As the aim of the study has been to map the environmental impact of an entire sector, it has been necessary to generalise based on available data. This has led to some uncertainties, whereof some have been quantified in the sensitivity analyses, but others are difficult to quantify and are therefore discussed qualitatively below. The focus here is on the production phase and the use phase – the two life-cycle phases contributing most to the results.

Production data parameters – primarily energy and chemical use of textile processes – have in several cases been based on reported literature data originating from one or a few production facilities. For example, data on the hospital uniform is from Roos (2012) which maps a specific supply chain. This has been a necessity on account of the lack of available data on industry averages. We have tried to minimise uncertainties imposed by such generalisations by considering several sources and either selecting a data point that lies between other available data points or by calculating an average. Emerging data collection tools, such as those developed by the Sustainable Apparel Coalition (SAC 2019), can potentially increase the available data massively, and – depending on the transparency of the data – make reliable industry averages available for LCA practitioners. The use of average values also means that differences in performance between suppliers, geographical scopes, etc., are not reflected in the results.

A particular category of production data often excluded in LCAs of clothing is water and air emissions from chemicals use in textile processes. These have been included in the present study, based on Roos et al. (2018), and matching characterisation factors were developed when such were not available in the applied LCIA method for toxicity (USEtox). Although this is a considerable improvement from most other LCA studies on clothing, it relies on several rough assumptions on the uptake of chemicals in the fabric, the efficiency of wet treatment processes, etc., which contribute to uncertainty.

Use-phase modelling was largely based on Swedish national statistics on import and export of clothing and surveys on user behavior. Nevertheless, several assumptions had to be made which add to uncertainty. Firstly, the six modelled garments had to represent several broad categories of garment types in the national statistics (see Appendix C). Compared to the first edition of this study (Roos et al. 2015), another garment (the socks) was added to the model to improve the garment representation in the national-level scale up, thereby a fibre type (viscose) was added which improved fibre representation and a different washing behavior was added (washed more frequently and at higher temperatures compared to the other everyday garments) which probably improved user behavior representation. In a possible future study, additional garments would improve the representation further – for example, including a garment made of wool would probably be a relevant improvement in terms of fibre representation.

As the user behavior surveys in some cases gave very unspecific answering alternatives (e.g. broad intervals for the number of uses of a garment and the transportation distance to the store), rough assumptions still had to be made on the number of uses per garment life cycle, the laundry behavior of each garment, and the means and distances of the user transport back and forth from the retailer. Also, self-reported surveys are known to have disadvantages, for example in terms of validity, unless the results can be confirmed by other methods, such as direct observation (Northrup 1997). Furthermore, the study has not considered the influence on the retail and distribution phase of the increasingly important online sales, due to a lack of data. This adds uncertainty also to the use-phase model presuming that buying online leads to different user transportation compared to buying in physical stores, as suggested by Zamani et al. (2017). Neither have private imports of clothing over the internet been included, as these are not part of the national statistics on imports. Overall, because of these weaknesses, the use phase is probably associated with the largest uncertainties among the life-cycle phases. In a possible future study, a considerable improvement would be to conduct a new user-behavior survey with more specific answering alternatives and/or to measure actual user behavior – one example of the latter is the ongoing research project "The Future of the Laundry" (Chalmers 2018).

Common uncertainties of LCA are those inflicted by human errors and the software-related errors. These were handled by modelling in two software packages in parallel – which is very unusual for LCA studies – which led to two mostly consistent models (see Appendix E for cross-software comparison of results). As a result, uncertainties due to human errors and software are deemed to be low compared to most other LCA studies of clothing. Also the fact that the study is an update of a previous report (Roos et al. 2015), in which several errors were found and corrected (see Appendix A), has reduced these uncertainties.

A further limitation of the study is that some of the included impact categories are associated with large uncertainties, particularly land use impact and toxicity, for which results therefore were not fully shown (see previous discussion). Also, some impact categories were excluded, such as acidification which in Roos et al. (2015) was found to largely correlate with climate impact, and eutrophication for which the LCI data was deemed to be too uncertain. Pollution of oceans by microplastics was also excluded, due to a general lack of LCA methodology to cover this issue. The omission of part of the results of toxicity and land use impact, and the omission of some impact categories, were done to make all presentations and analyses of results meaningful – but some trade-offs between impact categories and life-cycle phases may thereby have been missed. Any future study of the environmental impacts of clothing should seek to include LCI data and LCIA methods that enable the study of further impact categories – but these should only be included if the results are sufficiently robust.

Another uncertainty of LCA concerns the choice of LCA methodology. Often the selection of allocation method is one critical such choice, where several, equally valid choices may be made. However, the allocation methods chosen for the present study (e.g., the credits given for heat and electricity produced in incineration processes, see Section 2.3.3) were shown not to influence overall results much.

Considering the aforementioned uncertainties, all results in the report should be seen as order-of-magnitude estimates.

5 summary of eight years of LCA work in Mistra Future Fashion

This chapter summarises 8 years of LCA work in Mistra Future Fashion on how to improve the sustainability performance of the textile industry. Each of our previously published LCA studies is briefly described, focussing on the main messages, and when feasible the results are discussed in relation to the impact of clothing consumption mapped in the present report.

The studies are sorted into sections reflecting different types of interventions and strategies for improving the environmental sustainability of clothing (although some studies relate to several of these): defining sustainability targets, design strategies, supply chain technologies and management, user behavior and business models, and textile recycling – the latter four correspond to the research themes of Mistra Future Fashion.
At the end, there is also a section outlining the work done in Mistra Future Fashion on social sustainability – primarily on the basis of working with Social LCA (SLCA), a method which builds on the traditional LCA method but instead focusses on issues of social sustainability – a topic of high concern for the fashion industry. At the Mistra Future Fashion website (www.mistrafuturefashion.com) there are also plenty of non-LCA studies available on how to make the textile industry more sustainable.

5.1 defining sustainability targets

LCA-based approach for measuring current status in relation to targets

LCA differs from many other environmental assessment methods in that it offers a quantitative evaluation. In contrast to simplified semi-quantitative methods, LCA results are directly proportional to the environmental impact. LCA results can thus be used to evaluate whether the effect of an action meant to reduce the environmental impact, an intervention, will be significant or insignificant compared to the total current impact. Roos et al. (2016) built on this strength of LCA and developed an approach for assessing the potential environmental benefits and downsides, at the level of an industry sector, of various interventions for impact reduction. This industry-sector approach consists of three steps addressing three questions:
1) What is the current sustainability performance of the sector?

2) What is an acceptable sustainability performance for the sector?

3) Are proposed interventions enough to reach an acceptable sustainability performance?

The approach was applied on the case of the Swedish clothing sector. The first question of the approach was addressed with the results of the previous version of the present report (Roos et al. 2015). For the second question, the planetary boundaries framework was used to define an acceptable environmental sustainability performance for the Swedish clothing sector, which translated to targets of impact reduction for several environmental impact categories. This procedure is further described in Sandin et al. (2015). The third question was addressed by evaluating ten interventions for impact reduction. Longer garment life lengths, renewable energy in production, replacement of conventional cotton, and better fuel economy had the highest potential to reduce climate impact and contributions to water depletion. For some categories, such as toxicity, the planetary boundaries framework does not (yet) provide any targets. (Social sustainability was also included in the case study, as is further described in Section 5.3.)

An important outcome of the study was that some interventions complement each other, which means that it is possible to work with longer garment life lengths, renewable energy, replacement of conventional cotton, fuel economy, and living wages, at the same time. Other interventions are competing, for example replacement of fossil polyester with bio-based or recycled feedstock, where only one of these interventions can be chosen for a specific material.

References for further reading:

Roos S, Zamani B, Sandin G, Peters GM, Svanström M, 2016. A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector. Journal of Cleaner Production, 133, 691–700.

Sandin G, Peters GM, Svanström M, 2015. Using the planetary boundaries framework for setting impact-reduction targets in LCA contexts. International Journal of Life Cycle Assessment 20, 1684–1700.

5.2 design strategies

LCA on fast and slow garment prototypes

Two overall, generic interventions in the current "fast fashion" business model are conceivable. One is to try and slow down fast fashion by various means, focussing on reducing consumption, reusing products and recycling them. This may be as much about influencing consumer behavior as any technical intervention. Another alternative is to focus less about how "fast" fashion is and instead focus on improving the processes within the fashion value chain. This means substituting suboptimal materials and processes for better ones throughout the life cycle. Peters et al. (2018) examined these two generic interventions using LCA.

In one scenario, a top was considered, and its life extended in extremis by a combination of sharing behaviours among family and friends, digital dye sublimation overprinting to update its appearance (and make it more valuable to its owners), and finally its incorporation as lining in an otherwise new jacket using laser technology. The original garment would today probably only be used about 20-30 times before disposal (22 times were assumed in the study, based on Roos et al. 2015), but in this scenario it was assumed to function as a garment or part of a garment for the extremely long life span of 30 years. The LCA demonstrated a large improvement of environmental performance over business-as-usual. The additional environmental burdens associated with transporting goods for recycling, and the use of overprinting and lasers, were outweighed by the avoidance of raw material, textile and garment production processes.

Other scenario modelling concerned the potential to make a top from a paper-based material instead of cotton. These paper materials have the benefit of being easier to recycle in existing recycling systems, but the principal benefit is that the production processes are in some ways less damaging to the environment than the use of conventional cotton. Paper garments are of course less durable, and the scenario modelling used a lifespan of two to five uses to illustrate the performance of these garments. The expectation of a shorter lifespan also allowed the garments to be designed lighter than conventional cotton garments, and this lighter weight also improved garment environmental performance so that it could outperform the conventional garment in cases when the latter is only used five times. However, interpretation of these LCA results is more complex than for the extended-life garment, because it relies on the assumption that users of the paper garments would not alternatively use conventional garments for their typical life span (here: 22 times) or longer. So exactly who uses a paper garment and whether they change their behavior (speed up their consumption) has the capacity to invert the relative environmental performance of the paper and conventional garments.

References for further reading:

Peters G, Sandin G, Spak B, Roos S, 2018. LCA on fast and slow garment prototypes. Mistra Future Fashion report number: 2018:06.

Goldsworthy K, Roos S, Sandin G, Peters G, 2016. Towards a Quantified Design Process: Bridging Design and Life Cycle Assessment. Proceedings from the Circular Transitions Conference Tate Britain & Chelsea College of Arts 23-24 November 2016, London, UK. http://ualresearchonline.arts.ac.uk/11635/1/CT_Quantified%20Design_Goldsworthy%20et%20al.pdf.

5.3 supply chain technologies and management

Environmental impact of textile fibres – w hat we know and what we don't know

Fibre production is responsible for about 16% of climate impact and 87% of water scarcity impact of Swedish clothing consumption (see Section 0). This means that improved production of conventional textile fibres as well as new and more sustainable fibres are important means for reducing the environmental impact of clothing. But what do we know about the environmental benefits and downsides of different fibre types? This question was addressed in Sandin et al. (2018), by a review of all publicly available data on the environmental impact of fibres, resulting in some main conclusions:

- There is a glaring lack of data on the environmental impact of fibres – for several fibres just a few studies were found, and often only one or a few environmental impacts are covered. For new fibres associated with sustainability claims there is seldom data available to support such claims.

- There are no "sustainable" or "unsustainable" fibre types – it is the suppliers that differ. The span within each fibre type (different suppliers) is often too large, in relation to differences between fibre types, to draw strong conclusions about differences between fibre types.

- It is essential to use the life-cycle perspective when comparing, promoting or selecting fibres. To achieve best environmental practice, apart from considering the impact of fibre production, one must consider the functional properties of a fibre and how it fits into an environmentally appropriate product life cycle, including the entire production chain, the use phase and the end-of-life management (i.e. its consequences for the life-cycle impact studied in the present study).

The report can hopefully contribute to a more nuanced discussion of textile fibres, and encourage and support the transition to better fibres in several ways: as input to broader studies including later life cycle stages of textile products (such as the present study), as a map over data gaps in relation to supporting claims on the environmental preferability of certain fibres over others, and as a basis for screening fibre alternatives, for example by designers and buyers.

Reference for further reading:

Sandin G, Roos S, Johansson M, 2019. Environmental impact of textile fibres – what we know and what we don't know. Fiber bible, part 2. Mistra Future Fashion report number 2019:03.

LCA on textile chemicals

Mistra Future Fashion has worked intensively to solve the problem of incomplete toxicity assessment in LCA studies of textile products. The emissions of toxic chemicals from textile production are an important environmental aspect for the textile industry, and hence it is important to include them in LCA studies of textile products.

The incompleteness is a consequence of the gaps in inventory data on the identity and quantities of chemicals that are used in textile processing, as also gaps in our ability to describe the health and environmental effects from toxicity of these chemicals in LCA tools. Therefore, a new framework was created (and applied in the present study). For 30 common textile processes, a complete LCI including textile chemicals was made, for which also LCA data on human and environmental toxicity was provided .

To simplify their use, the LCI datasets are based on modules in a generic chemical products inventory. The datasets can be used as they are for screening LCA studies or be modified based on new data on recipes of input chemicals, where the chemical product inventory provides LCA-compatible content and emission data for many common input chemicals. The datasets and the chemical product inventory can also be used as data collection templates in more detailed LCA studies.

The structure of the chemical product inventory is based on the function of each chemical, such as detergents, dyestuff and solvents. For each function, an inventory of BAT, average, and worst-case chemical products that provide this function is available. This enables comparison both of process parameters (e.g., dosing of chemicals or treatment of emissions) as well as comparison of different chemical products. Characterisation factors for toxicity were collected either from the USEtox database, the COSMEDE database, or calculated with the USEtox model – these are published in Roos et al. (2017).

References for further reading:

Roos S, Jönsson C, Posner S, Arvidsson R, Svanström M, 2018. An inventory framework for inclusion of textile chemicals in life cycle assessment. International Journal of Life Cycle Assessment, https://doi.org/10.1007/s11367-018-1537-6.

Roos S, Holmquist H, Jönsson C, Arvidsson R, 2017. USEtox characterisation factors for textile chemicals based on a transparent data source selection strategy. International Journal of Life Cycle Assessment 23(4), 890–903.

Roos S, 2016. Advancing life cycle assessment of textile products to include textile chemicals. Inventory data and toxicity impact assessment. PhD thesis, Chalmers University of Technology, Gothenburg, Sweden.

Reducing microplastics shedding

Micro-sized particles of plastic, so-called "microplastics", have become an environmental problem in marine and coastal waters. The oil-based microplastic particles attract contaminants that are normally not soluble in water. When the microplastics enter animals and plants in the aquatic environment, they bring contaminants with hazardous properties with them. Studies indicate that textiles might be an important source of microplastics.

A study was made on the relation between polyester fabric properties and microplastics shedding. Fabrics samples were collected from participating companies to be tested for microplastics shedding. In the absence of a standardised test method, the first part of the project consisted of developing a trustworthy method, based on Gyrowash.

The study showed no support for the assumption that fabrics made of recycled polymers shed more than fabrics made of virgin polymers. It might instead be assumed that the concern that recycled polyester sheds more than virgin polyester, is explained by the fact that fleece shed more than other polyester materials and traditionally fleece has been made from recycled polyester bottles – that is, the concern that recycled polymers are particularly prone to shedding is an example of misplaced causality.

Preliminary findings from the study are that the risk for microplastics shedding from garments is reduced if:

- brushing is reduced,
- ultrasound cutting is applied in the confectioning, and
- microparticles on fabrics are removed already at the production stage.

The literature provides some additional advice on fabric construction for reduced microplastics shedding: two studies point to that the shedding is less when yarn size is above the microfibre range.

Reference for further reading:

Roos S, Levenstam Arturin O, Hanning A-C, 2017. Microplastics shedding from polyester fabrics. Mistra Future Fashion report number 2017:1.

Sustainable production processes

Textile production processes, where fibres are turned into garments via yarn spinning, weaving/knitting, dyeing and finishing and finally confectioning, give rise to the majority of the environmental impacts of Swedish clothing consumption (see Section 0). Still, little attention is given to textile processing when means for reducing the environmental impact of clothing are discussed. Knowledge of textile production processes is sparse and there is even less known about the environmental benefits and downsides of different techniques from a life cycle perspective.

A review of publicly available data on the environmental impact of textile processing techniques was made with a special focus on emerging textile production techniques for wet processing. Since the field is vast, a selection was made based on potential for environmental impact reduction identified via a set of feasibility and sustainability criteria from Sandin et al. (2019).

The review shows that emerging water-less dyeing techniques such as dope dye (spin dye/ solution dye) and supercritical CO2 dyeing have a large potential for reducing climate, water and chemicals-related impacts. However, the analysis of the feasibility parameters, in particular the possible for upscaling, is dependent on fibre selection. These dyeing techniques are only applicable on synthetic fibres that are currently phased out in the sustainability work in some companies due to their fossil origin, which creates a situation of conflicting aims (phasing out fossil resources or reducing the climate, water and chemicals-related impacts of dyeing).

References for further reading:

Roos S, Rex D, 2019. Sustainable textile production processes. Mistra Future Fashion report series. To be published.

Johannesson C, 2016. Emerging Textile Production Technologies Sustainability and feasibility assessment and process LCA of supercritical CO2 dyeing. Master's thesis, Chalmers University of Technology, Gothenburg, Sweden.

5.4 user behavior and business models

Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion?

This study explored whether clothing libraries can reduce the environmental impact of clothing by increasing the number of uses per garment. The starting point of the study was the previous version of the present report (Roos et al. 2015) and its LCA of a T-shirt, a pair of jeans and a dress relying on a conventional linear business model and an average number of uses per garment. Key parameters in this LCA were varied to reflect potential clothing library setups: 2 or 4 times as many uses per garment; 11, 22 or 44 users per garment; a physical (offline) library or an online library; and different user transport. The scenarios did not reflect a specific clothing library, but a range of hypothetical clothing libraries – in order to identify key parameters influencing the environmental viability of clothing libraries in general.

For all garments, the results show potential benefits of clothing libraries when service lives are sufficiently prolonged. Benefits arise because of reduced production impact, as each garment's production burden is shared between more uses. The results also demonstrate a risk of problem shifting: the reduced production impact can be completely offset by the combination of more frequent user transportation and high-impact transportation (car driving and/or long distance). Potential environmental gains appear to be more likely for three of the studied impact categories: climate change, freshwater eutrophication and freshwater consumption, whereas there appears to be a higher risk of problem-shifting for freshwater toxicity (the toxicity results are, however, more uncertain).

The results highlight the need to account for logistics when implementing collaborative consumption business models – as increased transport made some impacts increase even when the clothing life length doubled – especially that stores and/or pickup-points are close to users or accessible by public transportation. The clothing library membership and payment system – such as the number of clothing pieces a user can borrow within a set time period and the length of that time period – was also identified as a key parameter, as it may influence the frequency of garment transactions and thus the frequency of user transportation. The results are expected to be valid also for the updated garment models of the present report, as the relative importance of the various life-cycle phases have not changed much since Roos et al. (2015).

Reference for further reading:

Zamani B, Sandin G, Peters G, 2017. Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion? Journal of Cleaner Production 162, 1368–1375.

5.5 textile recycling

Environmental impact of textile reuse and recycling – a review

Increased reuse and recycling are often framed as important solutions to the environmental challenges of the textile industry. This study explored to what extent this is true, by reviewing studies of the environmental impact of textile reuse and recycling. Forty-one studies were reviewed, whereof 85% deal with recycling and 41% with reuse (27% cover both reuse and recycling), including the study of clothing libraries summarised above. Figure 5.1 shows the reuse and recycling routes found in the review, illustrating the plethora of ways to utilise the textile after its first use cycle.

The reviewed publications provide strong support for claims that textile reuse and recycling in general reduce environmental impact compared to incineration and landfilling, and that reuse is more beneficial than recycling. But scenarios were found under which reuse and recycling are not beneficial for certain environmental impacts. For example, as benefits mainly arise when production of new products is avoided, there may not be benefits in cases of low replacement rates or if the avoided production processes are relatively clean. Also, for reuse, induced user transport may cause environmental impact that exceeds the benefits of avoided production, unless the use phase is sufficiently extended.

So how large are the potential benefits of reuse and recycling in relation to the life-cycle impact of clothing consumption? Variations between systems and knowledge gaps make it challenging to quantify such benefits. Estimates in the present report indicate benefits of 49% for climate impact and 48% for water scarcity impact if garments are used twice as long (see Section 1.20). For recycling, presuming a high replacement rate and an efficient recycling technology powered by renewables, the climate benefit could be up to a few kg CO2 equivalent per kg recycled material (Östlund et al. 2015) or roughly 10% of the climate impact of a typical garment life cycle according to the present study (see figure 5.1).

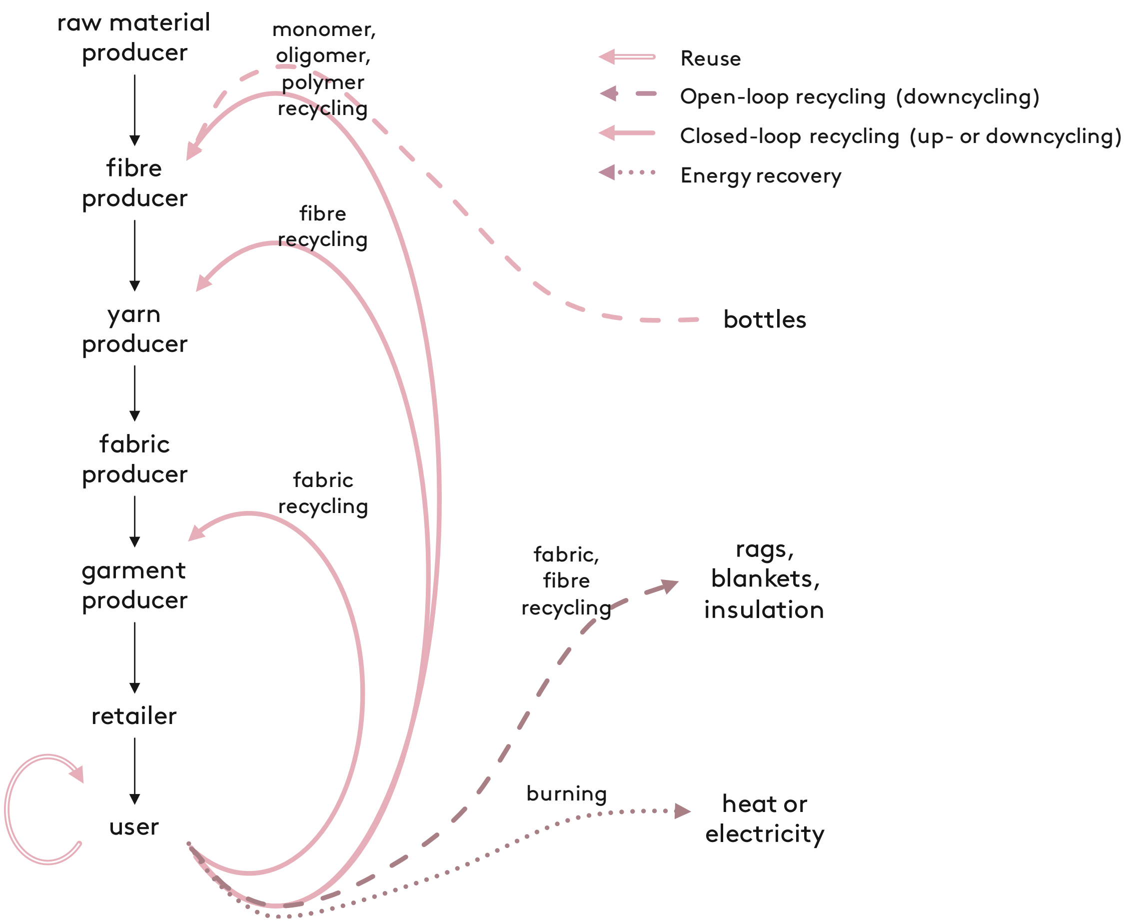


figure 5.1: A classification of textile reuse and recycling routes. Adapted from Sandin and Peters (2018).

For other environmental impacts driven by energy use, the potential benefits are in the same range. For water scarcity, for which cotton cultivation is the main contributor in the textile industry, the gains of recycling can be more than 90% assuming virgin cotton is replaced (see the water scarcity results for the cotton T-shirt, figure A 3).

Reference for further reading:

Sandin G, Peters GM, 2018. Environmental impact of textile reuse and recycling – a review. Journal of Cleaner Production 184, 353–365.

LCA on recycling of blended fibre fabrics

Landfilling and incineration are practical and common technologies for the management of textile waste today. From an environmental point of view there are two key issues with this status quo. One is the potential for emissions. To avoid the emission of contaminants to the air and groundwater, landfills require intergenerational management, which cannot be guaranteed. While incineration avoids this challenge, well-managed incinerators still emit petrochemical carbon dioxide on combustion of synthetic fibres. The other key issue is the lost potential to provide recycled materials as a feedstock to production of new textile products. To the extent that recycled materials can replace the production of raw materials, large environmental benefits are potentially available.

On the other hand, recycling textile waste is challenging due to the complexity of textile products. Not only do garments typically incorporate metallic and plastic components (e.g. zippers) but the very yarns themselves may be blends of several synthetic and natural polymers. Considerable effort is underway around the world to find ways to recycle blended fabrics. In Mistra Future Fashion, a process called Blend Re:wind has been developed (de la Motte & Palme 2018, Palme et al. 2017) based on alkaline dissolution of polyester, creating raw materials for the production of viscose (or other regenerated cellulose fibres) and for polyester. As is the case with all recycling initiatives, the question arises: does the process cause more impact than it prevents? To investigate this, this study used LCA to study a scenario in which Swedish health-care sector textile waste is diverted from commercial laundries and recycled with the Blend Re:wind process. The choice of this relatively small flow (850 tonnes per annum) was based on the reality that major upscaling to take in larger flows is predicated on the demonstration of operational feasibility at a smaller scale, and that the health care sector flows are a relatively homogenous, well-defined set of materials compared with national textile waste flows. Inventory data was only available for bench-scale batch processing, so assumptions had to be made to scale it up to this pilot-scale, using basic principles of chemical engineering, databases and dialogue with oil industry engineers, who operate some related large-scale equipment.

The outcome of this LCA is at face value an evenly balanced message, with some indicators favouring the recycling scenario and others favouring a baseline with single use of polyester and viscose fibres. However, the difference between the single use and recycling alternatives has a similar scale to the difference in performance among existing virgin viscose production facilities, suggesting that careful design can make Blend Re:wind superior to the alternatives in relation to most of the indicators (e.g. by selecting integrated viscose production facilities or other regenerated cellulosic fibres that have relatively low impacts during production). Moreover, since this is a comparison between a process existing only at bench scale (Blend Re:wind) and large scale industrial processes that have been subjected to worker-centuries of process optimisation studies (e.g. polyester production from petrochemical resources), it can be said that the future looks bright for Blend Re:wind.

References for further reading:

Peters G, Spak B, Sandin G, 2019. LCA on recycling of blended fibre fabrics. Mistra Future Fashion report series. To be published.

Peters G, Sandin G, Spak B, 2019. Environmental prospects for mixed textile recycling in Sweden. ACS Sustainable Chemistry and Engineering, https://pubs.acs.org/doi/10.1021/acssuschemeng.9b01742.

Design for circularity

The ambition to create a sustainable circular fashion industry involves several possibilities for making garments more circular. One option is to use bio-based fibres such as wool, cotton and viscose, in which the main feedstock is part of the natural carbon cycle if land is sustainably managed (however, if energy and chemical inputs are still of fossil origin, the fibres can hardly be called "circular"). There are also several market options for circularity such as second-hand retailers, mending services, redesigned products that recycle textile material on the level of garments or fabrics, etc. Garments can also be shredded and recycled into fibres and used for coarser fabrics or other products than textiles, e.g. insulation or composites. Finally, garments can be recycled back to textile fibres (synthetic or regenerated fibres) via chemical recycling. See figure 5.1 above for a summary of various options for circularity.

The communication about textile reuse and recycling is filled with myths, misunderstandings and conflicting messages. Misunderstandings arise mainly from mixing up what is possible today, what we see emerging in the near future, and what we hope for the more distant future. But textile reuse and recycling are also areas of conflicting targets: some are interested in recycling and reuse as a means for reducing the environmental and health impact of current clothing value chains, others may be more focussed on new ways of utilising the value of textile waste. The conflicting messages arise from these misinterpretations and conflicting targets or are sometimes myths resulting from excessively opportunistic marketing claims in a time when the circular economy is seen as the key for reaching a sustainable future.

Roos et al. (2019a) provides guidance on design for recycling to clothing companies. It is an overview of currently existing recycling possibilities for different materials, which can be used as a tool for designing garments and selecting fabric construction for better recyclability. The report also provides the broad picture of textile recycling, the development of new recycling techniques and how environmental benefits can be achieved.

Reference for further reading:

Roos S, Sandin G, Peters G, Spak B, Schwarz Boer L, Perzon E, Jönsson C, 2019. Guidance for fashion companies on design for recycling (Design for circularity). Mistra Future Fashion report series. To be published.

5.6 social sustainability

Towards identification and assessment of social impacts of the textile industry

Textile supply chains are typically a complicated network of suppliers and subcontractors, and production is most often located far from end markets. A consequence of globalisation has been social issues such as forced labour, child labour, low wages and insufficient workplace safety. The complexity of textile supply chains makes it difficult for clothing importers to track where and under which conditions garments are produced.

The SLCA work in Mistra Future Fashion aimed to identify and assess the social challenges of the textile industry, and to assess the potential of interventions in relation to achieving social sustainability targets.

A survey was conducted to identify priorities for social issues among end users and industry experts and to explore similarities and differences between them. The results show that the top ten prioritised indicators for both users and industry experts relate to employee health and safety, child labour, fair salary, employment security, avoidance of discrimination, and fair competition. Users were also highly concerned about the provision of social benefits for employees and about corporate commitment to human rights.

A SLCA with data from the social hotspots database (SHDB 2019) was carried out to identify the social hotspots of textile imports to Sweden. The results suggest that significant social risks mainly relate to wage levels, child labor and exposure to carcinogens at the workplace. The risk-level intensity was highest for indicators of low wages. The SLCA also identified industrial sectors of concern. In addition to some of the main sectors of the production system itself, some unexpected sectors of the background/ supporting systems were identified as important hotspots, such as commerce and business services.

Currently there is an absence of models for impact pathways that reflect actual damages or benefits of company-level activities on social end-points further down the cause-effect chain, such as human well-being or staff turnover rate. SLCA work in Mistra Future Fashion has therefore been unable to assess the impact of company-level interventions. Relevant social cause-effect chains must be developed to enable the measurement of social benefits caused by interventions. This would help in assessing and guiding companies' work towards achieving social sustainability targets.

References for further reading:

Zamani B, 2016. The challenges of fast fashion - environmental and social LCA of Swedish clothing consumption. PhD thesis, Chalmers University of Technology, Gothenburg, Sweden.

Roos S, Zamani B, Sandin G, Peters GM, Svanström M, 2016. A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector. Journal of Cleaner Production, 133, 691–700.

Roos S, Sandin G, Zamani B, Peters G, Svanström M, 2017. Will clothing be sustainable? Clarifying sustainable fashion. In: Muthu SS (ed.), 2017. Handbook of Textiles and Clothing Sustainability. Springer.

Zamani B, Sandin G, Svanström M, Peters GM, 2018. Hotspot identification in the clothing industry using social life cycle assessment – opportunities and challenges of input-output modelling. International Journal of Life Cycle Assessment 23(3), 536–546.

6 conclusions and recommendations

The aim of the present report was to map and understand the current environmental impact of Swedish clothing consumption. This was done by evaluating the environmental impact of six garments by means of LCA, using indicators of climate impact, energy use, water scarcity, land use impact, freshwater ecotoxicity, and human toxicity, and then scaling up the results to represent the Swedish national clothing consumption over one year. Due to uncertainties, results should be considered order-of-magnitude estimates. The main conclusions follow below, along with recommendations regarding what producers, retailers, policy makers and end users can to do reduce the environmental impact of clothing. This is just a brief overview of what different actors can do, further recommendations are provided in the summaries of previous LCA work in Mistra Future Fashion (Chapter 5) and in other reports available at www.mistrafuturefashion.com.

6.1 hotspots of the environmental impact of Swedish clothing

Environmental impacts of clothing arise mainly in the production phase. Most production processes are important in terms of climate, energy and toxic impacts, whereas fibre production (specifically cotton cultivation) dominates water scarcity impacts. Particular culprits regarding energy use and climate impacts are the electricity used for weaving and the confectioning of complex garments such as jackets, and the heating of water for wet treatment processes. Also the use-phase matters, mainly the transport back and forth from the store but also laundry. The latter was, however, found to be of a minor contribution climate-wise, which contrasts with other studies (in a scenario in which the European electricity mix was assumed to power the laundry processes, the importance of laundry increased).

In total, the carbon footprint of Swedish clothing consumption was found to be about 330 kg CO2 eq. per person and the annual water use amounted to 610 scarcity-weighted cubic metres per person.

6.2 interventions for reducing impact

Several interventions for reducing the environmental impact of clothing were explored, in isolation and in combination. Longer use of garments was found to be a very effective intervention – twice as many uses per garment life-cycle eliminated almost 50% of impact regardless of impact category. Solar-powered production reduces climate impact by between 27% and 44%, depending on garment, and walking to the store instead of taking a car determines roughly 12-24% of climate impact. In contrast, lowering the washing temperature had negligible influence on results when average Swedish electricity is used. Replacing cotton with, for instance, forest-based fibres such as viscose and lyocell can reduce the water scarcity impact of a cotton garment with about 90%. Selecting less toxic chemicals in textile processes can reduce toxicity impacts by several orders of magnitude, while improved process conditions such as reduced consumption of chemicals or better waste water treatment translate to much lower toxicity impact reductions, although still important.

6.3 recommendations for actions

Below follow the most important recommendations based on the results of this report directed towards different actors: producers, retailers, policy makers and users. The effects of some of the actions are additive and all actors can contribute to a lower environmental burden. For example, using renewable energy is possible for each actor in the value chain, without reducing the room for improvement for other actors. Some actions have an overlapping effect. An example of this is the user transport back and forth from the store, where the gains of a policy reducing the transport by car to shopping malls overlap with the gains of users reducing their own transportation (regardless of policy). More detailed advice on actions for reducing the environmental impact of textile production is found in Roos et al. (2019b).

6.3.1 producers

As impacts mainly arise during production, producers can implement actions that directly translate to environmental gains. Key such measures include:

- Use renewable energy, for both electricity and heat.
- Eliminate toxic chemicals, adopt state-of-the-art chemical management systems and waste water treatment systems.
- For producers of natural fibres: adopt best available land and water management practices.
- For producers which are also buyers of fibres, yarns or fabrics: purchase products which are best in class environmentally. Especially for fibres, there are tremendous differences between producers (Sandin et al. 2019).
- Contribute to supply chain traceability that allows subsequent actors to act sustainable, by measuring/collecting and communicating transparent data on chemical use, energy use, emissions to air, water and soil, etc.

6.3.2 retailers

- Source garments from producers that adopt the above recommended actions.
- Demand and assist the implementation of traceability and transparency initiatives throughout the entire production chain, from fibre to garment.
- Facilitate and promote sustainable behavior among users, most importantly in terms of prolonging the use of each purchased garment but also in terms of how the user travels to store. Prolonged service life can be encouraged by timeless design, sufficient technical quality for intended use, mending services, and business models for collaborative consumption. Sustainable user travels can, for example, be encouraged by the site selection of the store (downtown stores, and possibly internet stores, are preferable over suburban shopping malls).

6.3.3 policy makers

- Use policy tools to steer and promote cleaner production. Examples are prohibition of harmful chemicals, environmental taxes, subsidies, research funding, support and demand the build-up of an infrastructure for systems of traceability and transparency along the clothing supply chain. It is important to base any policy on the best available knowledge.
- Use policy tools to steer and promote better user behavior, in terms of using clothes longer (e.g. tax deduction for mending services) and the availability of public transport and cycleways.
- Utilise the possibility of making demands in public procurement to encourage cleaner production and transparency in the supply chain.

6.3.4 users

- Use and take care of garments already in the wardrobe, for example by mending.
- When buying a garment, consider buying second hand, renting or borrowing. To rent or borrow is particularly important for clothing expected to be used only one or a few times, such as special-occasion dresses and suits.
- Walk, bicycle or take public transportation to the store.
- Exert consumer pressure on retailers. For example, ask where clothing is produced and under what conditions, ask for the content of hazardous data and the environmental impacts of clothing (e.g. data backing up various sustainability claims), choose retailers based on what answers they provide (or don't provide), etc.

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8. Abbreviations

Abbreviations	Definition
AWARE	AVailable Water REmaining (characterisation method for water scarcity in LCA)
BAT	Best available technology
BREF	BAT reference document from the European IPPC Bureau
CED	Cumulative energy demand
CH	CH is found in the names of data from the Ecoinvent database in the report where CH denotes a process relevant at the Swiss level. Nomenclature from Eurostat.
CN (1)	Combined nomenclature.
CN (2)	CN is found in the names of data from the Ecoinvent database in the report where CN denotes a process relevant at the Chinese level. Nomenclature from Eurostat.
CO2	Carbon dioxide
CTUe	Comparative toxic unit for ecosystem
CTUh	Comparative toxic unit for human
DMAC	Dimethyl acetamide
DMT	Dimethyl terephthalate
Dtex	Decitex = mass in grams per 10,000 meters. This is a common measure for the width of textile yarns.
DTY	Drawn and texturized yarn
DWR	Durable water repellent

EoL	End-of-life (the last phase in the garment life cycle)
EG	Ethylene glycol
FDY	Fully drawn yarn (FDY)
GLO	GLO is found in the names of data from the Ecoinvent database in the report where GLO denotes a globally relevant process. Nomenclature from Eurostat.
GWP	Global warming potential (characterisation method for climate change in LCA)
ILCD	International reference life cycle data system
IPCC	Intergovernmental panel for climate change
IPPC	Integrated pollution prevention and control
ISO	International organization for standardization
LANCA	LANd use indicator CAlculation tool (characterisation method for land use impact in LCA)
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NOEC	No-observed effect concentration
Polyacrylic acid	PAA
PA	Polyamide
PAF	Potentially affected fraction of species

PED	Primary energy demand
PEFCR	Product environmental footprint category rules
PES	Polyester
PET	Polyethylene terephthalate, one of the possible polymer bases for polyester materials
POY	Partially oriented yarn
PU	Polyurethane
RER	RER is found in the names of data from the Ecoinvent database in the report where RER denotes a process relevant at the European level. Nomenclature from Eurostat.
RME	Rapeseed methyl ester
RoW	RoW is found in the names of data from the Ecoinvent database in the report where RoW denotes a process relevant at the Rest-of-the-World level. Nomenclature from Eurostat.
SLCA	Social life cycle assessment
SE	SE is found in the names of data from the Ecoinvent database in the report where SE denotes a process relevant at the Swedish level[a]. Nomenclature from Eurostat.
SQI	Soil quality indicator
USEtox	Characterisation method for toxicity in LCA

[a] Also other country/regional level abbreviations occur from Eurostat.

Appendix A. **Change log**

Table A-1: Change log between the present report and a previous version of the report (Roos et al. 2015). Main changes are included.

Subject of change	Roos et al. (2015)	The present report
Set of impact categories and characterisation methods	Climate change, acidification, freshwater eutrophication, human toxicity (carcinogenic and non-carcinogenic) and freshwater ecotoxicity (USEtox 1.0), photochemical ozone formation, agricultural land occupation, freshwater consumption (Swiss Ecoscarcity model), energy resources (non-renewables)	Climate change, freshwater ecotoxicity, human toxicity (carcinogenic and non-carcinogenic) and freshwater ecotoxicity (USEtox 2.02), land use impact (LANCA), freshwater depletion (AWARE), energy resources (renewables and non-renewables)
Use of software	T-shirt, jeans and dress were modelled in Gabi, jacket and hospital uniform were modelled in Simapro.	All garments were modelled in both Gabi and Simapro (although not all impact categories were characterised in both software packages, see Section 2.3.5).
Number of modelled garments	Five garments	Six garments (the pair of socks were added)
Modelling of hospital uniform	Reflecting a garment from a specific supplier, based on Roos (2012)	Reflecting a generic garment
Statistics behind national-level scale up	Based on year 2012	Based on year 2017
Import/export statistics behind use phase modelling (e.g. number of uses per garment)	Based on year 2008	Based on year 2017
Import statistics behind electricity mix modelling	Based on three countries dominating direct imports in year 2012	Based on seven countries dominating direct and indirect imports in year 2013-2017
Data on electricity use, heat use, chemicals use, sewing time, material losses, etc., in production	Use of older references	All data choices and pertinent assumptions were revised. In general, use of more updated references, e.g. van der Velden (2014).
Datasets on background processes	Use of the Ecoinvent 2 database, and use of production datasets (e.g. excluding transports to suppliers)	Use of the Ecoinvent 3.5 database, and use of market datasets (e.g. including transports to suppliers)
Datasets on transportation	Use of the Ecoinvent 2 database, and use of production datasets, less modern transportation (e.g. EURO 3 trucks in Asia, EURO 5 trucks in Sweden)	Use of the Ecoinvent 3.5 database, use of market datasets, more modern transportation (e.g. EURO 4 trucks in Asia, EURO 6 trucks in Sweden)
Dataset on detergent	Modified version of data from Saouter & van Hoof (2002)	Data from AISE (2016), a PEFCR dataset
Datasets on textile incineration	Modified version of dataset from the ELCD database, implemented in the Gabi Professional database, on waste incineration of textile fraction is municipal solid waste in EU-27	Ecoinvent 3.5 datasets (choice depending on textile content, see Appendix B, Section 0)

Modelling of water scarcity impact	Omission of water losses in some processes, e.g. in laundry	More emphasis has been made on estimating water losses in processes and connecting each water flow to regionalised characterisation factors
Wet treatment ecotoxicity	An own chapter due to immature methodology	Included in the normal LCIA
Restructuring of report	-	Among others, introduction, method, modelling and results chapters restructured; other interventions for impact reduction evaluated in results chapters, additional interventions summarised in separate chapter (based on previous LCA reports in Mistra Future Fashion); reorganisation and reformatting of appendices
Correction of errors	Among others, wrong quantities of chemicals inputs to elastane fibre production; wrong share (4%) of elastane in denim yarn; discrepancies between data/assumptions stated in the main text and the appendices; an error in the scaling up of the results of the dress which significantly overestimated the national-level contribution of the use-phase transport; an error when calculating the number of dresses purchased per year	Among others, correct quantities of chemical inputs to elastane fibre production, correct share (7%) of elastane in denim yarn; consistent data/assumptions stated in the main text and in the appendices; correct scaling up of the results of the dress; correct number of uses per dress

Appendix B. **Modelling details**

Overview of all life-cycle phases

Table B-1: Contributing processes for each of the six modelled garments, per kg garment in the use phase.

Process	Quantity per kg of garment (kg)					
	T-shirt	Jeans	Dress	Jacket	Socks	Hospital uniform
Production phase						
Cotton fibre production	1.356	1.308	-	0.211	-	0.711
Polyester fibre production	-	-	1.244	0.413	-	0.711
Polyamide fibre production	-	-	-	0.484	0.278	-
Elastane fibre production	-	0.026	-	0.023	0.010	-
Viscose fibre production	-	-	-	-	0.742	-
Yarn production	1.206	1.335	1.238	0.859	1.025	1.266
Fabric production – knitting	1.188	-	0.584	0.205	1.010	-
Fabric production – weaving	-	1.172	0.637	0.643	-	1.250
Fabric production – nonwoven process	-	-	-	0.242	-	-
Wet treatment[22]	1.188	1.335	1.238	1.090	1.025	1.250
Confectioning	1.010	1.010	1.010	1.010	(part of fabric production)	1.000
Distribution & retail phase						
T-shirt, jeans, dress, jacket and socks, distribution and retail	1.01	1.01	1.01	1.01	1.01	-
Hospital uniform, distribution	-	-	-	-	-	1.00
Use phase						
Use of T-shirt	1.00	-	-	-	-	-
Use of jeans	-	1.00	-	-	-	-
Use of dress	-	-	1.00	-	-	-
Use of jacket	-	-	-	1.00	-	-
Use of socks	-	-	-	-	1.00	-
Use of hospital uniform	-	-	-	-	-	1.00
Detergent production/kg wash	0.0158	0.0158	0.0158	0.0158	0.0158	0.009
Residential washing/kg wash	1.00	1.00	1.00	1.00	1.00	-
Residential drying (% of washing cycles)	34%	29%	19%	21%	58%	-
Residential ironing (% of washing cycles)	15%	15%	18%	5%	1%	-
Industrial laundry	-	-	-	-	-	1.00
End-of-life phase						
Incineration with energy recovery	1.00	1.00	1.00	1.00	1.00	1.00

[22] Wet treatment in the production of jeans and socks is made on yarn prior to fabric production.

Production phase

Electricity mix in production

Based on the respective countries' share of the seven biggest contributors to Swedish clothing imports in 2013-2017: China, Bangladesh, Turkey, India, Pakistan, Vietnam and Cambodia (Statistics Sweden 2019a, Eurostat 2019), a production country electricity mix was created and used for all production processes except where a certain production country dominates production (e.g., melt spinning of polyester and polyamide 6 fibres and dry spinning of elastane fibres were all assumed to be situated in China, hence the Chinese electricity mix was assumed). See further details in Section 3.4.1.

Table B-2: Production country electricity mix.

Inputs	Dataset used in model	Share of electricity mix
Electricity mix China	CN: market group for electricity, medium voltage (EI3.5)	55.8%
Electricity mix Bangladesh	BD: market for electricity, medium voltage (EI3.5)	17.8%
Electricity mix Turkey	TR: market for electricity, medium voltage (EI3.5)	12.6%
Electricity mix India	IN: market group for electricity, medium voltage (EI3.5)	6.1%
Electricity mix Pakistan	PK: market for electricity, medium voltage (EI3.5)	3.0%
Electricity mix Vietnam	VN: market for electricity, medium voltage (EI3.5)	2.6%
Electricity mix Cambodia	KH: market for electricity, medium voltage (EI3.5)	2.1%

Production of chemical products used in production

Chemical products in Table B-3 were modelled after Roos et al. (2018). Ecoinvent 3.5 datasets were used for other chemical products used in production, see respective tables in subsections below.

Table B-3: Chemical products used in production.

***Chemical product*/datasets used in model**	**Quantity**	**Unit**
Antifoaming agent, average		
GLO: market for benzo[thia]diazole-compound (EI3.5)	0.02	kg
GLO: market for polydimethylsiloxane (EI3.5)	0.05	kg
RoW: dimethyl sulfate production (EI3.5)	0.001	kg
GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.02	kg
GLO: market for water, ultrapure (EI3.5)	0.94	kg
Detergent, average		
RoW: market for acrylic acid (EI3.5)	0.1	kg
RoW: market for dimethyl sulfate (EI3.5)	0.05	kg
RoW: market for ethoxylated alcohol (AE3) (EI3.5)	0.25	kg
RoW: market for ethoxylated alcohol (AE7) (EI3.5)	0.1	kg
GLO: market for water, ultrapure (EI3.5)	0.5	kg
Detergent/wetting agent, average		
RoW: market for ethoxylated alcohol (AE7) (EI3.5)	0.2	kg
GLO: market for maleic anhydride (EI3.5)	0.1	kg
GLO: market for water, ultrapure (EI3.5)	0.7	kg
Lubricant, average		
RoW: market for acrylic acid (EI3.5)	0.1	kg
GLO: market for polyacrylamide (EI3.5)	0.2	kg
GLO: market for water, ultrapure (EI3.5)	0.7	kg

Peroxide stabilizer		
RoW: market for acrylic acid (EI3.5)	0.1	kg
GLO: market for magnesium oxide (EI3.5)	0.005	kg
GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.1	kg
GLO: market for water, ultrapure (EI3.5)	0.795	
Reducing agent VAT, average		
RoW: market for calcium carbonate, precipitated (EI3.5)	0.02	kg
RoW: market for sodium dithionite, anhydrous (EI3.5)	0.9	kg
RoW: market for sodium sulfite (EI3.5)5	0.08	kg
Softener, average		
GLO: market for diethanolamine (EI3.5)5	0.03	kg
GLO: market for stearic acid (EI3.5)	0.2	kg
GLO: market for water, ultrapure (EI3.5)	0.77	kg
Wetting agent for better printability		
GLO: market for 2-methyl-1-butanol (EI3.5)	0.15	kg
GLO: market for 2-methylpentane (EI3.5)	0.1	kg
RoW: market for ethoxylated alcohol (AE7) (EI3.5)	0.75	kg
Wetting/penetrating agent, cellulosic		
GLO: market for 3-methyl-1-butanol (EI3.5)	0.2	kg
GLO: market for alkylbenzene sulfonate, linear, petrochemical	0.6	kg
GLO: market for ethoxylated alcohol (AE11) (EI3.5)	0.1	kg
GLO: market for water, ultrapure (EI3.5)	0.1	kg
Wetting/penetrating agent, synthetic		
GLO: market for fatty alcohol (EI3.5)	0.5	kg
GLO: market for maleic anhydride (EI3.5)	0.15	kg
GLO: market for water, ultrapure (EI3.5)	0.35	kg

Treatment of textile waste in production phase

Table B-4: Treatment of textile waste in production (no credit for energy recovery).

Waste fraction	Dataset used in model
Cotton, viscose	RoW: treatment of waste paperboard, municipal incineration (EI3.5)
Polyester	RoW: treatment of waste polyethylene terephthalate, municipal incineration (EI3.5)
Polyamide 6, elastane	RoW: treatment of waste polyurethane, municipal incineration (EI3.5)

Fibre production

Cotton fibre production was modelled with datasets originally from Cotton Inc (2016). For impact categories of climate change and energy use, we used the Cotton Inc data as implemented in the Gabi Professional database (GLO: Cotton fiber (bales after ginning)), and for other impact categories we used the Cotton Inc data as implemented in the (EI3.5) database (GLO: market for cotton fibre). The Ecoinvent dataset was not used to calculate climate change and energy use results due to a suspected error in its energy data (the climate impact result generated with the Ecoinvent dataset differs considerably from that of the Cotton Inc (2016) report and that generated by using the Gabi Professional dataset).

Viscose fibre production was modelled with a (EI3.5) market dataset on viscose production (GLO: market for viscose fibre).

Table B-5: Model of melt spinning of polyester fibres.

Inputs	Dataset used in model	Quantity	Unit
Polyester	GLO: market for polyethylene terephthalate, granulate, amorphous	1.0	kg
Lubricating oil	RoW: market for lubricating oil (EI3.5)	0.01	kg
Antimony	GLO: market for antimony (EI3.5)	0.0002	kg
Toluene diisocyanate	RoW: market for toluene diisocyanate (EI3.5)	0.0002	kg
Electricity	CN: market group for electricity, medium voltage (EI3.5)	1.5	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	2.2	MJ
Outputs			
PES fibres	(to yarn production /nonwoven production)	1.0	kg
Terephtalate, dimethyl	(emission to air)	0.00001	kg

Table B-6: Model of melt spinning of polyamide fibres.

Inputs	Dataset used in model	Quantity	Unit
Polyamide 6	GLO: market for polyethylene terephthalate, granulate, amorphous	1.0	kg
Lubricating oil	RoW: market for lubricating oil (EI3.5)	0.01	kg
Sodium formate	GLO: sodium formate production (EI3.5)	0.001	kg
Toluene diisocyanate	RoW: market for toluene diisocyanate (EI3.5)	0.0002	kg
Electricity	CN: market group for electricity, medium voltage (EI3.5)	1.5	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	2.2	MJ
Outputs			
Polyamide 6 fibres	(to yarn production)	1.0	kg
Caprolactam	(emission to air)	0.00001	kg

Table B-7: Model of dry spinning of elastane fibres.

Inputs	Dataset used in model	Quantity	Unit
Polyurethane	RoW: market for polyurethane, flexible foam (EI3.5)	1.0	kg
Lubricating oil	RoW: market for lubricating oil (EI3.5)	0.06	kg
Dimethylacetamide	GLO: market for dimethylacetamide (EI3.5)	0.02	kg
Electricity	CN: market group for electricity, medium voltage (EI3.5)	1.5	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	2.2	MJ
Outputs			
Elastane fibres	(to yarn production)	1.0	kg
Air emissions from 1 kg Dimethylacetamide	(emission to air)	0.002	kg

Yarn production

Table B-8: Yarn spinning to cotton yarn for T-shirt, 169 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton fibres	(see description above)	1.1236	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	4	kWh
Outputs			
Cotton yarn 169 dtex	(to knitting)	1.0	kg

Inputs	Dataset used in model	Quantity	Unit
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.1236	kg

Table B-9: Yarn spinning to cotton and elastane yarn for jeans, 470 dtex

Inputs	Dataset used in model	Quantity	Unit
Cotton fibres	(see description above)	1.0449	kg
Elastane fibres	(see description above)	0.07865	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	2	kWh
Outputs			
Cotton/elastane yarn 578 dtex	(to bleaching)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.1236	kg

Table B-10: Yarn spinning to cotton yarn for jeans, 578 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton fibres	(see description above)	1.1236	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	2	kWh
Outputs			
Cotton yarn 578 dtex	(to dyeing)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.1236	kg

Table B-11: Yarn spinning to polyester staple yarn for dress, 114/119 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES fibres	(see description above)	1.005	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	3.8	kWh
Outputs			
PES yarn 114/119 dtex	(to weaving/knitting)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Polyester waste	(to incineration without energy recovery)	0.005	kg

Table B-12: Yarn spinning to polyester staple yarn for jacket lining, 70 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES fibres	(see description above)	1.005	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	4	kWh
Outputs			
PES yarn 70 dtex	(to weaving)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Polyester waste	(to incineration without energy recovery)	0.005	kg

Table B-13: Yarn spinning to cotton/elastane yarn for jacket gussets, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton fibres	(see description above)	1.0146	kg
Elastane fibres	(see description above)	0.1090	kg

Inputs	Dataset used in model	Quantity	Unit
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	3.3	kWh
Outputs			
Cotton/elastane yarn 300 dtex	(to knitting)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.005	kg

Table B-14: Yarn spinning to polyamide staple yarn for jacket, 90 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyamide fibres	(see description above)	1.005	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	1.5	kWh
Outputs			
Polyamide yarn 90 dtex	(to weaving)	1.0	kg
Air emissions from use of lubricant, average	(emission to air)	0.0016	kg
Polyamide waste	(to incineration without energy recovery)	0.005	kg

Table B-15: Yarn spinning to polyamide staple yarn for jacket, 200 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyamide fibres	(see description above)	1.005	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	0.75	kWh
Outputs			
Polyamide yarn 200 dtex	(to weaving)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Polyamide waste	(to incineration without energy recovery)	0.005	kg

Table B-16: Yarn spinning to viscose/polyamide/elastane yarn for socks, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Viscose fibres	(see description above)	0.724	kg
Polyamide fibres	(see description above)	0.272	
Elastane fibres	(see description above)	0.010	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	3.3	kWh
Outputs			
Viscose/polyamide/elastane yarn 300 dtex	(to dyeing)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.0036	kg
Polyamide/polyurethane waste	(to incineration without energy recovery)	0.0014	kg

Table B-17: Yarn spinning to cotton/polyester staple yarn for hospital uniform, 200 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton fibres	(see description above)	0.5618	kg
PES fibres	(see description above)	0.5618	kg
Lubricant, average	(see description above)	0.0016	kg
Electricity	Production country mix (see description above)	3.8	kWh
Outputs			

Inputs	Dataset used in model	Quantity	Unit
Cotton/PES yarn 200 dtex	(to weaving)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.0016	kg
Cotton waste	(to incineration without energy recovery)	0.06180	kg
Polyester waste	(to incineration without energy recovery)	0.06180	kg

Fabric production

Table B-18: Circular knitting to cotton tricot for T-shirt, 169 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton yarn 169 dtex	(see description above)	1.0152	kg
Lubricant, average	(see description above)	0.08	kg
Electricity	Production country mix (see description above)	0.21	kWh
Outputs			
Cotton tricot 169 dtex	(to bleaching)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.08	kg
Cotton waste	(to incineration without energy recovery)	0.0152	kg

Table B-19: Circular knitting to polyester tricot for dress, 114 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES yarn 114 dtex	(see description above)	1.0152	kg
Lubricant, average	(see description above)	0.08	kg
Electricity	Production country mix (see description above)	0.33	kWh
Outputs			
Polyester tricot 114 dtex	(to dyeing)	1.0	kg
Air emissions from 1 kg lubricant, average	(emission to air)	0.08	kg
Polyester waste	(to incineration without energy recovery)	0.0152	kg

Table B-20: Circular knitting to cotton/elastane tricot for jeans, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton/elastane yarn 300 dtex	(see description above)	1.0152	kg
Lubricant, average	(see description above)	0.08	kg
Electricity	Production country mix (see description above)	0.13	kWh
Outputs			
Cotton/elastane tricot 300 dtex	(to dyeing)	1.0	kg
Air emissions from use of lubricant, average	(emission to air)	0.08	kg
Cotton waste	(to incineration without energy recovery)	0.0108	kg
Polyurethane waste	(to incineration without energy recovery)	0.0042	kg

Table B-21: Fully-fashioned knitting for socks, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Viscose/polyamide/elastane yarn 300 dtex	(see description above)	1.0152	kg
Lubricant, average	(see description above)	0.08	kg
Electricity	Production country mix (see description above)	4.15	kWh
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg

Inputs	Dataset used in model	Quantity	Unit
Outputs			
Viscose/polyamide/elastane socks 300 dtex	(to distribution & retail)	1.0	kg
Air emissions from use of lubricant, average	(emission to air)	0.08	kg
Viscose waste	(to incineration without energy recovery)	0.0108	kg
Polyamide/elastane waste	(to incineration without energy recovery)	0.0042	kg

Table B-22: Weaving to cotton/elastane for jeans, 470/578 dtex.

Inputs	Dataset used in model	Quantity	Unit
Bleached cotton/elastane yarn 470 dtex	(see description below)	0.3293	kg
Dyed cotton yarn 578 dtex	(see description below)	0.6839	kg
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg
Electricity	Production country mix	2.4	kWh
Outputs			
Cotton/ denim weave 470/578 dtex	(to confectioning)	1.0	kg
Air emissions from 1 kg acrylic acid, average	(emission to air)	0.05	kg
Water emissions from 1 kg acrylic acid, average	(emission to water)	0.05	kg
Cotton waste	(to incineration without energy recovery)	0.0132	kg

Table B-23: Weaving to polyester weave for dress, 119/114 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES yarn 119/114 dtex	(see description above)	1.0132	kg
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg
Electricity	Production country mix (see description above)	8.3	kWh
Outputs			
Polyester weave 119/114 dtex	(to pre-treatment)	1.0	kg
Air emissions from 1 kg acrylic acid, average	(emission to air)	0.05	kg
Water emissions from 1 kg acrylic acid, average	(emission to water)	0.05	kg
Polyester waste	(to incineration without energy recovery)	0.0132	kg

Table B-24: Weaving to polyester weave for jacket, 70 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES yarn 70 dtex	(see description above)	1.0132	kg
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg
Electricity	Production country mix (see description above)	19.5	kWh
Outputs			
Polyester weave 70 dtex	(to dyeing)	1.0	kg
Air emissions from 1 kg acrylic acid, average	(emission to air)	0.05	kg
Water emissions from 1 kg acrylic acid, average	(emission to water)	0.05	kg
Polyester waste	(to incineration without energy recovery)	0.0132	kg

Table B-25: Weaving to polyamide weave for jacket 90/200, dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyamide yarn 90 dtex	(see description above)	1.0066	kg
Polyamide yarn 200 dtex	(see description above)	1.0066	kg
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg

Inputs	Dataset used in model	Quantity	Unit
Electricity	Production country mix (see description above)	5.1	kWh
Outputs			
Polyamide weave 90/200 dtex	(to dyeing)	1.0	kg
Air emissions from 1 kg acrylic acid, average	(emission to air)	0.05	kg
Water emissions from 1 kg acrylic acid, average	(emission to water)	0.05	kg
Polyamide waste	(to incineration without energy recovery)	0.0132	kg

Table B-26: Weaving to cotton/polyester weave for hospital uniform, 200 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton/PES yarn 200 dtex	(see description above)	1.0132	kg
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg
Electricity	Production country mix (see description above)	6.8	kWh
Outputs			
Cotton/polyester weave 200 dtex	(to dyeing)	1.0	kg
Cotton waste	(to incineration without energy recovery	0.0066	kg
Air emissions from 1 kg acrylic acid, average	(emission to air)	0.05	kg
Water emissions from 1 kg acrylic acid, average	(emission to water)	0.05	kg
Polyester waste	(to incineration without energy recovery)	0.0066	kg

Table B-27: Production of polyester needle-punched nonwoven for jacket, 200 dtex.

Inputs	Dataset used in model	Quantity	Unit
PES fibres	(see description above)	1.0	kg
Electricity	Production country mix (see description above)	6.8	kWh
Outputs			
Cotton/polyester weave 200 dtex	(to dyeing)	1.0	kg

Wet treatment

Table B-28: Bleaching cotton tricot for T-shirt, 169 dtex.

Inputs	Dataset used in model	Quantity	Unit
Water, river	(Resource flow)	0.06	m^3
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.05	kg
Fluorescent whitening agent	GLO: market for fluorescent whitening agent, distyrylbiphenyl type (EI3.5)	0.06	kg
Formic acid	RoW: market for formic acid (EI3.5)	0.01	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.07	kg
Lubricant, average	(see description above)	0.08	kg
Peroxide stabilizer, average	(see description above)	0.002	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.025	kg
Softener, average	(see description above)	0.03	kg
Sulphuric acid	RoW: market for sulfuric acid (EI3.5)	0.02	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			

Inputs	Dataset used in model	Quantity	Unit
Bleached cottontricot 169 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.006	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.006	kg
Air emissions from 1 kg Wetting/penetrating agent, worst case	(emission to air)	0.003	kg
Air emissions from 1 kg Peroxide stabilizer, average	(emission to air)	0.003	kg
Air emissions from 1 kg Bleach (H2O2), average	(emission to air)	0.046	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.006	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.006	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.006	kg
Water emissions from 1 kg Wetting/penetrating agent, worst case	(emission to water)	0.003	kg
Water emissions from 1 kg Peroxide stabilizer, average	(emission to water)	0.003	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.03	kg
Water emissions from 1 kg Bleach (H2O2), average	(emission to water)	0.046	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.006	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3

Table B-29: Bleaching cotton/elastane yarn for jeans, 470 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton/elastane yarn 470 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.024	m^3
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.006	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.046	kg
Peroxide stabilizer, average	(see description above)	0.003	kg
Phosphoric acid	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.006	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.03	kg
Sulphuric acid	RoW: market for sulfuric acid (EI3.5)	0.006	kg
Wetting/penetrating agent, cellulosic	(see description above)	0.003	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ

Inputs	Dataset used in model	Quantity	Unit
Cotton/elastane yarn 470 dtex	(see description above)	1.0	kg
Output			
Bleached otton/elastane yarn 470 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.006	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.006	kg
Air emissions from 1 kg Wetting/penetrating agent, worst case	(emission to air)	0.003	kg
Air emissions from 1 kg Peroxide stabilizer, average	(emission to air)	0.003	kg
Air emissions from 1 kg Bleach (H2O2), average	(emission to air)	0.046	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.006	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.006	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.006	kg
Water emissions from 1 kg Wetting/penetrating agent, worst case	(emission to water)	0.003	kg
Water emissions from 1 kg Peroxide stabilizer, average	(emission to water)	0.003	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.03	kg
Water emissions from 1 kg Bleach (H2O2), average	(emission to water)	0.046	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.006	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-30: Dyeing cotton yarn for jeans, 578 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton yarn 578 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.05	m^3
Acrylic acid	RoW: market for acrylic acid (EI3.5)	0.05	kg
Aniline	RoW: market for aniline (EI3.5)	0.02	kg
Antifoaming agent	(see description above)	0.02	kg
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.02	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.055	kg
Peroxide stabilizer, average	(see description above)	0.001	kg
Reducing agent VAT, average	(see description above)	0.015	kg
Soda ash	GLO: market for soda ash, dense (EI3.5)	0.01	Kg

Inputs	Dataset used in model	Quantity	Unit
Cotton yarn 578 dtex	(see description above)	1.0	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.02	kg
Sodium sulphate	RoW: market for sodium sulfate, anhydrite (EI3.5)	0.015	kg
Wetting/penetrating agent, cellulosic	(see description above)	0.005	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed cotton yarn 578 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.01	kg
Air emissions from 1 kg Peroxide stabilizer, average	(emission to air)	0.001	kg
Air emissions from 1 kg Bleach (H_2O_2), average	(emission to air)	0.035	kg
Air emissions from 1 kg Blue VAT dyestuff (indigo), average	(emission to air)	0.02	kg
Air emissions from 1 kg Wetting/penetrating agent, worst case	(emission to air)	0.005	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.05	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.01	kg
Air emissions from 1 kg Oxidizing agent (H_2O_2), average	(emission to air)	0.02	kg
Air emissions from 1 kg Sizing agent, average	(emission to air)	0.1	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.01	kg
Water emissions from 1 kg Peroxide stabilizer, average	(emission to water)	0.001	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.02	kg
Water emissions from 1 kg Bleach (H_2O_2), average	(emission to water)	0.035	kg
Water emissions from 1 kg Blue disperse dyestuff, BAT	(emission to water)	0.02	kg
Water emissions from 1 kg Reducing agent VAT, average	(emission to water)	0.015	kg
Water emissions from 1 kg Wetting/penetrating agent, worst case	(emission to water)	0.005	kg
Water emissions from 1 kg Conducting salt	(emission to water)	0.15	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.05	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.01	kg
Water emissions from 1 kg Base/Soda ash (Na_2CO_3), average	(emission to water)	0.01	kg

Inputs	Dataset used in model	Quantity	Unit
Cotton yarn 578 dtex	(see description above)	1.0	kg
Water emissions from 1 kg Sizing agent, average	(emission to water)	0.1	kg
Water emissions from 1 kg Oxidizing agent (H2O2), average	(emission to water)	0.02	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-31: Pre-treatment before printing polyester weave for dress, 119/114 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyester weave 119/114 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.06	m^3
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.05	kg
Lubricant, average	(see description above)	0.005	kg
Phosphoric acid	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.005	kg
Wetting agent for better printability	(see description above)	0.005	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Pre-treated polyester weave 119/114 dtex	(to disperse printing)	1.0	kg
Air emissions from 1 kg Lubricant, average	(emission to air)	0.005	kg
Air emissions from 1 kg Detergent/wetting, average	(emission to air)	0.005	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.005	kg
Air emissions from 1 kg Wetting agent for better printability, average	(emission to air)	0.005	kg
Water emissions from 1 kg Lubricant, average	(emission to water)	0.005	kg
Water emissions from 1 kg Detergent/wetting, average	(emission to water)	0.005	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.005	kg
Water emissions from 1 kg Wetting agent for better printability, average	(emission to water)	0.005	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-32: Disperse printing polyester weave for dress, 119/114 dtex.

Inputs	Dataset used in model	Quantity	Unit
Pre-treated polyester weave 119/114 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.00027	m^3
1-propanol	GLO: market for 1-propanol (EI3.5)	0.105	kg
Acrylic dispersion	RoW: market for acrylic dispersion, without water, in 65% solution state (EI3.5)	0.03	kg
Aniline	RoW: market for aniline (EI3.5)	0.165	kg
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.01	kg
Formic acid	RoW: market for formic acid (EI3.5)	0.005	kg
Reducing agent VAT, average	(see description above)	0.01	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.01	kg
Softener, average	(see description above)	0.15	kg
Electricity	Production country mix (see description above)	0.112	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	1.90	MJ
Outputs			
Printed polyester weave 119/114 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Thickener, average	(emission to air)	0.105	kg
Air emissions from 1 kg Reduction agent printing, average	(emission to air)	0.03	kg
Air emissions from 1 kg Black pigment, average	(emission to air)	0.165	kg
Air emissions from 1 kg Detergent/wetting agent, BAT	(emission to water)	0.01	kg
Air emissions from 1 kg Reducing agent VAT, average	(emission to air)	0.01	kg
Air emissions from 1 kg Acid (formic acid), average	(emission to air)	0.005	kg
Water emissions from 1 kg Thickener, average	(emission to water)	0.105	kg
Water emissions from 1 kg Reduction agent printing, average	(emission to water)	0.03	kg
Water emissions from 1 kg Black pigment, average	(emission to water)	0.165	kg
Water emissions from 1 kg Detergent/wetting agent, BAT	(emission to water)	0.01	kg
Water emissions from 1 kg Reducing agent VAT, average	(emission to water)	0.01	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.01	kg
Water emissions from 1 kg Acid (formic acid), average	(emission to water)	0.005	kg
Water emissions from 1 kg Softener, average	(emission to water)	0.15	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3

Inputs	Dataset used in model	Quantity	Unit
Pre-treated polyester weave 119/114 dtex	(see description above)	1.0	kg
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-33: Dyeing polyester tricot for dress, 114 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyester tricot 114 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.078	m^3
Ammonium sulphate	GLO: market for ammonium sulfate, as N (EI3.5)	0.01	kg
Aniline	RoW: market for aniline (EI3.5)	0.05	kg
Detergent, average	(see description above)	0.075	kg
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.02	kg
Ethylene glycol	RoW: market for ethylene glycol monoethyl ether (EI3.5)	0.015	kg
Formic acid	RoW: market for formic acid (EI3.5)	0.015	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.015	kg
Reducing agent VAT, average	(see description above)	0.005	kg
Sequestering agent	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.02	kg
Soda ash	GLO: market for soda ash, dense (EI3.5)	0.0225	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.005	kg
Softener, average	(see description above)	0.2	kg
Wetting/penetrating agent, synthetic	(see description above)	0.01	kg
Electricity	Production country mix	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Printed polyester weave 119/114 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.075	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.02	kg
Air emissions from 1 kg Acid (formic acid), average	(emission to air)	0.015	kg
Air emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to air)	0.01	kg
Air emissions from 1 kg Dispergent, average	(emission to air)	0.015	kg
Air emissions from 1 kg Antireduction agent (H2O2), average	(emission to air)	0.015	kg
Air emissions from 1 kg Black disperse dyestuff, average	(emission to air)	0.05	kg
Air emissions from 1 kg Detergent/wetting agent, BAT	(emission to air)	0.02	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.075	kg

Inputs	Dataset used in model	Quantity	Unit
Polyester tricot 114 dtex	(see description above)	1.0	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.02	kg
Water emissions from 1 kg Antifoaming agent, average	(emission to water)	0.0015	kg
Water emissions from 1 kg Base/Soda ash (Na2CO3), average	(emission to water)	0.0025	kg
Water emissions from 1 kg Acid (formic acid), average	(emission to water)	0.015	kg
Water emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to water)	0.01	kg
Water emissions from 1 kg Dispergent, average	(emission to water)	0.015	kg
Water emissions from 1 kg Decalcifier ((NH4)2SO4), average	(emission to water)	0.01	kg
Water emissions from 1 kg Antireduction agent (H2O2), average	(emission to water)	0.015	kg
Water emissions from 1 kg Black disperse dyestuff, average	(emission to water)	0.05	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.005	kg
Water emissions from 1 kg Reducing agent VAT, average	(emission to water)	0.005	kg
Water emissions from 1 kg Soda (CaCO3), average	(emission to water)	0.02	kg
Water emissions from 1 kg Detergent/wetting agent, BAT	(emission to water)	0.02	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-34: Dyeing cotton/elastane tricot for jacket, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton/elastane tricot 300 dtex	(see description above)	1.0	kg
Water, river	(eesource flow)	0.06	m^3
Detergent, average	(see description above)	0.12	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.07	kg
Lubricant, average	(see description above)	0.08	kg
Peroxide stabilizer, average	(see description above)	0.002	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.025	kg
Softener, average	(see description above)	0.03	kg
Sulphuric acid	RoW: market for sulfuric acid (EI3.5)	0.03	kg
Wetting/penetrating agent, cellulosic	(see description above)	0.005	kg
Electricity	Production country mix (see description above)	0.7	kWh

Inputs	Dataset used in model	Quantity	Unit
Cotton/elastane tricot 300 dtex	(see description above)	1.0	kg
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed cotton/elastane tricot 300 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Lubricant, average	(emission to air)	0.08	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.04	kg
Air emissions from 1 kg Peroxide stabilizer, average	(emission to air)	0.002	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.01	kg
Air emissions from 1 kg Bleach (H2O2), average	(emission to air)	0.07	kg
Air emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to air)	0.02	kg
Air emissions from 1 kg Blue disperse dyestuff, average	(emission to air)	0.05	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.08	kg
Water emissions from 1 kg Lubricant, average	(emission to water)	0.08	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.04	kg
Water emissions from 1 kg Peroxide stabilizer, average	(emission to water)	0.002	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.025	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.01	kg
Water emissions from 1 kg Bleach (H2O2), average	(emission to water)	0.07	kg
Water emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to water)	0.02	kg
Water emissions from 1 kg Blue disperse dyestuff, average	(emission to water)	0.05	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.08	kg
Water emissions from 1 kg Softener, average	(emission to water)	0.03	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-35: Dyeing polyester weave for jacket, 70 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyester weave 70 dtex	(see description above)	1.0	kg
Water, river	(eesource flow)	0.078	m^3

Inputs	Dataset used in model	Quantity	Unit
Polyester weave 70 dtex	(see description above)	1.0	kg
Ammonium sulphate	GLO: market for ammonium sulfate, as N (EI3.5)	0.02	kg
Aniline	RoW: market for aniline (EI3.5)	0.19	kg
Antifoaming agent	(see description above)	0.003	kg
Detergent, average	(see description above)	0.15	kg
Detergent/wetting agent average	RoW: market for acrylic acid (EI3.5)	0.02	kg
Ethylene glycol	RoW: market for ethylene glycol monoethyl ether (EI3.5)	0.03	kg
Formic acid	RoW: market for formic acid (EI3.5)	0.03	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.03	kg
Reducing agent VAT, average	(see description above)	0.005	kg
Sequestering agent	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.04	kg
Soda ash	GLO: market for soda ash, dense (EI3.5)	0.025	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.005	kg
Softener, average	(see description above)	0.2	kg
Wetting/penetrating agent, synthetic	(see description above)	0.015	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed polyester weave 70 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.15	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.04	kg
Air emissions from 1 kg Acid (formic acid), average	(emission to air)	0.03	kg
Air emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to air)	0.015	kg
Air emissions from 1 kg Dispergent, average	(emission to air)	0.03	kg
Air emissions from 1 kg Antireduction agent (H2O2), average	(emission to air)	0.03	kg
Air emissions from 1 kg Yellow disperse dyestuff, average	(emission to air)	0.006	kg
Air emissions from 1 kg Red disperse dyestuff, average	(emission to air)	0.013	kg
Air emissions from 1 kg Reducing agent VAT, average	(emission to air)	0.005	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.02	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.15	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.04	kg

Inputs	Dataset used in model	Quantity	Unit
Polyester weave 70 dtex	(see description above)	1.0	kg
Water emissions from 1 kg Antifoaming agent, average	(emission to water)	0.003	kg
Water emissions from 1 kg Base/Soda ash (Na2CO3), average	(emission to water)	0.005	kg
Water emissions from 1 kg Acid (formic acid), average	(emission to water)	0.03	kg
Water emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to water)	0.015	kg
Water emissions from 1 kg Dispergent, average	(emission to water)	0.03	kg
Water emissions from 1 kg Decalcifier ((NH4)2SO4), average	(emission to water)	0.02	kg
Water emissions from 1 kg Antireduction agent (H2O2), average	(emission to water)	0.03	kg
Water emissions from 1 kg Yellow disperse dyestuff, average	(emission to water)	0.006	kg
Water emissions from 1 kg Red disperse dyestuff, average	(emission to water)	0.013	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.005	kg
Water emissions from 1 kg Reducing agent VAT, average	(emission to water)	0.005	kg
Water emissions from 1 kg Soda (CaCO3), average	(emission to water)	0.02	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.02	kg
Water emissions from 1 kg Softener, average	(emission to water)	0.2	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-36: Dyeing polyamide weave for jacket, 90/200 dtex.

Inputs	Dataset used in model	Quantity	Unit
Polyamide weave 90/200 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.088	m^3
Aniline	RoW: market for aniline (EI3.5)	0.0615	kg
Antifoaming agent	(see description above)	0.003	kg
Detergent, average	(see description above)	0.1	kg
Formic acid	RoW: market for formic acid (EI3.5)	0.05	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.01	kg
Lubricant, average	(see description above)	0.02	kg
Polydimethylsiloxane	GLO: market for polydimethylsiloxane (EI3.5)	0.5	kg
Sequestering agent	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.04	kg
Soda ash	GLO: market for soda ash, dense (EI3.5)	0.01	kg

Inputs	Dataset used in model	Quantity	Unit
Polyamide weave 90/200 dtex	(see description above)	1.0	kg
Wetting/penetrating agent, synthetic	(see description above)	0.009	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed polyamide weave 90/200 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Detergent. average	(emission to air)	0.1	kg
Air emissions from 1 kg Sequestering agent. average	(emission to air)	0.04	kg
Air emissions from 1 kg Acid (formic acid). average	(emission to air)	0.05	kg
Air emissions from 1 kg Wetting/penetrating agent (synthetic). average	(emission to air)	0.009	kg
Air emissions from 1 kg Lubricant. average	(emission to air)	0.02	kg
Air emissions from 1 kg Black disperse dyestuff. average	(emission to air)	0.05	kg
Air emissions from 1 kg Yellow disperse dyestuff. average	(emission to air)	0.01	kg
Air emissions from 1 kg Blue disperse dyestuff. average	(emission to air)	0.0015	kg
Air emissions from 1 kg DWR agent. average	(emission to air)	0.5	kg
Water emissions from 1 kg Detergent. average	(emission to water)	0.1	kg
Water emissions from 1 kg Sequestering agent. average	(emission to water)	0.04	kg
Water emissions from 1 kg Antifoaming agent. average	(emission to water)	0.003	kg
Water emissions from 1 kg Base (NaOH). average	(emission to water)	0.01	kg
Water emissions from 1 kg Acid (formic acid). average	(emission to water)	0.05	kg
Water emissions from 1 kg Wetting/penetrating agent (synthetic). average	(emission to water)	0.009	kg
Water emissions from 1 kg Lubricant. average	(emission to water)	0.02	kg
Water emissions from 1 kg Black disperse dyestuff. average	(emission to water)	0.05	kg
Water emissions from 1 kg Yellow disperse dyestuff. BAT	(emission to water)	0.01	kg
Water emissions from 1 kg Blue disperse dyestuff. average	(emission to water)	0.0015	kg
Water emissions from 1 kg Soda (CaCO3). average	(emission to water)	0.01	kg

Inputs	Dataset used in model	Quantity	Unit
Polyamide weave 90/200 dtex	(see description above)	1.0	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-37: Dyeing viscose/polyamide/elastane yarn for socks, 300 dtex.

Inputs	Dataset used in model	Quantity	Unit
Viscose/polyamide/elastane yarn 300 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.06	m^3
Detergent, average	(see description above)	0.12	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.07	kg
Lubricant, average	(see description above)	0.08	kg
Peroxide stabilizer, average	(see description above)	0.002	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.025	kg
Softener, average	(see description above)	0.03	kg
Sulphuric acid	RoW: market for sulfuric acid (EI3.5)	0.03	kg
Wetting/penetrating agent, cellulosic	(see description above)	0.005	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed viscose/polyamide/elastane yarn 300 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Lubricant, average	(emission to air)	0.08	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.04	kg
Air emissions from 1 kg Peroxide stabilizer, average	(emission to air)	0.002	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.01	kg
Air emissions from 1 kg Bleach (H2O2), average	(emission to air)	0.07	kg
Air emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to air)	0.02	kg
Air emissions from 1 kg Blue disperse dyestuff, average	(emission to air)	0.05	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.08	kg
Water emissions from 1 kg Lubricant, average	(emission to water)	0.08	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.04	kg
Water emissions from 1 kg Peroxide stabilizer, average	(emission to water)	0.002	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.025	kg

Inputs	Dataset used in model	Quantity	Unit
Viscose/polyamide/elastane yarn 300 dtex	(see description above)	1.0	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.01	kg
Water emissions from 1 kg Bleach (H_2O_2), average	(emission to water)	0.07	kg
Water emissions from 1 kg Wetting/penetrating agent (synthetic), average	(emission to water)	0.02	kg
Water emissions from 1 kg Blue disperse dyestuff, average	(emission to water)	0.05	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.08	kg
Water emissions from 1 kg Softener, average	(emission to water)	0.03	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-38: Dyeing cotton/polyester weave for hospital uniform, 200 dtex.

Inputs	Dataset used in model	Quantity	Unit
Cotton/polyester weave 200 dtex	(see description above)	1.0	kg
Water, river	(resource flow)	0.06	m^3
Aniline	RoW: market for aniline (EI3.5)	0.04	kg
Detergent, average	(see description above)	0.24	kg
Hydrogen peroxide	RoW: market for hydrogen peroxide, without water, in 50% solution state (EI3.5)	0.01	kg
Lubricant, average	(see description above)	0.04	kg
Reducing agent VAT, average	(see description above)	0.012	kg
Sequestering agent	GLO: market for phosphoric acid, industrial grade, without water, in 85% solution state (EI3.5)	0.006	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.012	kg
Softener	(see description above)	0.12	kg
Sulphuric acid	RoW: market for sulfuric acid (EI3.5)	0.052	kg
Wetting/penetrating agent, average	(see description above)	0.004	kg
Electricity	Production country mix (see description above)	0.7	kWh
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	30	MJ
Outputs			
Dyed cotton/polyester weave 200 dtex	(to drying)	1.0	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.1	kg
Air emissions from 1 kg Bleach (H_2O_2), average	(emission to air)	0.01	kg
Air emissions from 1 kg Wetting/penetrating agent, worst case	(emission to air)	0.004	kg
Air emissions from 1 kg Sequestering agent, average	(emission to air)	0.006	kg

Inputs	Dataset used in model	Quantity	Unit
Cotton/polyester weave 200 dtex	(see description above)	1.0	kg
Air emissions from 1 kg Acid (sulfuric acid), average	(emission to air)	0.052	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.08	kg
Air emissions from 1 kg Lubricant, average	(emission to air)	0.04	kg
Air emissions from 1 kg Blue VAT dyestuff (indigo), average	(emission to air)	0.02	kg
Air emissions from 1 kg Blue disperse dyestuff, average	(emission to air)	0.02	kg
Air emissions from 1 kg Reducing agent VAT, average	(emission to air)	0.012	kg
Air emissions from 1 kg Detergent, average	(emission to air)	0.06	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.1	kg
Water emissions from 1 kg Bleach (H2O2), average	(emission to water)	0.01	kg
Water emissions from 1 kg Wetting/penetrating agent, worst case	(emission to water)	0.004	kg
Water emissions from 1 kg Sequestering agent, average	(emission to water)	0.006	kg
Water emissions from 1 kg Base (NaOH), average	(emission to water)	0.012	kg
Water emissions from 1 kg Acid (sulfuric acid), average	(emission to water)	0.052	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.08	kg
Water emissions from 1 kg Lubricant, average	(emission to water)	0.04	kg
Water emissions from 1 kg Indigo dyestuff	(emission to water)	0.02	kg
Water emissions from 1 kg Blue disperse dyestuff, average	(emission to water)	0.02	kg
Water emissions from 1 kg Reducing agent VAT, average	(emission to water)	0.012	kg
Water emissions from 1 kg Detergent, average	(emission to water)	0.06	kg
Water emissions from 1 kg Softener, average	(emission to water)	0.12	kg
COD, Chemical Oxygen Demand	(emission to water)	0.0002	kg
Water, river	(to waste water treatment)	0.045	m^3
Sludge	CH: treatment of sludge from pulp and paper production, sanitary landfill (EI3.5)	0.5	kg

Table B-39: Drying of bleached/dyed yarn/textile in stenter frame.

Inputs	Dataset used in model	Quantity	Unit
Yarn or woven/ knitted textile	(see description above)	1.0	kg
Electricity	Production country mix (see description above)	0.8	kWh

Inputs	Dataset used in model	Quantity	Unit
Heat	RoW: heat production, light fuel oil, at boiler 100kW, non-modulating (EI3.5)	8	MJ
Outputs			
Yarn or woven/knitted textile	(to knitting/confectioning or confectioning)	1.0	kg

Confectioning

Table B-40: T-shirt confectioning.

Inputs	Dataset used in model	Quantity	Unit
Knitted cotton fabric, 169 dtex	(see description above)	1.176	kg
Water	GLO: market group for tap water (EI3.5)	0.18	kg
Sowing thread	GLO: market for cotton fibre (EI3.5)	0.0035	kg
Confectioning template	GLO: market for kraft paper, unbleached (EI3.5)	0.05	kg
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg
Electricity	Production country mix (see description above)	2.711 (including ironing)	kWh
Heat	GLO: market group for heat, central or small-scale, natural gas (EI3.5)	0.07	MJ
Outputs			
T-shirt	(to distribution & retail)	1.0	kg
Cotton waste	(to incineration without energy recovery)	0.176	kg

Table B-41: Jeans confectioning.

Inputs	Dataset used in model	Quantity	Unit	Comment
Woven cotton/elastane fabric, 470/578 dtex	(see description above)	1.176	kg	
Water	GLO: market group for tap water (EI3.5)	0.19	kg	
Sowing thread	GLO: market for cotton fibre (EI3.5)	0.0035	kg	
Brass	RoW: market for brass (EI3.5)	0.019	kg	Button raw material
	GLO: market for metal working, average for metal product manufacturing (EI3.5)	0.019	kg	Button production
Steel	GLO: market for steel, low-alloyed (EI3.5)	0.013	kg	Zipper raw material
	GLO: market for metal working, average for steel product manufacturing (EI3.5)	0.013	kg	Zipper production
Confectioning template	GLO: market for kraft paper, unbleached (EI3.5)	0.05	kg	
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg	
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg	
Residential washing	(see description below)	1.0	kg	
Electricity	Production country mix (see description above)	2.78	kWh	
Heat	GLO: market group for heat, central or small-scale, natural gas (EI3.5)	0.067	MJ	
Outputs				
Jeans	(to distribution & retail)	1.0	kg	
Cotton waste	(to incineration without energy recovery)	0.250	kg	

Table B-42: Dress confectioning.

Inputs	Dataset used in model	Quantity	Unit
Knitted polyester fabric, 114 dtex	(see description above)	0.625	kg
Woven polyester fabric, 114/119 dtex	(see description above)	0.625	kg
Water	GLO: market group for tap water (EI3.5)	0.356	kg
Sowing thread	GLO: market for cotton fibre (EI3.5)	0.0035	kg
Confectioning template	GLO: market for kraft paper, unbleached (EI3.5)	0.05	kg
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg
Electricity	Production country mix (see description above)	5.16 (including ironing)	kWh
Heat	GLO: market group for heat, central or small-scale, natural gas (EI3.5)	0.126	MJ
Outputs			
Dress	(to distribution & retail)	1.0	kg
Polyester waste	(to incineration without energy recovery)	0.250	kg

Table B-43: Jacket confectioning.

Inputs	Dataset used in model	Quantity	Unit	Comment
Woven polyamide fabric, 90/200 dtex, olive	(see description above)	0.359	kg	
Woven polyamide fabric, 90/200 dtex, black	(see description above)	0.186	kg	
Woven polyester fabric, 70 dtex, orange	(see description above)	0.1926	kg	
Knitted cotton/elastane fabric, 300 dtex,	(see description above)	0.235	kg	
Nonwoven polyester fabric,	(see description above)	0.2774	kg	
Water	GLO: market group for tap water (EI3.5)	0.61	kg	
Sowing thread	GLO: market for cotton fibre (EI3.5)	0.0035	kg	
Brass	RoW: market for brass (EI3.5)	0.0133	kg	Button raw material
	GLO: market for metal working, average for metal product manufacturing (EI3.5)	0.0133	kg	Button production
Steel	GLO: market for steel, low-alloyed (EI3.5)	0.0115	kg	Zipper raw material
	GLO: market for metal working, average for steel product manufacturing (EI3.5)	0.0115	kg	Zipper production
Confectioning template	GLO: market for kraft paper, unbleached (EI3.5)	0.05	kg	
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg	
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.06	kg	
Electricity	Production country mix (see description above)	8.938	kWh	
Heat	GLO: market group for heat, central or small-scale, natural gas (EI3.5)	0.0216	MJ	
Outputs				
Jacket	(to distribution & retail)	1.0	kg	
Polyester waste	(to incineration without energy recovery)	0.094	kg	
Cotton waste	(to incineration without energy recovery)	0.042	kg	
Polyamide/elastane waste	(to incineration without energy recovery)	0.114	kg	

Table B-44: Hospital uniform confectioning.

Inputs	Dataset used in model	Quantity	Unit
Cotton/polyester weave 200 dtex	(see description above)	1.250	kg
Water	GLO: market group for tap water (EI3.5)	0.165	kg
Sowing thread	GLO: market for cotton fibre (EI3.5)	0.0035	kg
Plastic buttons	RoW: polyethylene terephthalate production, granulate, bottle grade (EI3.5)	0.007	kg
Confectioning template	GLO: market for kraft paper, unbleached (EI3.5)	0.05	kg
Rubber bands	GLO: market for synthetic rubber (EI3.5)	0.00012	kg
Packaging film	GLO: market for packaging film, low density polyethylene (EI3.5)	0.02	kg
Corrugated board box	RoW: market for corrugated board box (EI3.5)	0.00059	kg
Electricity	Production country mix (see description above)	2.552 (including ironing)	kWh
Heat	GLO: market group for heat, central or small-scale, natural gas (EI3.5)	0.058	MJ
Outputs			
Hospital uniform	(to distribution & retail)	1.0	kg
Cotton waste	(to incineration without energy recovery)	0.125	kg
Polyester waste	(to incineration without energy recovery)	0.125	kg

Distribution & retail phase

Table B-45: Distribution and retail of T-shirt, jeans, dress, jacket and socks.

Inputs	Dataset used in model	Quantity	Unit	Comment
Garment	(from confectioning process)	1.01	kg	
Transport (from manufacturing country to Sweden)	GLO: market for transport, freight, sea, transoceanic ship (EI3.5)	18.88	tkm	Distance according to Sea-Distances.org (2015) from Shanghai to Gothenburg (empty return trip not included)
Transport (distribution to store)	RER: market for transport, freight, lorry 16-32 metric ton, EURO6 (EI3.5)	2.85	tkm	Data from HM (2012)
Transport (distribution to store)	RER: market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 (EI3.5)	0.32	tkm	Data from HM (2012)
Transport (retail staff)	GLO: market for transport, regular bus (EI3.5)	0.1	pkm	Data from HM (2012)
Transport (retail staff)	GLO: market for transport, passenger, aircraft (EI3.5)	0.0008	pkm	Data from HM (2012)
Transport (retail staff)	RER: market for transport, passenger car (EI3.5)	0.19	pkm	Data from HM (2012)
Electricity (store)	SE: market for electricity, low voltage (EI3.5)	1.94	kWh	Data from HM (2012)
Electricity (credit from packaging waste)	SE: market for electricity, low voltage (EI3.5)	-0.06	kWh	Credit for electricity production in waste treatment of packaging waste
Heat (credit from packaging waste)	Swedish average district heating, see table B-47	-0.45	MJ	Credit for heat production in waste treatment of packaging waste
Electricity (credit from textile waste)	SE: market for electricity, low voltage (EI3.5)	~0.01 (depends on material)	kWh	Credit for electricity production in waste treatment of textile waste
Heat (credit from textile waste)	Swedish average district heating (see description below)	0.04-0.08 (depends on material)	MJ	Credit for heat production in waste treatment of textile waste
Outputs				

Inputs	Dataset used in model	Quantity	Unit	Comment
Garment	(to main use phase process)	1.00	kg	
Packaging waste to treatment	RoW: treatment of waste graphical paper, municipal incineration (EI3.5)	0.13	kg	Produces 0.48 kWh power and 3.49 MJ heat per kg treated material
Textile waste to treatment	(depends on material, see **Fel! Hittar inte referenskälla.**)	0.01	kg	Production of power and heat per kg depends on material, see **Fel! Hittar inte referenskälla.**

Table B-46: Distribution of hospital uniform.

Inputs	Dataset used in model	Quantity	Unit	Comment
Garment	(from confectioning process)	1.00	kg	
Transport (from manufacturing country to Sweden)	GLO: market for transport, freight, sea, transoceanic ship (EI3.5)	18.88	tkm	Distance according to Sea-Distances.org (2015) from Shanghai to Gothenburg (empty return trip not included)
Transport (distribution in Sweden)	RER: market for transport, freight, lorry 16-32 metric ton, EURO6 (EI3.5)	2.85	Tkm	Same assumption as in the distribution of the other garments
Transport (distribution in Sweden)	RER: market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 (EI3.5)	0.32	Tkm	Same assumption as in the distribution of the other garments
Outputs				
Garment	(to use phase)	1	kg	
Packaging waste to treatment	-	0.0002	Kkg	Disregarded due to negligible weight

Table B-47: District heating, Swedish average 2017, based on Swedenergy (2019).

Inputs	Dataset used in model	Quantity	Unit	Comment
Heat from secondary biofuels (e.g. waste from logging) (27.2%)	CH: heat production, untreated waste wood, at furnace 1000-5000 kW, state-of-the-art 2014 (EI3.5)	0.272	MJ	In this dataset, all burden is allocated to treatment of waste, and the heat is free of environmental burden
Heat from waste incineration (22%)	SE: heat, from municipal waste incineration to generic market for heat district or industrial, other than natural gas (EI3.5)	0.220	MJ	In this dataset, all burden is allocated to treatment of waste, and the heat is free of environmental
Industrial waste heat (7.9%)	N/A	0.079	MJ	Assumed to be free of environmental burden
Heat from recycled wood chips (7.2%)	CH: heat production, wood chips from industry, at furnace 1000kW, state-of-the-art 2014 (EI3.5)	0.072	MJ	
Heat from pellets, briquettes and powder (5.2%)	CH: [heat from] wood pellets, burned in stirling heat and power co-generation unit, 3 kW electrical, future (EI3.5)	0.052	MJ	
Renewable power to electric boilers, heat pumps and distribution (4.6%)	CH: [electricity from] wood pellets, burned in stirling heat and power co-generation unit, 3 kW electrical, future (EI3.5)	0.046	MJ	
Heat from heat pumps (net) (4.1%)	N/A	0.041	MJ	Environmental burden included in other inputs

Heat from landfill gas, sewage gas, industrial waste gas (1.9%)	(no suitable dataset found)	0.019	MJ	Disregarded as no suitable dataset was found
Heat from peat and peat briquettes (1.8%)	NORDEL: peat, burned in power plant (EI2.0)	0.018	MJ	
Heat from biooil and crude tall-oil (1.6%)	CH: heat production, wood chips from industry, at furnace 1000kW, state-of-the-art 2014 (EI3.5)	0.016	MJ	
Heat from coal (1.5%)	SE: heat and power co-generation, hard coal (EI3.5)	0.015	MJ	
Heat from natural gas (1.4%)	SE: heat and power co-generation, natural gas, conventional power plant, 100MW electrical (EI3.5)	0.014	MJ	
Heat from fuel oil (1.2%)	SE: heat and power co-generation, oil (EI3.5)	0.012	MJ	
Nuclear power to electric boilers, heat pumps and distribution (0.4%)	SE: electricity production, nuclear, boiling water reactor (EI3.5)	0.004	MJ	
Fossil power to electric boilers, heat pumps and distribution (0.3%)	SE: electricity production, oil (EI3.5)	0.003	MJ	
Output				
Heat to district heating system		1	MJ	

Use phase

Table B-48: Main use phase process of T-shirt.

Inputs	Dataset used in model	Quantity	Unit	Comments
T-shirt	(from distribution & retail phase)	0.11	kg	
Transport (to and from the store)	RER: market for transport, passenger car EI3.5	0.94	km	Assumed 17 km/kg garment and 50% car transportation, see Section 3.6.1.
Transport (to and from the store)	GLO: market for transport, regular bus EI3.5	0.94	pkm	Assumed 17 person-km/kg garment and 50% public transportation, see Section 3.6.1.
Washing of garment (40°C)	(from residential washing 40°C process)	1.65	kg	Assumed 15 washing cycles per functional unit, see Section 3.6.1, and washing temperature of 40°C see Section 3.6.3.
Drying of garment	(from residential drying process)	0.56	kg	Assumed to be dried after 34% of the washes, see Section 3.6.3.
Ironing of garment	(from residential ironing process)	6.75	min	Assumed to be ironed after 15% of washes, assumed 3 minutes of ironing per T-shirt, see Section 3.6.3.
Output				
T-shirt	(to end-of-life phase)	0.11	kg	

Table B-49: Main use phase process of jeans.

Inputs	Dataset used in model	Quantity	Unit	Comments
Jeans	(from distribution & retail phase)	0.477	kg	
Transport (to and from the store)	RER: market for transport, passenger car EI3.5	4.05	km	Assumed 17 km/kg garment and 50% car transportation, see Section 3.6.1.

Transport (to and from the store)	GLO: market for transport, regular bus EI3.5	4.05	pkm	Assumed 17 person-km/kg garment and 50% public transportation, see Section 3.6.1.
Washing of garment (40°C)	(from residential washing 40°C process)	11.5	kg	Assumed 24 washing cycles per functional unit, see Section 3.6.1, and washing temperature of 40°C, see Section 3.6.3.
Drying of garment	(from residential drying process)	3.32	kg	Assumed to be dried after 29% of the washes, Section 3.6.3.
Ironing of garment	(from residential ironing process)	21.6	min	Assumed to be ironed after 15% of washes, assumed 6 minutes of ironing per jeans, see Section 3.6.3.
Output				
Jeans	(to end-of-life phase)	0.477	kg	

Table B-50: Main use phase process of dress.

Inputs	Dataset used in model	Quantity	Unit	Comments
Dress	(from distribution & retail phase)	0.478	kg	
Transport (from store to user´s home)	RER: market for transport, passenger car EI3.5	4.06	km	Assumed 17 km/kg garment and 50% car transportation, see Section 3.6.1.
Transport (to and from the store)	GLO: market for transport, regular bus EI3.5	4.06	pkm	Assumed 17 person-km/kg garment and 50% public transportation, see Section 3.6.1.
Washing of garment(40°C)	(from residential washing 40°C process)	4.16	kg	Assumed 8.7 washing cycles per functional unit, see Section 3.6.1, and washing temperature of 40°C, see Section 3.6.3.
Drying of garment	(from residential drying process)	0.79	kg	Assumed to be dried after 19% of washes, Section 3.6.3.
Ironing of garment	(from residential ironing process)	9.40	min	Assumed to be ironed after 18% of washes, assumed 6 minutes of ironing per dress Section 3.6.3.
Output				
Dress	(to end-of-life phase)	0.478	kg	

Table B-51: Main use phase process of jacket.

Inputs	Dataset used in model	Quantity	Unit	Comments
Jacket	(from distribution & retail phase)	0.444	kg	
Transport (to and from the store)	RER: market for transport, passenger car EI3.5	3.77	km	Assumed 17 km/kg garment and 50% car transportation, see Section 3.6.1.
Transport (to and from the store)	GLO: market for transport, regular bus EI3.5	3.77	pkm	Assumed 17 person-km/kg garment and 50% public transportation, see Section 3.6.1.
Washing of garment (40°C)	(from residential washing 40°C process)	0.62	kg	Assumed 1.4 washing cycles per functional unit, see Section 3.6.1, and washing temperature of 40°C, see Section 3.6.3.
Drying of garment	(from residential drying process)	0.13	kg	Assumed to be dried after 21% of washes, see Section 3.6.3.
Ironing of garment	(from residential ironing process)	0.28	min	Assumed to be ironed after 5% of washes, assumed 4 minutes of ironing per jeans, see Section 3.6.3. According to Beton et al. (2014), a jacket is ironed for 3-5 minutes, thus the 4-minute assumption.
Output				
Jacket	(to end-of-life phase)	0.444	kg	

Table B-52: Main use phase process of socks.

Inputs	Dataset used in model	Quantity	Unit	Comments
Socks	(from distribution & retail phase)	0.043	kg	
Transport (to and from the store)	RER: market for transport, passenger car EI3.5	0.37	km	Assumed 17 km/kg garment and 50% car transportation, see Section 3.6.1.
Transport (to and from the store)	GLO: market for transport, regular bus EI3.5	0.37	pkm	Assumed 17 person-km/kg garment and 50% public transportation, see Section 3.6.1.
Washing of garment (60°C)	(from residential washing 60°C process)	1.16	kg	Assumed 27 washing cycles per functional unit, see Section 3.6.1, and washing temperature of 60°C, see Section 3.6.3.
Drying of garment	(from residential drying process)	0.67	kg	Assumed to be dried after 58% of the washes, Section 3.6.3.
Ironing of garment	(from residential ironing process)	0.27	min	Assumed to be ironed after 1% of washes, see, assumed 1 minutes of ironing per socks, see Section 3.6.3. Socks were not included in Beton et al. (2014), so the lowest number for any garment in Beton et al. was assumed.
Output				
Socks	(to end-of-life phase)	0.043	kg	

Table B-53: Main use phase process of hospital uniform.

Inputs	Dataset used in model	Quantity	Unit	Comments
Hospital uniform	(from distribution phase)	0.34	kg	
Transport (to and from the laundry)	CH: transport, freight, lorry 28 metric ton, vegetable oil methyl ester 100%	0.02245	tkm	
Industrial washing and drying	(from industrial laundry process, see **Fel! Hittar inte referenskälla.**)	25.5	kg	75 washes per garment life cycle (Roos 2012)
Output				
Hospital uniform	(to end-of-life phase)	0.34	kg	

Table B-54: Residential washing.

Inputs	Dataset in model	Quantity	Unit
Garment	(from main use phase process)	1	kg
Water	RER: market group for tap water (EI3.5)	6.2	kg
Detergent	(from detergent process)	0.0158	kg
Electricity	SE: market for electricity, low voltage (EI3.5)	0.225 (40°C)/ 0.405 (60°C)	kWh
Outputs			
Garment	(to main use phase process)	1	kg
Water to treatment	Europe without Switzerland: market for wastewater, average	5.2	kg

Table B-55: Residential drying.

Inputs	Dataset in model	Quantity	Unit
Garment	(from main use phase process)	1	kg
Electricity	SE: market for electricity, low voltage (EI3.5)	0.67	kWh
Output			
Garment	(to main use phase process)	1	kg

Table B-56: Residential ironing, 1 minute of ironing.

Inputs	Dataset in model	Quantity	Unit	Comments
Garment	(from use phase process)	-	-	
Electricity	SE: market for electricity, low voltage (EI3.5)	0.027	kWh/min	Beton et al. (2014) assumes an average iron power of 1600 kW, corresponding to 0.027 kWh/min
Output				
Garment	(to main use phase process)	-	-	

Table B-57: Industrial laundry of hospital uniform.

Inputs	Dataset in model	Quantity	Unit
Garment	(from main use phase process)	1	kg
Water	RER: market group for tap water (EI3.5)	12	kg
Detergent	(from detergent process)	0.009	kg
Electricity	SE: market for electricity, low voltage (EI3.5)	0.4	kWh
Heat	CH: wood pellets, burned in stirling heat and power co-generation unit, 3 kW electrical, future (EI3.5)	6.84	**MJ**
Outputs			
Garment	(to main use phase process)	1	kg
Water to treatment	Europe without Switzerland: market for wastewater, average	11	kg

Table B-58: Detergent, liquid.

Inputs	Dataset in model	Quantity	Unit
Alkyl sulphate	GLO: market for alkyl sulphate (C12-14) (EI3.5)	0.1038	kg
Citric acid	RER: citric acid production (EI3.5)	0.0228	kg
Enzymes	RER: enzymes production (EI3.5)	0.0058	kg
Glycerine	RER: market for glycerine (EI3.5)	0.0285	kg
Non-ionic surfactant	GLO: market for non-ionic surfactant (EI3.5)	0.0591	kg
Polyethylene	GLO: market for polyethylene, linear low density, granulate (EI3.5)	0.0466	kg
Soap	RER: soap production (EI3.5)	0.0241	kg
Sodium hydroxide	GLO: market for sodium hydroxide, without water, in 50% solution state (EI3.5)	0.0231	kg
Water	Europe without Switzerland: market for water, deionised, from tap water, at user (EI3.5)	0.7022	kg
HDPE bottle	GLO: market for polyethylene, high density, granulate (EI3.5)	0.0466	kg
PP cork	GLO: market for polypropylene, granulate (EI3.5)	0.0101	kg
Label	GLO: market for printed paper (EI3.5)	0.00126	kg
Electricity	RER: market group for electricity, medium voltage (EI3.5)	0.25	kWh
Output			
Liquid detergent (density 0.95 kg/l)	(to washing process)	1	kg

End-of-life phase

At end-of-life, each garment is subject to one of the waste treatment processes in Table B-59, where the assumed dataset depends on the material content of each garment. As shown in the table, the heat and power recovered after the incineration also depends on the garment. The power is assumed to replace the Swedish market electricity mix, assuming an Ecoinvent 3.5 dataset (SE: market for electricity, low voltage) and the heat is assumed to replace the Swedish district heating mix (see Table B-47). To the waste treatment there is a 30 km transport by truck, assuming an Ecoinvent 3.5 dataset (RER: market for transport, freight, lorry 3.5-7.5 metric ton, EURO6).

Table B-59: Treatment of textile and packaging waste in distribution & retail, use and end-of-life phases.

Waste fraction	**Dataset used in model**	**Power produced per kg treated material**	**Heat produced per kg treated material**
Cotton, viscose, paper packaging	CH: treatment of waste paperboard, municipal incineration (EI3.5)	0.55 kWh	3.98 MJ
Polyester	CH: treatment of waste polyethylene terephthalate, municipal incineration (EI3.5)	0.83 kWh	5.81 MJ
Polyamide 6, elastane	CH: treatment of waste polyurethane, municipal incineration (EI3.5)	1.54 kWh	10.69 MJ
Polyethylene, polypropylene packaging	CH: treatment of waste polyethylene, municipal incineration (EI3.5)	1.54 kWh	10.69 MJ

Appendix C. **Garment representation, national-level scale up**

Table C-1: Representation of the six garments in the national-level scale up.

CN code	Description	Representative garment	Net Swedish import 2017 (tonnes)
6101	Men's or boys' overcoats, car coats, capes, cloaks, anoraks (including ski jackets), windcheaters, wind-jackets and similar articles, knitted or crocheted, other than those of heading 6103	dress	664
6102	Women's or girls' overcoats, car coats, capes, cloaks, anoraks (including ski jackets), windcheaters, wind-jackets and similar articles, knitted or crocheted, other than those of heading 6104	dress	1 365
6103	Men's or boys' suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches and shorts (other than swimwear), knitted or crocheted	jeans	1 969
6104	Women's or girls' suits, ensembles, jackets, blazers, dresses, skirts, divided skirts, trousers, bib and brace overalls, breeches and shorts (other than swimwear), knitted or crocheted	jeans	7 592
6105	Men's or boys' shirts, knitted or crocheted	T-shirt	1335
6106	Women's or girls' blouses, shirts and shirt-blouses, knitted or crocheted	dress	971
6107	Men's or boys' underpants, briefs, nightshirts, pyjamas, bathrobes, dressing gowns and similar articles, knitted or crocheted	T-shirt	2 455
6108	Women's or girls' slips, petticoats, briefs, panties, nightdresses, pyjamas, négligés, bathrobes, dressing gowns and similar articles, knitted or crocheted	T-shirt	2784
6109	T-shirts, singlets and other vests, knitted or crocheted	T-shirt	10 697
6110	Jerseys, pullovers, cardigans, waistcoats and similar articles, knitted or crocheted	dress	14 060
6111	Babies' garments and clothing accessories, knitted or crocheted	T-shirt	1 709
6112	Tracksuits, ski suits and swimwear, knitted or crocheted	T-shirt	537
6113	Garments, made up of knitted or crocheted fabrics of heading 5903, 5906 or 5907	jacket	463
6114	Other garments, knitted or crocheted	socks	1 356
6115	Pantyhose, tights, stockings, socks and other hosiery, including graduated compression hosiery (for example, stockings for varicose veins) and footwear without applied soles, knitted or crocheted	socks	5 829
6116	Gloves, mittens and mitts, knitted or crocheted	socks	1 684
6117	Other made-up clothing accessories, knitted or crocheted; knitted or crocheted parts of garments or of clothing accessories	socks	423
6201	Men's or boys' overcoats, car coats, capes, cloaks, anoraks including ski jacket, windcheaters, wind-jackets and similar articles, other than those of heading 6203	jacket	3 215
6202	Women's or girls' overcoats, car coats, capes, cloaks, anoraks including ski jackets, windcheaters, wind-jackets and similar articles, other than those of heading 6204	jacket	4 825
6203	Men's or boys' suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches and shorts (other than swimwear)	jeans	12 249

6204	Women's or girls' suits, ensembles, jackets, blazers, dresses, skirts, divided skirts, trousers, bib and brace overalls, breeches and shorts (other than swimwear)	jacket	11 132
6205	Men's or boys' shirts	uniform	2 235
6206	Women's or girls' blouses, shirts and shirt-blouses	uniform	2 606
6207	Men's or boys' singlets and other vests, underpants, briefs, nightshirts, pyjamas, bathrobes, dressing gowns and similar articles	uniform	403
6208	Women's or girls' singlets and other vests, slips, petticoats, briefs, panties, nightdresses, pyjamas, négligés, bathrobes, dressing gowns and similar articles	uniform	687
6209	Babies' garments and clothing accessories	jeans	355
6210	Garments, made up of fabrics of heading 5602, 5603, 5903, 5906 or 5907	jacket	3 485
6211	Tracksuits, ski suits and swimwear	jacket	1 900
6212	Brassières, girdles, corsets, braces, suspenders, garters and similar articles and parts thereof, whether or not knitted or crocheted	jacket	828
6213	Handkerchiefs	dress	26
6214	Shawls, scarves, mufflers, mantillas, veils and the like	dress	490
6215	Ties, bow ties and cravats	jacket	54
6216	Gloves, mittens and mitts	socks	559
6217	Other made-up clothing accessories; parts of garments or of clothing accessories, other than those of heading 6212	jacket	210
Total volume			101 152

Appendix D. **Description of impact categories**

Descriptions below about the impac categories of climate change, water scarcity impact and toxicity are taken from Roos et al. (2015) and Peters et al. (2019), with some minor modifications.

Climate change

Climate change refers to the consequences of increased average temperatures of the earth's atmosphere and oceans. This increase is mainly because of emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) from anthropogenic sources such as the combustion of fossil fuels and deforestation (IPCC 2013).

For characterising climate impact, in this report we used the Global Warming Potential (GWP) with a 100-year perspective (GWP100) expressed in kg CO_2 equivalents (IPCC 2013), and assumed that biogenic CO_2 emissions are climate neutral. The latter assumption presumes that within relevant spatial system boundaries (e.g. at a landscape or national level) or within a reasonable time horizon (e.g. within one rotation period: the time period from harvest to harvest), the forestry or agriculture that generates the extracted biomass is carbon neutral. This means that the land management practices are assumed to ensure that as much carbon is sequestered (above and below ground) as is harvested. In other words, the land is sustainably used with regard to carbon extraction.

Energy use

To consider total energy use (both renewable and non-renewable energy) reflects a concern about the equitable sharing of all energy resources among contemporary needs. To consider an energy use indicator is also relevant as it is a driver behind many other impacts, and as it can be used as a basis for identifying parts of the product system with a potential for increased (energy) efficiency, regardless of whether the energy happens to be, in the current system, provided by renewable or non-renewable resources. In the two LCA software used in the present study, somewhat different energy use indicators were used, as the software packages had not implemented the same indicators. In Gabi, we used the renewable and non-renewable primary energy demand (PED) indicator, and in Simapro we used the renewable and non-renewable cumulative energy demand (CED) indicator. These indicators measure energy use in similar ways, but there could possibly be slight differences in how they interpret LCI data (see the slightly differing energy use results of Appendix E) – these differences have not been further explored in the present study,.

Water scarcity impact

Freshwater resources, particularly surface water flows in lakes and rivers, and groundwater flows and stocks (which include deep aquifers with slow recharge rates) are increasingly under stress due to human industrial and agricultural interventions. Excessive consumption of water by for example cotton production can have consequences, not only for other human users of water in the local area, who might have put it to use in food production, but also downstream users and the environment. Environmental impacts of excess water use include the destruction of wetland ecosystems, riparian forests and the extinction of associated animals. Additionally, the reduction in river flows reduces the resilience of river systems to nutrient and other pollutant discharges.

Water scarcity impact is considered in this LCA using the AWARE method (Boulay et al. 2018). This is essentially a midpoint indicator system, in which the use of water in a catchment is adjusted by a factor between 0.1 and 100 that reflects the scarcity of water in the location of use. We used the method as implemented in the LCA software Simapro.

Land use impact

Land use and land use change can have numerous environmental impacts, including erosion, loss of fertile topsoil, water availability, water quality, biodiversity loss, etc., which can have subsequent impact on ecosystem services: the provision of food, feed and fibre, air quality and water purification, nutrient cycling, etc. Often the impacts are connected, e.g. loss of water and topsoil can harm biodiversity. In the present report, the ambition has been to follow the PEFCR guidance on recommended LCIA methods, which for land use impact recommends the use of the soil quality index (SQI). SQI is an aggregated indicator based on four midpoint indicators modelled using the LANCA 2.5 model (de Laurentiis et al. 2019), reflecting four consequences of land use and land use change: biotic production loss, erosion, groundwater regeneration reduction, and infiltration reduction (i.e., reduced water infiltration capacity, which influences water flow regulation and water purification). SQI and LANCA 2.5 were, however, not yet supported by the LCA software used in the present study (Gabi and Simapro), and therefore land use impact was instead presented at the level of the four midpoint indicators using LANCA 2.3[23]. Each of these midpoint indicators consists of two sub-indicators, one reflecting occupation land use (i.e., the impact of occupying a piece of land during a period of time) and one reflecting transformation impact (i.e., the impact of transforming a piece of land from one state to another). By multiplying the transformation impact with a regeneration time, the two indicators can be aggregated. When aggregating to the SQI, de Laurentiis et al. (2019) assume regeneration times of 20 years for biotic land uses and 85 years for artificial land uses (sealed land). As it was not practically possible to apply several regeneration times in the present study, 85 years was used for all kinds of land uses. Note that this simplification leads to a overestimation of the impact of processes and products dominated by biotic land uses in relation to those dominated by artificial land uses. Due to these of shortcomings of LANCA as implemented in Gabi, the results of land use impact were associated with high uncertainties and thus only quantitatively presented for the T-shirt, see Section 4.3, and qualitatively discussed at the national level, see Section 4.2.2.

Toxicity

The toxicity has been evaluated with the LCIA method USEtox (Rosenbaum et al. 2008, Huijbregts et al. 2015). USEtox calculates characterization factors for human toxicity and freshwater ecotoxicity at midpoint level. The characterization factor for human toxicity impacts (human toxicity potential) is expressed in comparative toxic units (CTUh), and is the estimated increase in morbidity in the total human population, per unit mass of a chemical emitted. The result is calculated as [CTUh per kg emitted] = [disease cases per kg emitted]. All

[23] LANCA 2.3 includes *five* midpoint indicators, but as two of them show strong correlation, one of these two was omitted when creating the aggregated SQI indicator (de Laruentiis et al. 2019). The present study considers the four midpoint indicators included in the SQI indicator.

cases of non-mortal human toxicity impacts, which do not lead to death but to disability and illness, are weighted against their relative severity compared to death. The characterization factor for freshwater ecotoxicity impacts (ecotoxicity potential) is expressed in comparative toxic units (CTUe), and is an estimate of the potentially affected fraction of species (PAF) integrated over time and volume, per unit mass of a chemical emitted. The result is calculated as [CTUe per kg emitted] = [PAF × m^3 × day per kg emitted]. One CTUe thus equals one cubic meter of freshwater where the species in the ecosystem are exposed daily to a concentration above their no-observed effect concentration (NOEC). An environmental concentration is considered to present an acceptable risk if not more than 5% of all species is exposed above their NOEC.

Many substances currently lack published characterisation factors for the LCIA of toxicity (Roos et al. 2017a). USEtox (Rosenbaum et al. 2008, Huijbregts et al. 2015) is currently the method that covers most chemicals, although also this model is lacking characterisation factors for many textile chemicals and their (sometimes more toxic) breakdown products. Therefore, the modelling of the toxicity is based on the framework created in Mistra Future Fashion (Roos 2016) where the life cycle inventory of textile processes is matched with characterisation factors in the impact assessment. Characterisation factors for toxicity are taken primarily from USEtox, the COSMEDE database (ADEME 2015) and Roos et al. (2017). The contribution from direct toxicity (direct emissions from foreground processes such as bleaching and dyeing) is reported separately from the background toxicity (toxic emissions from background processes such as fuel production and waste management).

Appendix E. **Sensitivity analysis: comparison of LCA software**

The results in Chapter 4 for climate impact and energy use were derived using the LCA software Gabi. These impact categories were also modelled in Simapro. Modelling in two software packages in parallel has enabled us to identify and correct several errors in both models. Remaining deviations are illustrated in below figures and are probably due to slight differences in the way the databases have been integrated in Gabi and Simapro, respectively (to some extent this a manual process prone to human errors). As such, the comparison of software models is thus a form of sensitivity analysis with respect to the choice of database. Overall, there appears to be little influence from the choice of software. Results are only shown for the T-shirt, the jeans and the dress – the results were similar for the remaining garments thus they were omitted for brevity.

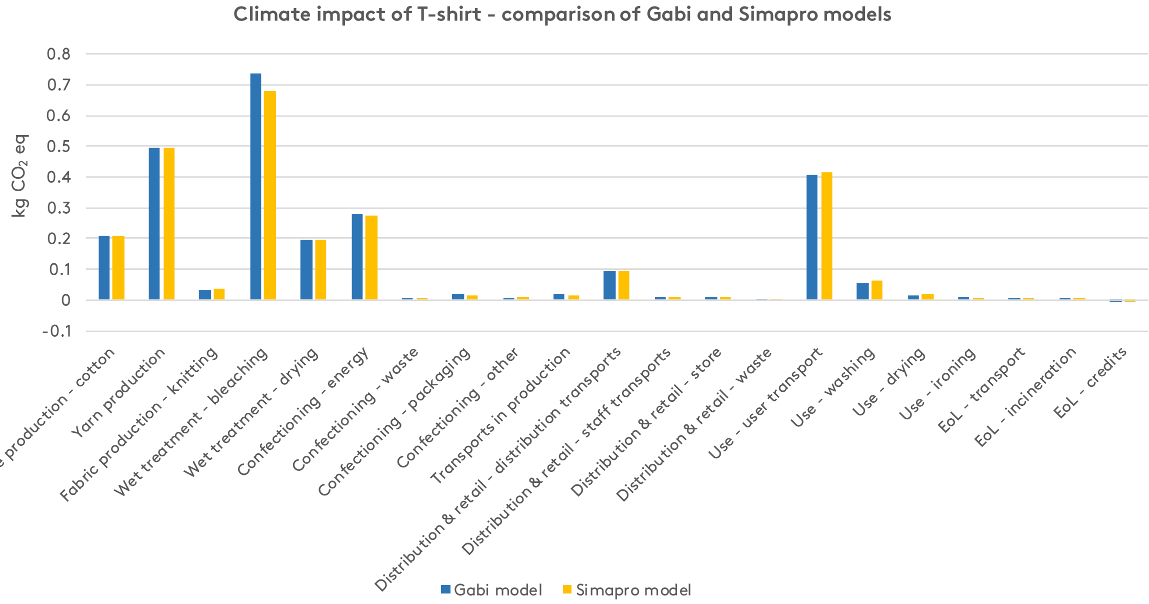

Figure E-1: Climate impact results of the T-shirt for the Gabi and Simapro models, per garment service life.

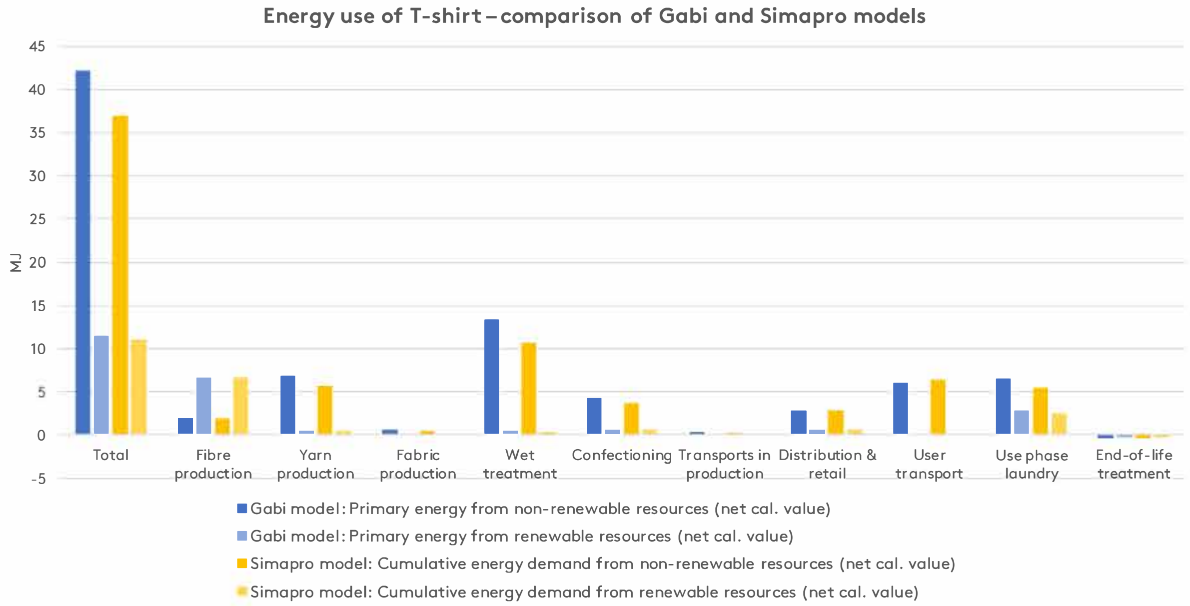

Figure E-2: Energy use results of the T-shirt for the Gabi and Simapro models, per garment service life.

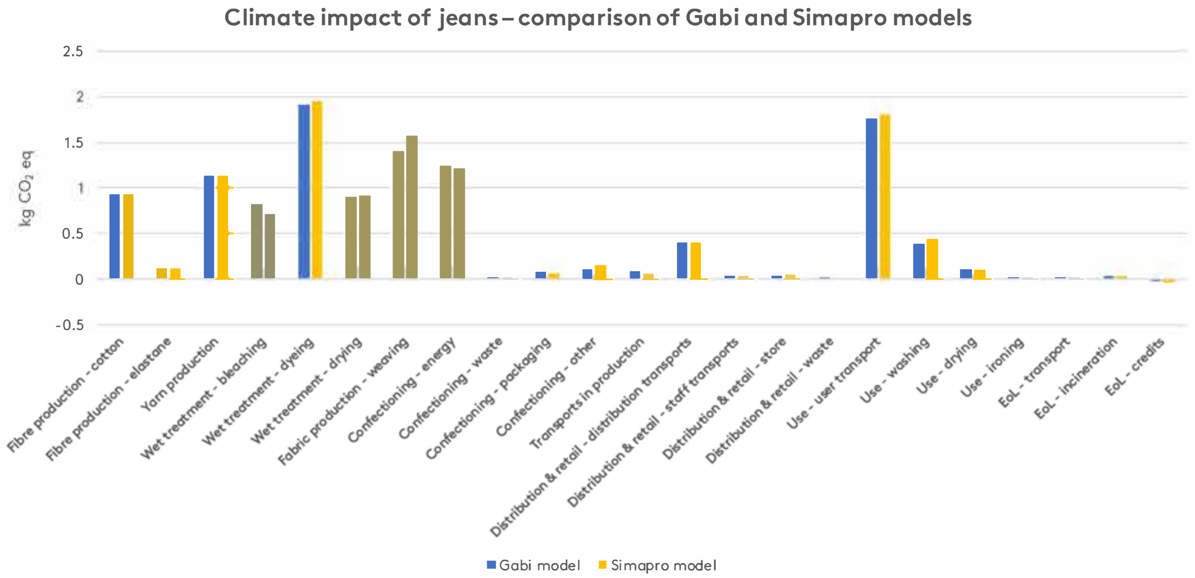

Figure E-3: Climate impact results of the jeans for the Gabi and Simapro models, per garment service life.

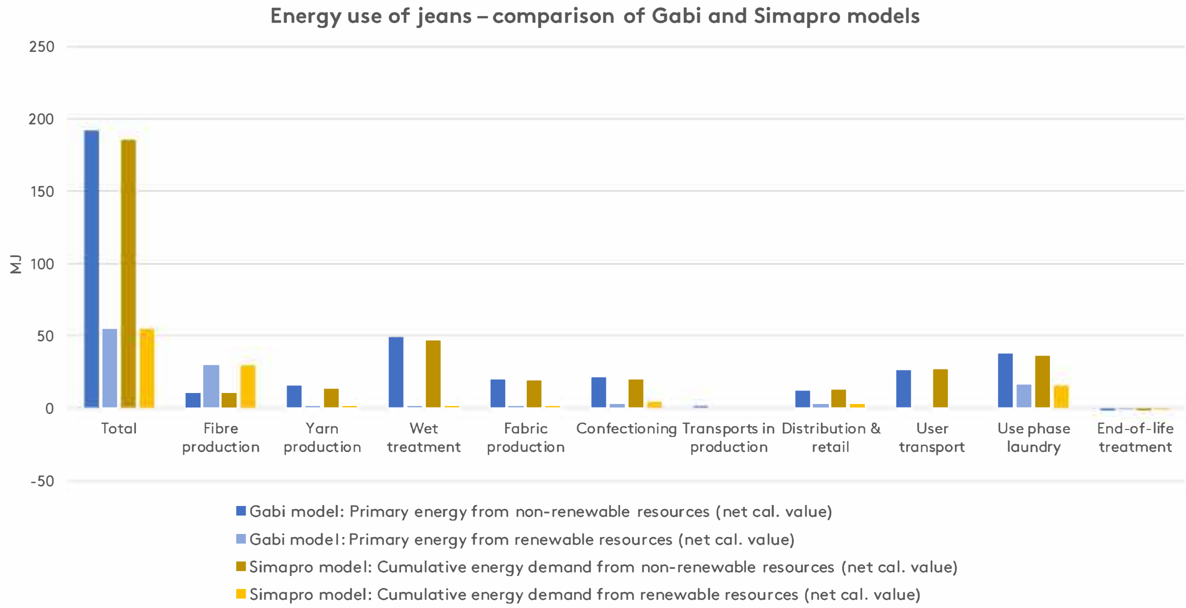

Figure E-4: Energy use results of the jeans for the Gabi and Simapro models, per garment service life.

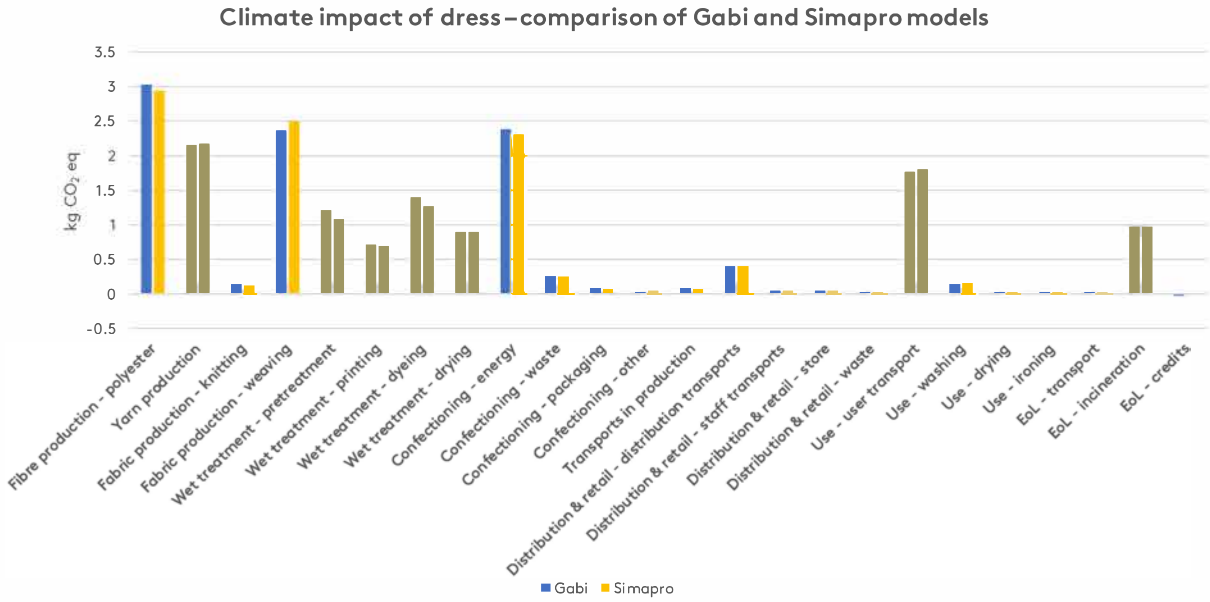

Figure E-5: Climate impact results of the dress for the Gabi and Simapro models, per garment service life.

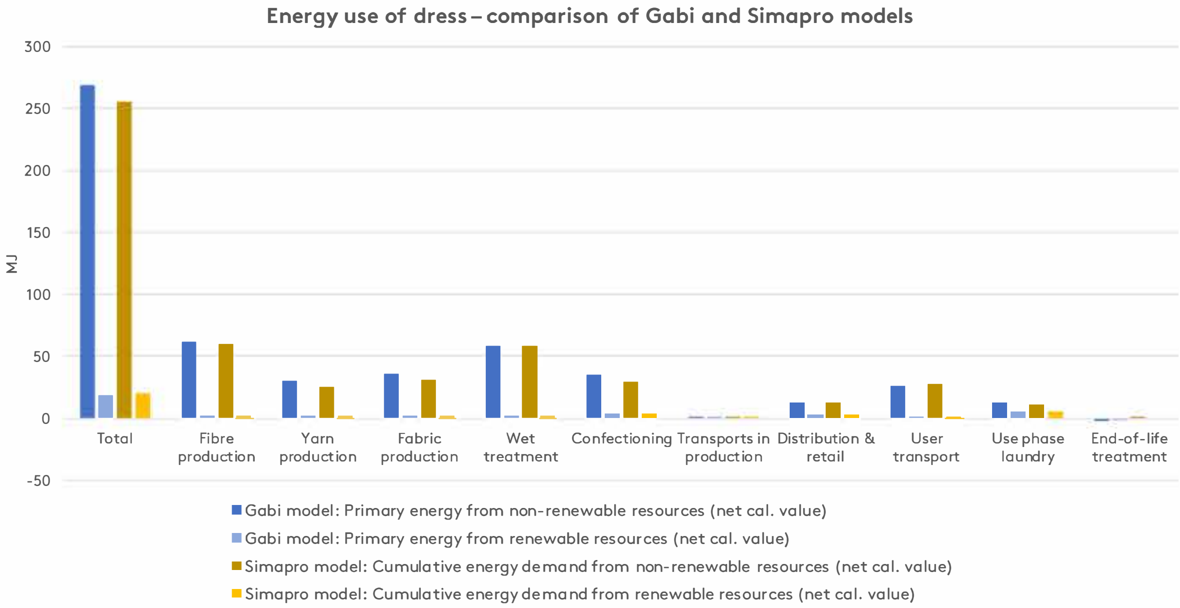

Figure E-6: Energy use results of the dress for the Gabi and Simapro models, per garment service life.

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Mistra Future Fashion is a research program that focuses on how to turn today's fashion industry and consumer habits toward sustainable fashion and behavior. Guided by the principles of the circular economy model, the program operates cross disciplinary and involves 60+ partners from the fashion ecosystem. Its unique system perspective combines new methods for design, production, use and recycling with relevant aspects such as new business models, policies, consumer science, life-cycle-assessments, system analysis, chemistry, engineering etc.

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