# Comparative LCA

**Viscose vs Cotton T-shirts**

Mikael Angelstam (mikang@kth.se), Anna Artman (aartman@kth.se), Joel Hanström (joehan@kth.se), David Martínez Rodríguez (davidmr@kth.se) and Daniel Uskali (duskali@kth.se)

Group 11

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## Abstract

Today the world is consuming almost 70 000 Mt of apparel every year, this accounts for 2% of the worlds GDP and presents a large threat to the environment (ICAC, 2013). One way to reduce the environmental impact is to change to another type of fabric than the traditional ones. This report is investigating if Swedish viscose could be that type of fabric, it is labelled as a natural product since it is produced from wood pulp. The LCA is conducted for two of T-shirts made from Swedish viscose and Asian cotton. The functional unit is a cotton or viscose T-shirt of 200 g during its whole life cycle, including the disposal phase, used in Sweden during 2 years, washed once every two weeks (for a total of 52 wash cycles). The system boundary for this study is cradle-to-grave. The impact categories that are assessed for the study are *freshwater eutrophication*, *terrestrial ecotoxicity* and *water depletion*. The LCA study shows that the viscose T-shirt has the lowest overall impact compared to the cotton T-shirt. A sensitivity analysis is conducted by remove the tumble dryer in the use phase. The lack of LCI data for making a T-shirt with viscose fabric could reduce the credibility of the results, future LCA studies are needed with data from the production phases of a viscose T-shirt.

# Contents

# 1 Introduction

The demand for fabrics at a global scale is increasing with population and affluence growth. Therefore, if we follow the general $I = PAT$ equation[1] (Graedel and Allenby, 2010), the negative environmental impact due to the supply of, mainly, cotton and synthetic fibres also rises. Cotton consumption has been stable between 1992 and 2010, but synthetic fibres consumption has increased more than twofold – out of the total world apparel fibre demand in 2010, estimated at over 69 billion tons, cotton and synthetic fibres consumption constitute 32.9% and 60.1% respectively (ICAC, 2013).

Cotton production has a large water footprint, requires significant pesticide use and is often grown in drought sensitive areas, therefore posing a considerable environmental impact in terms of land use, water use and toxicity. Synthetic fibres, on the other hand, are mainly derived from fossil oil, resulting in increased global warming potential by the unleash of fossil carbon stocks and, in addition, the material is biologically persistent and leads to long term environmental impacts in both terrestrial and marine ecosystems (van Dam, 2008).

New alternatives to natural cellulose-based fabrics using Swedish wood pulp could be a potential trend breaker and help alleviate the overall negative impacts, if they prove to be relatively more efficient or less damaging than cotton or synthetic fibres with regards to clothing apparel consumed in Sweden. Examples of such man-made (or regenerated) cellulose fibres are the diverse types of Rayon: lyocell, viscose and modal. The main differences between these fibres stem from the production process and the chemical routes that are used to convert wood pulp to cellulosic materials (Woodings, 2001). On one hand, lyocell, a much newer process, is based on direct dissolution of the cellulose in an amine-oxide solvent (N-methyl morpholine oxide, abbreviated *NMMO*). The benefits of this approach is that NMMO itself is not toxic and that no hazards are caused by the effluent (White, 2001). On the other hand, viscose, historically older, uses a combination of sodium hydroxide, carbon disulphide and sulphuric acid to recover the dissolved cellulose (Wilkes, 2001).

According to White (2001) and Shen and Patel (2008), lyocell fibres have a higher environmental performance than viscose, due to the inherent differences in their manufacturing processes. Therefore, it would be the best choice to compare to cotton in the present study, to assess the potential benefits of using the former instead of the latter. However, industrial patents are still in place for the lyocell manufacturing and thus the detailed process data that is needed for a comprehensive *life cycle assessment* (LCA) is not available. Because of the data unavailability, this project is focused on assessing cotton and viscose, instead.

# 2 Goal and scope definition

The following subsections cover in more detail the issue that this particular LCA is addressing, as well as the boundaries and limitations of the assessment itself.

## 2.1 Goal of the study

The project focuses on the difference in environmental impact when producing and using viscose garments compared to cotton, by analysing the full cradle-to-grave life cycle impacts of a T-shirt made from either of the two materials. Special focus will be put into chemicals (pesticides, fertilizers) and water and land-use in the impact assessment

[1]The $I = PAT$ equation stands for $Impact = Population \cdot Affluence \cdot Technology$.

process, because these are the impact categories which cotton has the highest burdens in.

### 2.1.1 Type of LCA

The type of study devised to assess the differences between cotton and viscose T-shirts is a comparative and attributional LCA, since we are comparing products that perform the same qualitative function (as explained in the Functional Unit subsection, later). We do not intend to do a consequential assessment, because we are not studying a system in transition — users are not shifting from one product to the other.

### 2.1.2 Intended application of LCA results

As stated before, the aim of the study is to provide the necessary insights into the potential impacts of both materials, as the basis for clothing, to understand whether viscose (wood-based regenerated cellulose fibres) could perform as a more environmentally-friendly substitute for cotton. Not only this replacement could deliver a lower environmental impact from a kind of product that is a basic necessity, but could also help reduce the dependency of the fashion industry and users to the global production of cotton. In particular, the environmental impact categories to be compared more thoroughly are *Freshwater Eutrophication*, *Terrestrial Ecotoxicity* and *Water Depletion*.

### 2.1.3 Intended audience

The audience that we intend to deliver the study to is composed of the stakeholders in the textile industry, as well as the fashion users. The reason behind this is that both textile producers and final users can have a stronger basis for decision when it comes to selecting the type of fibre they want to use, based on the environmental burdens of the textiles. Furthermore, fashion companies could start using this information to do "eco-labelling" of the garments, thus providing incentives to users so they choose the most eco-efficient fabric possible.

## 2.2 Scope of the study

### 2.2.1 Functional unit

The chosen functional unit (FU) of the study is a cotton/viscose T-shirt of 200 g during its whole life cycle, including the disposal phase, used in Sweden during 2 years, washed once every two weeks (for a total of 52 wash cycles).

The choice for the number of wash cycles is based on an assumption and is subject to a sensitivity analysis later in the interpretation phase of the project, in order to assess whether the wash cycles contribute to a large extent to the potential impacts within the life cycle.

With regards to the actual function of the compared T-shirts, we are aware that some properties of the garments might differ because of the choice of material. Textile fibres have many different properties that should be considered when comparing alternatives in a comprehensive and complete way. These are, at a basic level, fineness, length and density. However, one can also consider: thermal properties, friction, quantity and rate of heat and water absorption, retention of water, swelling, tensile properties, variability, elasticity, rheology, directionality, thermo-mechanics, breakage and fatigue as well as mechanical, electric such as dielectric, resistance, statics and optical properties (Morton and Hearle, 2008). We do not assess the T-shirts in relation to any of these characteristics, but rather in terms of being a fashion element, for which many people are not concerned on the fine differences between fabric types.

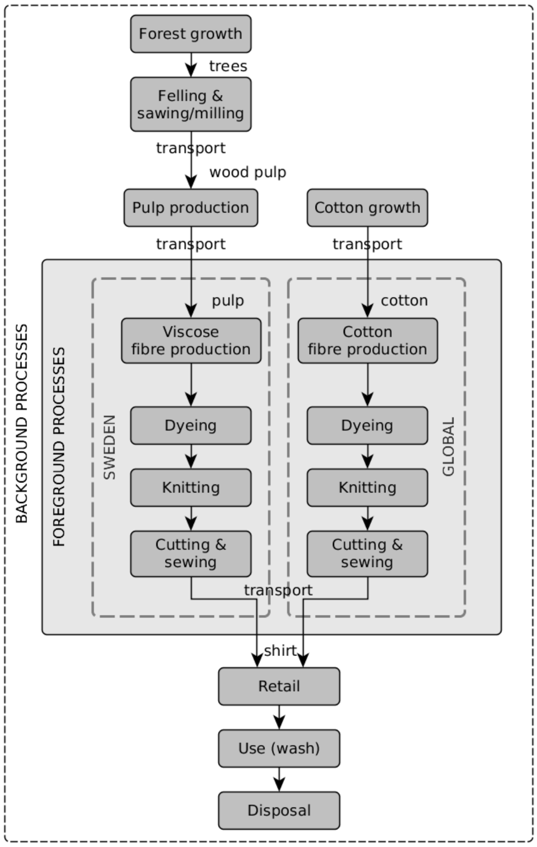


**Figure 1:** Initial flow chart including foreground and background processes of the cradle-to-grave life-cycle of a T-shirt made from Viscose and Cotton respectively.

### 2.2.2 System boundaries

This LCA study includes inputs of material and energy needed in the production of viscose and cotton T-shirts, all along their life cycles. A more comprehensive explanation of the included processes is given in the following sections and in Figure 1.

#### Initial flow chart

Figure 1 represents the flowchart of the defined system, where the foreground processes (manufacturing process for cotton and viscose T-shirts) are shown in some detail: thread production, dyeing, knitting and clothing manufacture. Background processes include raw material acquisition, the use phase and final disposal. The boundary between foreground and background processes is drawn on the basis of market availability of cotton and wood pulp, which the textile industry uses as primary inputs. Moreover, textile manufacturers have no influence in the raw material extraction, typically.

These two thread material types will then be modelled into identical stages of thread-to-shirt production processes. There is no detailed data available for the exact material and energy inputs required for all of the individual steps for each of the materials. This is unfortunate since its this part of the production that constitutes the foreground processes of the T-shirt production. The finished T-shirts will be modelled as being retailed, used for two years and then recycled within Sweden.

**Geographical boundaries**

The geographical boundaries for the retail, use and waste management phases and are set to the national borders of Sweden. In the case of the cotton shirt, the production phase of both the fabric and the T-shirt itself are located in Sri Lanka. However, the cultivation of the cotton and its collection is situated in India. For the viscose T-shirt, European and Swedish supply chains are used, to the maximum extent possible, both for manufacturing and raw material extraction. The choice of countries for the cotton production and manufacture is determined by the data availability, as presented in the Life Cycle Inventory analysis section.

**Time horizon**

As recent data as possible is used so it is easier to perform the comparison in the Impact Assessment phase. Regarding the generalization of the results in the future, projected long term impacts of today's production system might not be accurate in the future if circular economy is fully implemented, since increased material recirculation would require less material inputs from the biosphere. Aside from this, all long-term impacts derived from the disposal phase of the product are included in the assessment.

**Cut-off criteria**

Difficult to model processes are left out from the LCA study, such as the potential travel between home and the store where the T-shirt is bought by the user. The main issues with these processes are the high uncertainties involved when doing any kind of assumptions on them. No other cut-off criteria are used throughout the project, but since the aim of the project is to assess the performance of viscose and cotton garments with relation to pesticides, fertilizers, water and land-use, some of the impact categories might be excluded from the discussion.

**Allocation**

All the included textile production processes refer to bigger amounts of T-shirts or intermediate materials than what is defined in the functional study of this project this is due to data availability. However, since none of these processes output co-products (they are all focused into the production of T-shirts only), the allocation of the single T-shirt that the FU represents is done by mass and introduces no uncertainties to the LCA.

Another allocation is performed when calculating the amount of energy and water used in the use phase (for washing and drying): an assumption is made that the T-shirt is washed along with another 8 kg of clothes, and the burdens are distributed also based on the mass proportion.

### 2.2.3 Assumptions and limitations

Besides the amounts of kilometres that the transportation processes take (detailed in Section 3), the main assumptions in the LCA model concern the manufacturing process of the t-shirts. We assume, because of a lack of data, that the knitting and dyeing and the cutting and sewing of the fabric into the garments are equal in terms of electricity consumption and heat (Shen and Patel, 2008). Not only this, but we also assume that material efficiency (losses of fibre and textiles in the manufacture process) are the same. Dyeing of the garments is also assumed to be equivalent and, furthermore, no pigment is used in the model, since it was not found in the EcoInvent database(Weidema et al., 2013).

The retail, use and disposal phases are also assumed to be equal; actually, the assumption is that they are sold in the same store, used the same way and disposed of the same way. However, due to the geographical setting of the manufacture processes, different transport distances and vehicles are used in the diverse steps that configure the production supply chain. Moreover, the electricity mixes for the processes taking place in different geographical areas also differ, so distinct impacts are derived from electricity consumption.

### 2.2.4 Impact categories and impact assessment method

The impact assessment method chosen is ReCiPe Hierarchist, with midpoint impact assessment, which is recommended by the European Commission and is fixed for practical reasons in this course (Finnveden, 2016).

Regarding the impact categories that the study is focused on, they were chosen on the basis of the biggest relative difference between the viscose and cotton material, this is, those categories in which a bigger difference in impacts could be found both in the characterisation and normalisation steps of the life cycle impact assessment. Concretely, the chosen impact categories are: *freshwater eutrophication*, *terrestrial ecotoxicity* and *water depletion*. This set of impacts is very much aligned with the initial design of the study, in which we considered water use and fertiliser and pesticide use to be the most important issues to assess with this LCA.

### 2.2.5 Normalization and weighting

On one hand, normalisation is used in the project to put the relative impacts of the t-shirts in perspective, by comparing them to the yearly average of an European citizen. This way, meaningful impacts can be evaluated in more detail (with more focus on certain impact categories). On the other hand, weighting is a controversial step and it is not used in this research project, since it is a comparative LCA study and is not recommended by Finnveden (2016) and not even allowed in comparative studies by the ISO 14040:2006 standard (Finnveden et al., 2009).

# 3 Life Cycle Inventory analysis

In this section the flowcharts made in SimaPro (PRé Consultants, 2016, Version 8.2.0 - Classroom License) of the cotton and viscose T-shirts are presented. The used data is shown in tables for the different stages both from the sources and when it comes to own assumptions.

## 3.1 Process flowchart

The process flowcharts made in SimaPro for the two life cycles can be seen in Figure 2 and Figure 3.

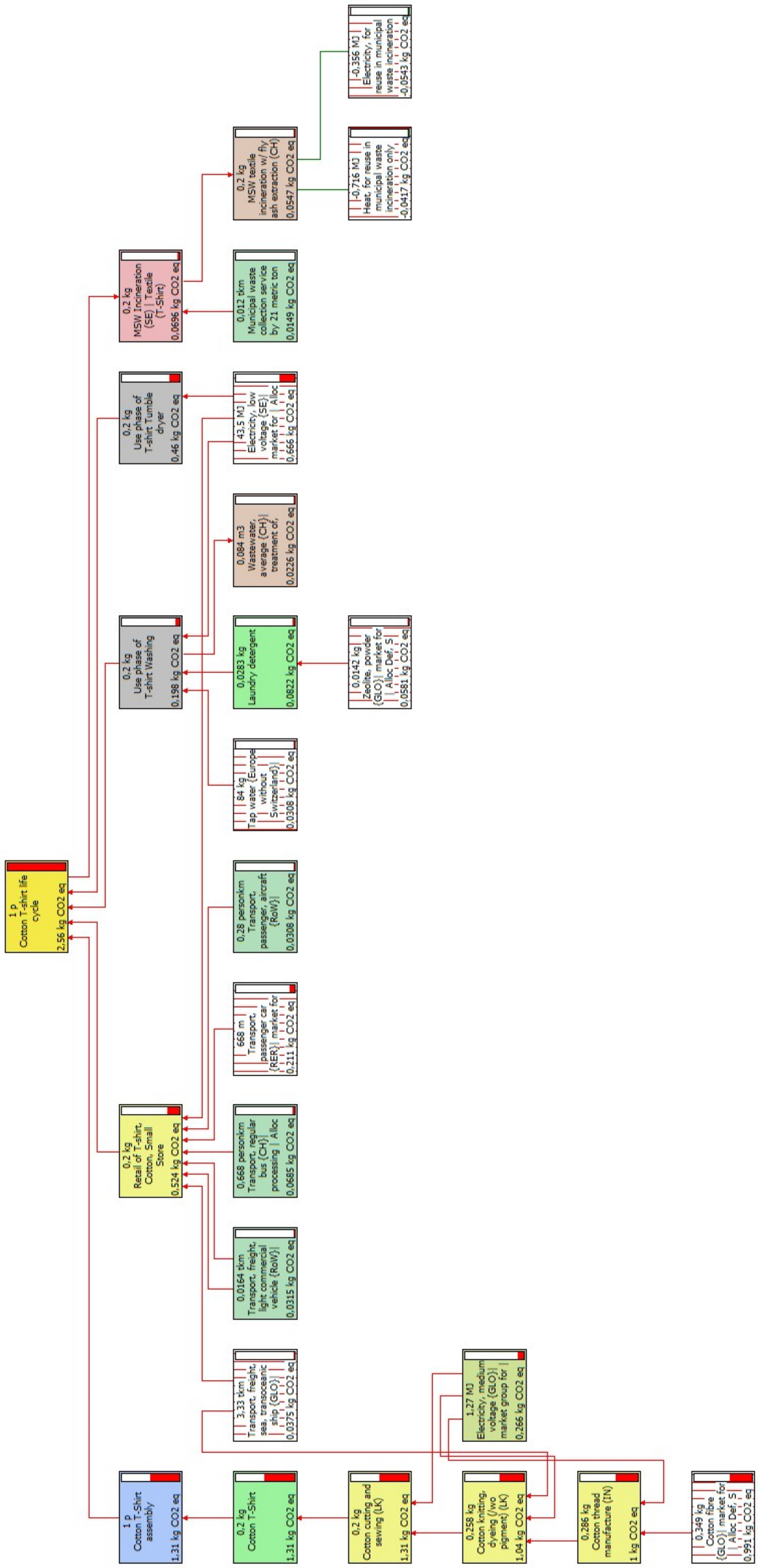


**Figure 2:** Flowchart for the life cycle of the cotton T-shirt, at a 0.5% cut-off.

**Figure 3:** Flowchart for the life cycle of the viscose T-shirt, at a 0.5% cut-off.

## 3.2 Data

The data collected for the LCA was based on a similar study that analysed a t-shirt made of organic cotton (Wendin, 2007). The data collected for the comparative LCA in the SimaPro is taken from the EcoInvent 3 database as well as the Dem Collective report (Wendin, 2007) together with own assumptions. The created processes in SimaPro can be seen in Tables 1-14. The early production stages of cotton and viscose are available in the LCA databases in SimaPro. The cotton model will be used as is based on global data while the viscose model will be adjusted to a hypothetical production taking place in Sweden, using raw materials sourced from within the European market. The amounts of every material are for the whole facilities and are scaled down to the functional unit when making the assembly.

**Please note that all the tables are added in the Appendix: LCI data, at the end of the document.**

### 3.2.1 Cotton T-shirt data

The manufacturing of the cotton thread takes place in India and the data used can be seen in Table 1. Since the manufacturing is mechanical, only electricity is used for the processing of cotton fibre to thread. Almost 18% of all cotton fibre used as an input are gone to waste, to make 1 kg of cotton thread a total amount of 1.22 kg cotton fibre is required.

The cotton thread is transported from the thread manufacturing in India to the knitting and dyeing factory, in Sri Lanka. The data used for the knitting and dyeing can be seen in Table 2. The total amount of cotton that is knitted and dyed are 13 300 t in this factory, 1300 t of the cotton fibre goes to waste. All types of threads that are used in this factory are assumed to use the same amount of electricity and are transported the same distance. The total output of knitted and dyed cotton that is used for the production of our product for one year is 1486 kg.

The dyeing process requires heating for which the petroleum is used, pigments are not used due to the lack of data in SimaPro. The chemicals used are both for the dyeing and knitting process.

The knitted and dyed cotton are then transported to the cutting and sewing factory that is also located in Sri Lanka where the cotton T-shirts are made. The data for the cotton cutting and sewing can be seen in Table 3. 1486 kg cotton is used to make 1150 kg T-shirts. The cutting and sewing processes are mechanical that only requires electricity and water usage.

The cotton T-shirts are shipped from the cutting and sewing factory in Sri Lanka to the small store in Stockholm by a freight ship, according to Wendin (2007) this distance is 13 329 km. The data for the retail of the cotton T-shirt can be seen in Table 4. The distance from the sewing factory to the dock and from the dock to the store were assumed to be the same. A small store uses 15 000 kW h according to Wendin (2007); the data was likewise to the one that EEF (2009) presented. All cotton T-shirts that are produced during one year are assumed to be sold during that year.

### 3.2.2 Viscose T-shirt data

The viscose fibre data used can be seen in Table 5 and is an updated version of the viscose fibre presented in EcoInvent, the input of electricity and transportations are changed to the Swedish market. The wood pulp have been sent to Aspa paper mill outside Askersund, Sweden where its processed to viscose fibre.

The viscose fibre is transported from Aspa paper mill to a viscose thread factory in Borås, Sweden. The viscose thread manufacturing data can be seen in Table 6 and is assumed to be identical to the cotton thread manufacturing. Since the manufacturing is mechanical, only electricity is used for the processing of viscose fibre to thread, Almost 18% of all viscose fibre used as an input are gone to waste, to make 1 kg of viscose thread a total amount of 1.22 kg viscose fibre is required.

The viscose thread manufacturing is assumed to be located is the same factory as where the knitting and dyeing processes take place, thus no transport is required. The data inventory for knitting and dyeing viscose thread can be seen in Table 7 and uses the data for organic cotton that Wendin (2007) presents.

The cutting and sewing processes are modelled as they are taking place in the same factory in Borås, thus no transported is required. This data inventory is based on the cutting and sewing of cotton thread process (Wendin, 2007) and the data used can be seen in Table 8. Of the 1414 kg viscose thread added to the process, 264 kg will go to municipal waste collection.

The viscose T-shirts are shipped from the factory in Borås to the small store in Stockholm by a freight lorry, this distance is 407 kg. The electricity usage in the store is the same used for Cotton t-shirt retail (SE). All viscose T-shirts that are produced during one year are assumed to be sold during that year. The data used for the retail of the Viscose T-shirt can be seen in Table 9.

### 3.2.3 Use phase data for the cotton and viscose T-shirt

The life cycle stages use and end of life are modelled to be identical for both cotton and viscose T-shirts. The two types of T-shirts are assumed to have the same use phase. The Laundry detergent was created using information from Smulders et al. (2007) and the data used can be seen in Table 10.

A person were assumed to use the cotton or viscose T-shirt for two years and wash it 52 times in total. The data used from Wendin (2007) were controlled by looking into the energy use for washing machines from Electrolux (2016) and compared with the EU Directive 2010/30/EU (EC, 2010), the result of the energy usage was almost the same. The data used for the washing of the two t-shirts can be seen in Table 11. The data used from Wendin (2007) were recalculated to fit the assumption of 52 uses of the tumble dryer during its life cycle and the data used can be seen in Table 12.

### 3.2.4 T-shirt disposal data

After two years of usage, the T-shirts are assumed to be incinerated. The cotton and viscose T-shirts are disposed as trash and are collected as municipal waste and the data for the municipal solid waste (MSW) incineration of textiles, disposal, used can be seen in Table 13. The T-shirts are incinerated, both heat and electricity are generated in this process that are reused in the same incineration plant. The data used for the incineration of textiles, treatment, can be seen in Table 14.

# 4 Life Cycle Impact Assessment

This section provides the result from the inventory analysis when looking at the comparison between the cotton and the viscose t-shirt for both the normalized and characterised impacts. The results and the chosen impact categories will provide the result for the discussion and conclusion of the impacts for the life cycle of the Two T-shirts. The differences of the life cycle stages and the comparison between the materials are shown.

The cotton t-shirt is represented in yellow and the viscose in blue in the different bar graphs when comparing the result. Later the characterized and normalized result is presented individually for the different life cycle stages for the two materials when it comes to the chosen impact categories. The method used the different bar graph when interpreting the characterized and normalized results is the ReCiPe Midpoint in the SimaPro.

## 4.1 Characterization

Viscose is preferable for the impact categories based on the characterised results (see Figure 4). Only in ozone depletion and ionising radiation is cotton slightly more preferable for the impact categories. The largest differences in impacts between the two materials are in terrestrial ecotoxicity, water depletion and marine eutrophication.

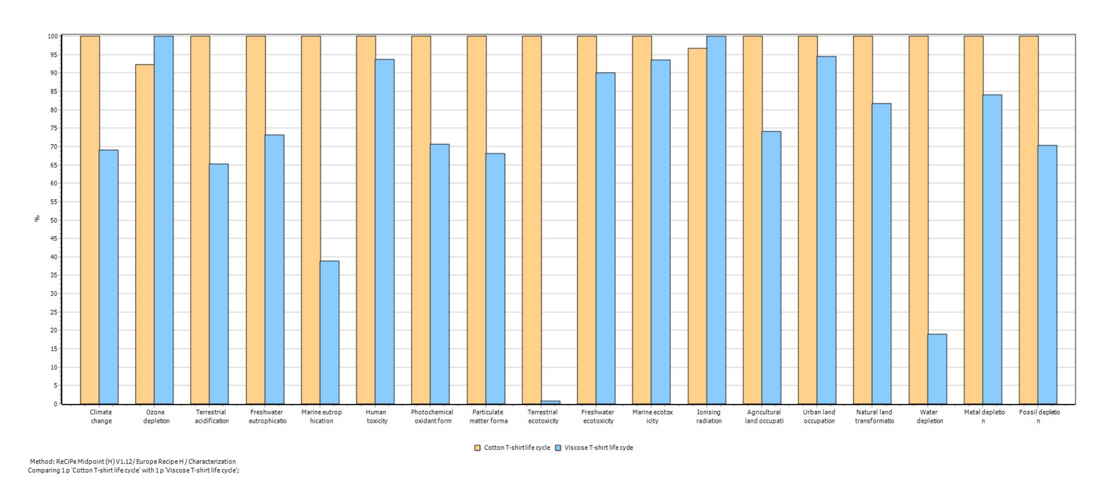


**Figure 4:** The characterised impacts presented in a bar graph between the cotton (yellow) and viscose (blue) T-shirt.

## 4.2 Normalization

The normalized results show the environmental impacts relative to the average European citizen, which can be seen in Figure 5. The impact in freshwater and marine ecotoxicity comes from energy use. The differences between materials are due to different electricity production mixes (Sweden vs rest of the world). Since the study is a material comparison, these two categories are omitted from the analysis. Therefore, the largest impact is terrestrial ecotoxicity, where cotton performs 100 times worse than viscose.

Freshwater and marine ecotoxicity comes from electricity production to the use phase, a large proportion of this originates from the municipal treatment (incineration) of scrap copper cables in the end of life. Land transformation comes mainly (40%) from hydroelectric power reservoirs as well as other sources within electricity production.

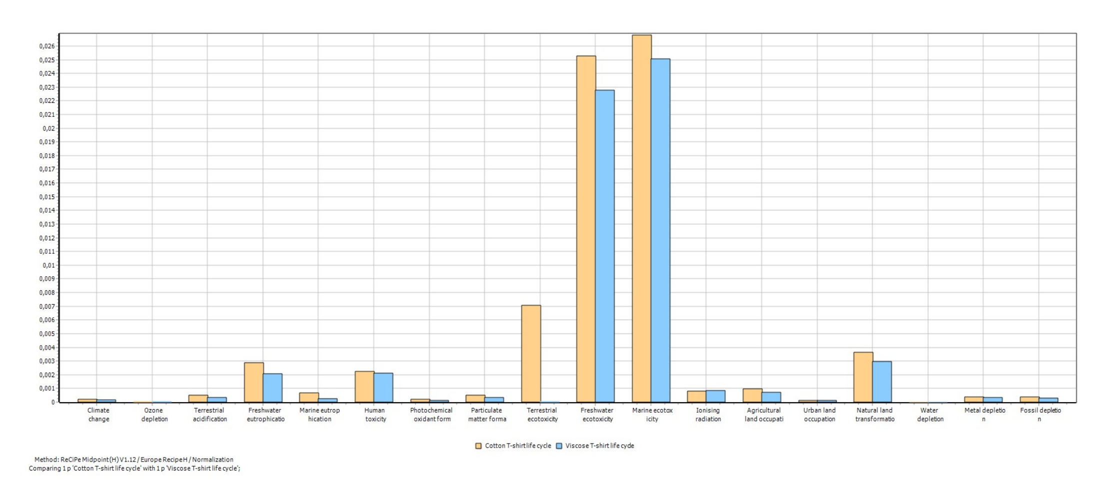


**Figure 5:** The normalized impacts for all impact categories when comparing the cotton to the viscose T-shirt.

### 4.3 Selected impact categories

The impact categorize chosen for further analysis for both normalization and characterisation are Freshwater eutrophication, Terrestrial ecotoxicity and water depletion. The characterization result in Figure 6 was compared to the normalization results in Figure 7. The normalized result shows that there is no value for the water depletion, since data is missing. Looking at the water demand for the two T-Shirts in their respectively life cycle flow chart had to be done to see values for the water depletion. This is important since the cotton production uses a high amount of water and this is the biggest factor to why the overall impact categories are higher for cotton. The terrestrial ecotoxicity has an overall high impacts for cotton compared to viscose which is due to the amount of pesticides used in cotton production that leaks out to nature. A relatively high amount of chemicals are used in pulp processes but since the demand of recirculation is higher, the impacts becomes smaller in comparison. All kind of human activities contribute to freshwater eutrophication, especially the nutrients and pesticides used in the prior stages of the both processes. Therefore the impacts in this categories is high for both of the processes.

The result in the chosen impact categories when looking at the impacts for the different life cycle stages can be seen for the cotton T-shirt in Figure 8 and for the Viscose T-shirt in Figure 9. As a further analysis the result shows proof for previous result that the T-shirt assembly has the highest impact when it comes to the Cotton T-shirt life cycle in all impact categories. This is due to prior result on the amount of water used in the production of cotton fibres. 40-50% of the contribution to the freshwater eutrophication is due to the cotton or viscose T-shirt assembly while in the other impact categories the assembly accounts for more of the impact. The freshwater eutrophication impact have a wider contribution when it comes to human activity which shows in the other stages. The Viscose T-shirt assembly also contribute mostly in the Freshwater Eutrophication and Terrestrial ecotoxicity although as can be seen, the water demand is not the highest for the assembly since less water is used in the production stage. Instead the use-phase of the viscose T-shirt when using tumble dryer and the washing machine contribute the most of its water depletion.

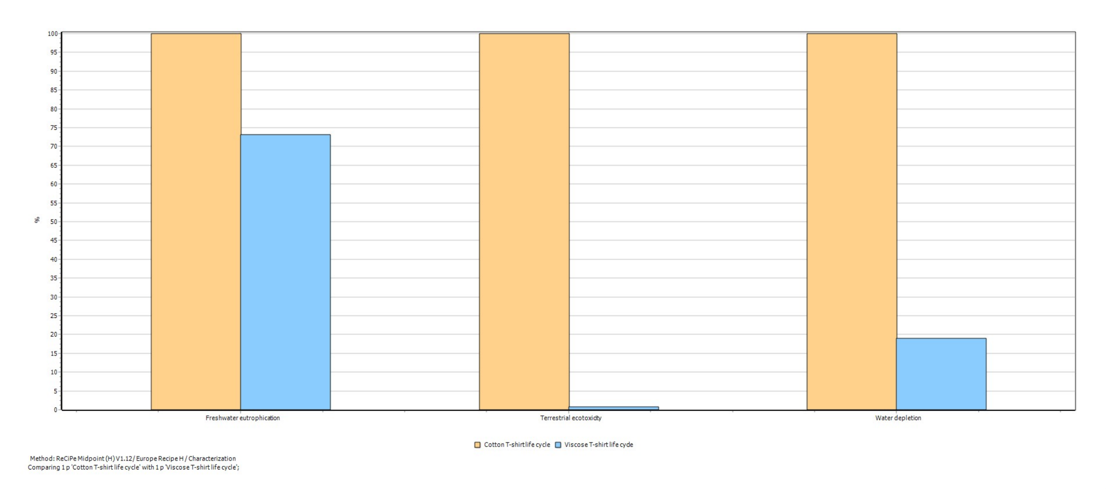


**Figure 6:** The characterization impact over the chosen impact categories comparing the viscose to the cotton T-shirt.

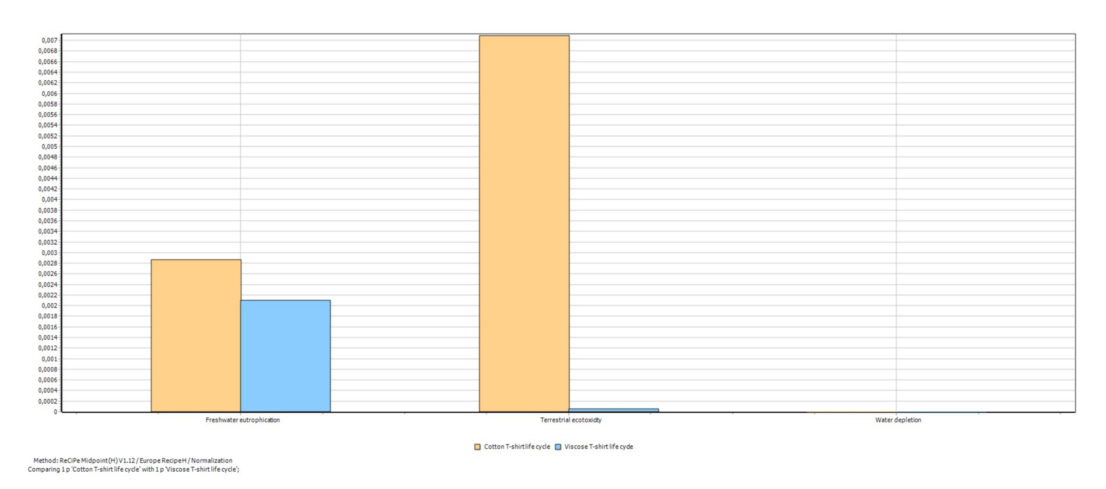


**Figure 7:** The normalized impacts of the chosen impact categories for the project when comparing Viscose to a cotton T-shirt.

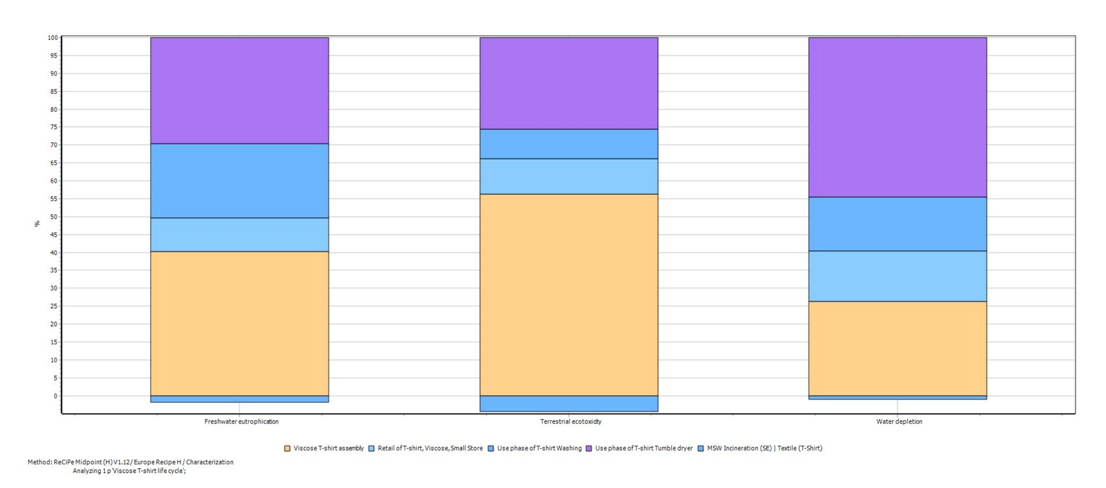


**Figure 8:** The characterized impacts when looking at the Cotton T-Shirt life cycle for the chosen impacts categories in the project.

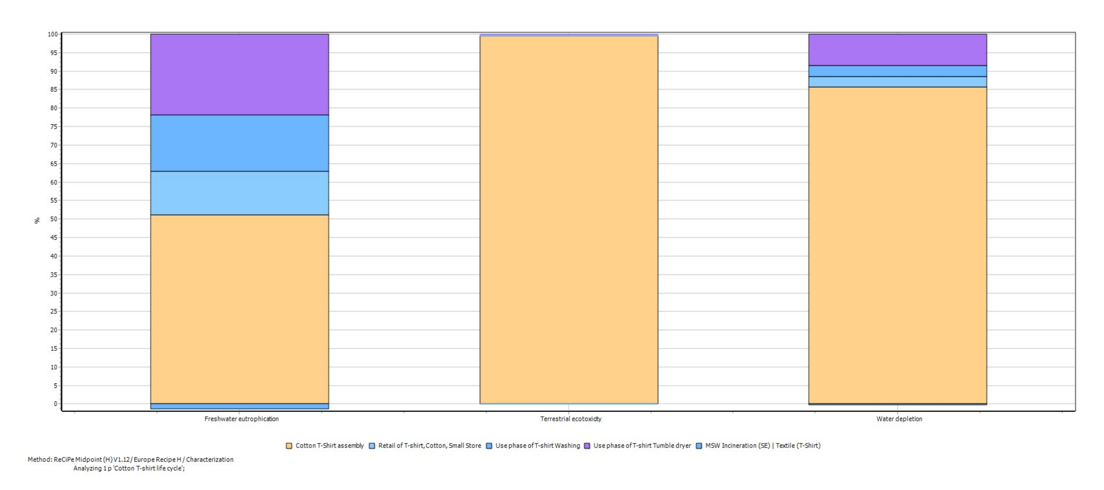


**Figure 9:** The characterized impacts when looking at the Viscose T-shirt different life cycle stages for the chosen impacts categories in the project.

### 4.3.1 Freshwater eutrophication

The viscose Freshwater eutrophication accounts for 73.2% of the Cotton. In Viscose it mainly comes from viscose fibre (40%) and electricity use in Sweden related to retail and use phase (45%) and in cotton it comes from cotton fibre (39%), electricity use in Sweden related to retail and use phase (32%), global electricity from cutting and sewing (12%) and the total T-shirt production stand for 52%.

### 4.3.2 Terrestrial ecotoxicity

In this category the impact of viscose is only 0,82% of that from cotton, this is because no pesticide has to be used in the silviculture. Whereas those chemicals are widely used in cotton agriculture. In Viscose it mainly comes from viscose fibre (48%) and electricity use in Sweden related to retail and use phase (40%) and in cotton it comes from cotton fibre production (99.5%).

### 4.3.3 Water depletion

In the water depletion category, viscose accounts for 19% of the Cotton. It mainly comes from irrigation during cotton fibre production (86%) for the cotton T-shirt and in viscose it mainly comes from electricity use in Sweden related to retail and use phase (67%), viscose fibre (25%) and tap water in the use phase (8%).

The water demand for the cotton production is the most intense and one of the additional differences compared in the project was the water demand for the both life cycles. The cotton fibre production accounts for the largest water usage when looking at the cotton T-shirt (see Figure 10). The washing phase uses the most water for the viscose T-shirt (see Figure 10). For the cotton 85.5% of the water use comes from the cotton fibre production and the life cycle water demand for Viscose is only 19% of the water demand for cotton. The washing stage is the same for both of the T-shirts and in comparison the result shows that how significant larger the water use is in the production of a cotton shirt. In Sweden when it comes to washing water as a resource is not scarce as in countries where the cotton production is made and large amount of water is used. Even Though eco-cotton is better than the conventional cotton the water use would still have similar results when doing a compression.

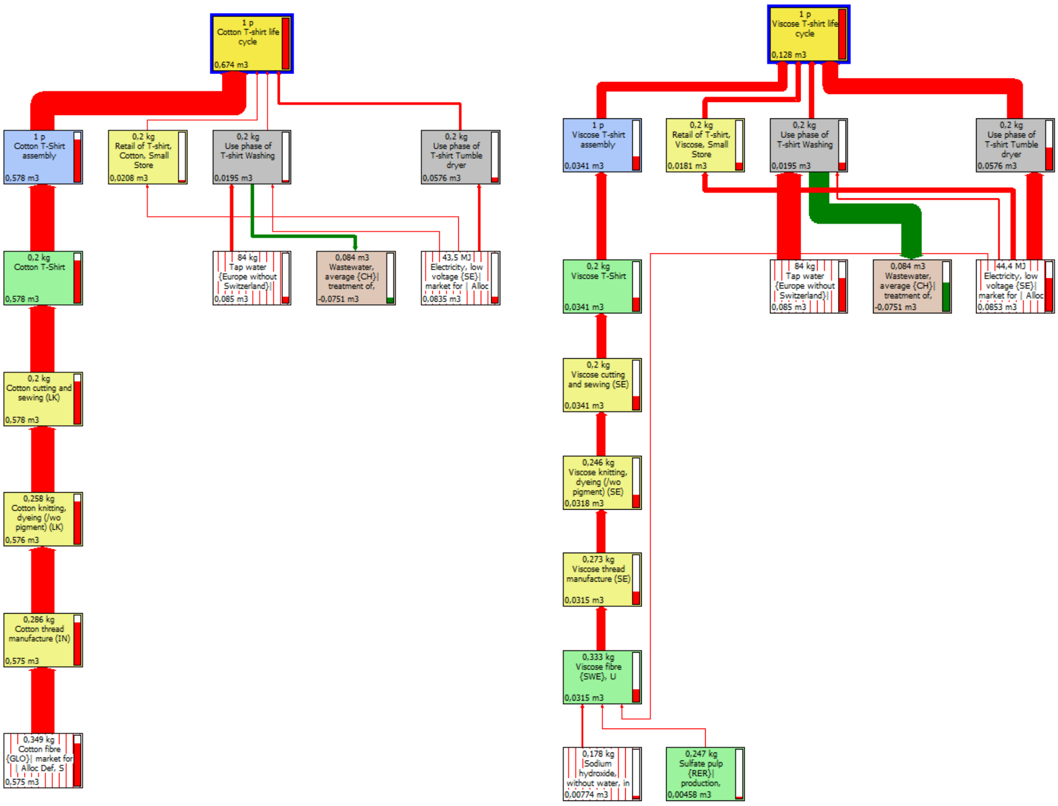


**Figure 10:** The T-shirt water use in the life cycle, for cotton (left) and viscose (right). Note that the use phase for both materials is the same.

According to Shen, Worrell, and Patel (2010) the cotton fibres are also stronger than the viscose fibres (cotton presents a tenacity of $24\,\mathrm{cN\,tex^{-1}}$–$36\,\mathrm{cN\,tex^{-1}}$ versus $24\,\mathrm{cN\,tex^{-1}}$–$26\,\mathrm{cN\,tex^{-1}}$ in the Viscose case) and an assumption can be made that the cotton fibre can last a longer time since the washing cycle can be longer.

There is no data for the water depletion relative to the average European for normalisation in ReCiPe H Midpoint. Therefore it is not possible to compare this impact category to the others (Figure 7 Figure 10). However, according to a study by WWF (2014) $1836\,\mathrm{m^3\,person^{-1}\,yr^{-1}}$ is the average EU water use, while another source indicates $4560\,\mathrm{m^3\,person^{-1}\,yr^{-1}}$ (Blomquist, Calbick, and Dinar, 2005). Figure 10 shows that a viscose T-shirt uses 128 l of water during its life cycle, whereas cotton requires 674 l. Another study found that a cotton t-shirt of 250 g has a water footprint of 2000 l (Hoekstra and A. K. Chapagain, 2007).

Water scarcity is not a big problem in Europe yet, however a study by A. Chapagain et al. (2006) shows that 84% of the water use related to the cotton products consumed in Europe is imported virtual water, with India as the main exporter. From a global perspective water scarcity is a big problem, today almost 2 billion people in India and China are affected by conditions of severe water scarcity for part of the year. On a global scale the number is 4 billion (Mekonnen and Hoekstra, 2016). Water use is important to consider since cotton agriculture is one of the most water intensive agricultural products in terms of virtual water use and is often grown in areas where water is scarce (Mekonnen and Hoekstra, 2011).

## 4.4 Sensitivity analysis

A sensitivity analysis was made in order to determine the magnitude of the impacts related to the use of a tumble dryer during the use phase. The results of this analysis can be seen in Figure 11 for all impact categories and in Figure 12 for the chosen impact categories for the project. Since the use and waste scenario these steps are the identical, with the exception of transport included in the retail stage. It is not valuable for the comparison to change the parameters in these steps, e.g. changing the temperature of the washing or excluding the use of a tumble dryer. However, by removing the tumble dryer from the life cycles of the T-shirts it is possible to half the impacts to freshwater and marine toxicity (Figure 11), this is due to the reduction of electricity use in Sweden.

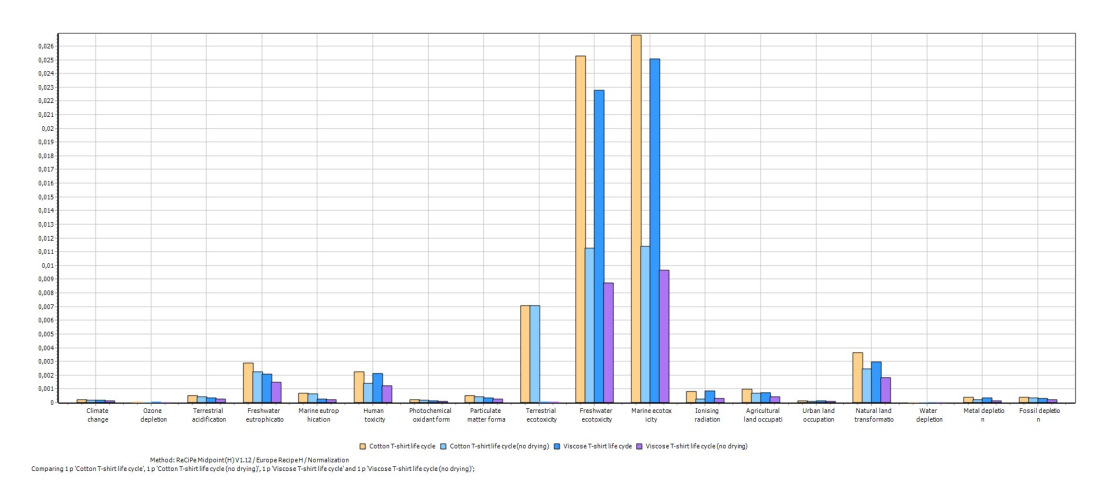


**Figure 11:** Normalized results from a sensitivity analysis for the two T-shirts when using (left) and not using the tumble dryer (right). Data from EcoInvent 3 and Wendin (2007).

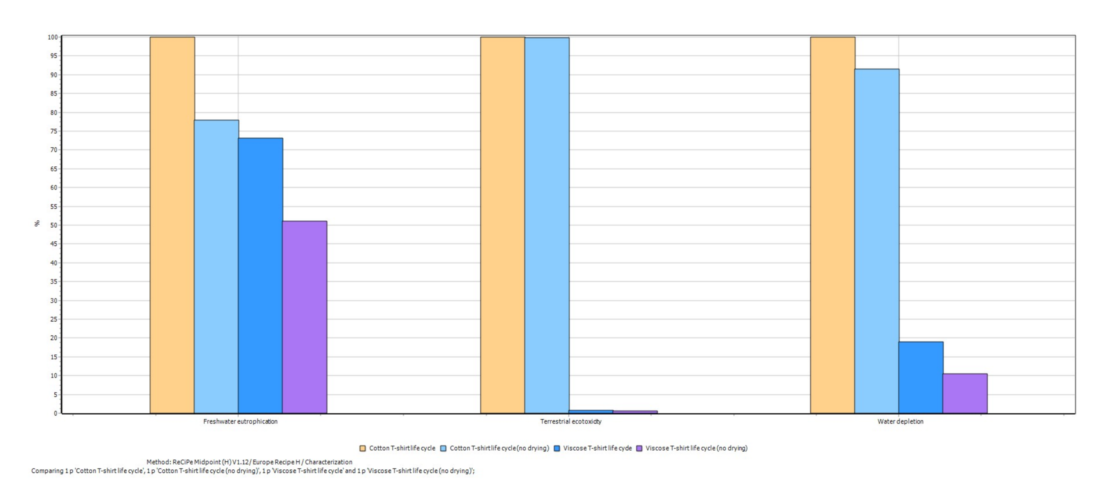


**Figure 12:** Characterised results from a sensitivity analysis for the two T-shirts when using (left) and not using the tumble dryer (right). Data from EcoInvent 3 and Wendin (2007).

# 5 Conclusions and recommendations

The results of the study show that a viscose T-shirt has a better environmental performance that one made from cotton. Out of the 18 impact categories included in ReCiPe viscose outperforms cotton in 16, with the exception of Ozone depletion and Ionizing radiation. In the three impact categories chosen for further analysis: Freshwater eutrophication, Terrestrial ecotoxicity and Water depletion, the viscose has an impact that is 73.2%, 0.82% and 19% of the cotton T-shirt.

Due to a data gap in the EcoInvent database, the pigment used in the dying process was excluded in the calculations and assumptions of the assessment. In reality dying has impacts in several different categories such as water depletion and toxicity. This biggest assumption made that could affect the result is that the same inputs of material and energy was used in the processes of spinning, knitting and sewing for both materials. The result for the manufacture of viscose fabric is based on the production line for cotton, which might leave some gaps in the data. Also the cotton production is based on a real case whereas the Viscose is made from a fictive case.

The water depletion impacts of cotton agriculture is commonly known, however the fact that the water use in washing the t-shirts through the life cycle was dwarfed by the water use in raw material production was surprising. The cotton for a single T-shirt needs 575 of the total 674 l of water for irrigation and a viscose T-shirt only needs 128 l in the whole life cycle.

Viscose is a very old process and today another type of Rayon textile, Lyocell, is an even more promising alternative that requires less chemicals. The recommendation for the textile industry is to use more of the local services and raw materials from Sweden and Europe. To be able to become more sustainable, create less environmental impacts and avoid shifting the burden of e.g. water depletion to water scarce regions in the world.

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# A Appendix: LCI data

The following are the tables that represent the Life Cycle Inventory of the project.

**Table 1:** Cotton thread manufacture data in India (Wendin, 2007; EcoInvent, 2016).

| Cotton thread manufacture (IN) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Cotton thread | 1 | kg |
| **Materials/fuels** | | |
| Cotton fibre {GLO}\| market for \| Alloc Def, S | 1,22 | kg |
| **Electricity/heat** | | |
| Electricity, medium voltage {GLO}\| market group for \| Alloc Def, S | 17 | kJ |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Allo | 0,2 | tkm |

**Table 2:** Cotton knitting and dyeing without pigment data in Sri Lanka (Wendin, 2007).

| Cotton knitting, dyeing (/wo pigment) (LK) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Cotton knit | 12000 | ton |
| **Resources** | | |
| Water, well, in ground, GLO | 1800000 | m3 |
| **Materials/fuels** | | |
| Cotton thread manufacture (IN) | 13300 | ton |
| Petroleum {GLO}\| market for \| Alloc Def, S | 1065081,6 | kg |
| Hydrogen peroxide, without water, in 50% solution state {GLO}\| market fo | 8400 | kg |
| Soap {GLO}\| market for \| Alloc Def, S | 3480 | kg |
| Acetic acid, without water, in 98% solution state {RER}\| acetic acid produ | 12000 | kg |
| EDTA, ethylenediaminetetraacetic acid {RER}\| EDTA production \| Alloc D | 2400 | kg |
| Sodium chloride, powder {GLO}\| market for \| Alloc Def, S | 168 | ton |
| Sodium percarbonate, powder {GLO}\| market for \| Alloc Def, S | 48 | ton |
| Carboxymethyl cellulose, powder {RER}\| production \| Alloc Def, S | 1980 | kg |
| Sodium hydroxide, without water, in 50% solution state {RER}\| chlor-alka | 12 | ton |
| **Electricity/heat** | | |
| Electricity, medium voltage {GLO}\| market group for \| Alloc Def, S | 157,6 | MWh |
| Transport, freight, lorry 16-32 metric ton, EURO3 {RoW}\| transport, freigh | 2660 | tkm |
| Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RoW}\| transport, freig | 465500 | tkm |
| Transport, freight, sea, transoceanic ship {GLO}\| market for \| Alloc Def, S | 30909200 | tkm |
| **Emissions to air** | | |
| Carbon dioxide | 379 | ton |
| Carbon monoxide | 301 | kg |
| Sulfur dioxide | 2384 | kg |
| Nitrogen oxide | 771 | kg |
| **Emissions to water** | | |
| Waste water/m3 | 1800000 | m3 |
| BOD5, Biological Oxygen Demand | 36 | ton |
| COD, Chemical Oxygen Demand | 414 | ton |
| Heat, waste | 86 | TJ |
| Hydroxide | 7,8 | kton |
| Suspended solids, unspecified | 85 | ton |
| **Waste to treatment** | | |
| Hazardous waste, for incineration {CH}\| treatment of hazardous waste, ha | 120 | ton |

**Table 3:** Cotton cutting and sewing data in Sri Lanka (Wendin, 2007).

| Cotton cutting and sewing (LK) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Cotton T-shirt | 1150 | kg |
| **Resources** | | |
| Water, well, in ground, GLO | 520 | l |
| **Materials/fuels** | | |
| Cotton knitting, dyeing (/wo pigment) (LK) | 1486 | kg |
| **Electricity/heat** | | |
| Electricity, medium voltage {GLO}\| market group for \| Alloc Def, S | 1995 | kWh |
| Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RoW}\| transport, freig | 37,14 | tkm |
| **Final waste flows** | | |
| Production waste | 336 | kg |

**Table 4:** Retail of Cotton T-shirt data, small store, Stockholm Sweden (Wendin, 2007; EcoInvent, 2016; EEF, 2009).

| Retail of T-shirt, Cotton, Small Store | Amount | Unit |
|---|---|---|
| Retail of T-shirt, Cotton, Small Store | 1150 | kg |
| **Materials/fuels** | | |
| Transport, freight, sea, transoceanic ship {GLO}\| market for \| Alloc Def, S | 15328 | tkm |
| Transport, freight, light commercial vehicle {RoW}\| processing \| Alloc Def | 47,2 | tkm |
| Transport, freight, light commercial vehicle {RoW}\| processing \| Alloc Def | 47,2 | tkm |
| Transport, regular bus {CH}\| processing \| Alloc Def, S | 3840 | personkm |
| Transport, passenger car {RER}\| market for \| Alloc Def, S | 3840 | km |
| Transport, passenger, aircraft {RoW}\| intercontinental \| Alloc Def, S | 1610 | personkm |
| Transport, freight, light commercial vehicle {GLO}\| market for \| Alloc Def, | 27 | tkm |
| **Electricity/heat** | | |
| Electricity, low voltage {SE}\| market for \| Alloc Def, S | 15000 | kWh |

**Table 5:** Viscose fibre production data in Sweden (EcoInvent, 2016).

| Viscose fibre {SWE}, U | Amount | Unit |
|---|---|---|
| **Product** | | |
| Viscose fibre | 1 | kg |
| **Resources** | | |
| Water, river, SE | 0,149171666 | m3 |
| **Materials/fuels** | | |
| Sodium hypochlorite, without water, in 15% solution state {GLO}\| market | 0,114037217 | kg |
| Chemical, organic {GLO}\| market for \| Alloc Def, S | 0,011352591 | kg |
| Sodium hydroxide, without water, in 50% solution state {GLO}\| market fo | 0,534511108 | kg |
| Sodium chloride, powder {GLO}\| market for \| Alloc Def, S | 0,09043651 | kg |
| Pulp factory {GLO}\| market for \| Alloc Def, S | 3,65223E-11 | p |
| Chemical, inorganic {GLO}\| market for chemicals, inorganic \| Alloc Def, S | 0,011352591 | kg |
| Carbon disulfide {GLO}\| market for \| Alloc Def, S | 0,066577955 | kg |
| Sulfate pulp {RER}\| production, unbleached \| Alloc Def, S | 0,744324395 | kg |
| Zinc monosulfate {GLO}\| market for \| Alloc Def, S | 0,01079453 | kg |
| Sulfuric acid {GLO}\| market for \| Alloc Def, S | 0,051119527 | kg |
| Oxygen, liquid {RER}\| market for \| Alloc Def, S | 0,002927468 | kg |
| Oxygen, liquid {RER}\| market for \| Alloc Def, S | 0,010669053 | kg |
| Nitrogen, liquid {RER}\| market for \| Alloc Def, S | 0,007375288 | kg |
| Nitrogen, liquid {RER}\| market for \| Alloc Def, S | 0,026878974 | kg |
| Sulfur dioxide, liquid {RER}\| market for \| Alloc Def, S | 0,049073023 | kg |
| Sulfur dioxide, liquid {RER}\| market for \| Alloc Def, S | 0,10176406 | kg |
| **Electricity/heat** | | |
| Heat, district or industrial, natural gas {RER}\| market group for \| Alloc Def | 3,677342345 | MJ |
| Electricity, low voltage {SE}\| market for \| Alloc Def, S | 0,746661822 | kWh |
| Electricity, medium voltage {SE}\| market for \| Alloc Def, S | 0,004554517 | kWh |
| Heat, central or small-scale, other than natural gas {Europe without Switz | 9,90380948 | MJ |
| **Emissions to air** | | |
| Water/m3 | 0,030580192 | m3 |
| **Emissions to water** | | |
| Water, SE | 0,118591475 | m3 |
| **Waste to treatment** | | |
| Hazardous waste, for incineration {GLO}\| market for \| Alloc Def, S | 1,3018E-05 | kg |
| Wastewater, average {GLO}\| market for \| Alloc Def, S | 7,45858E-05 | m3 |
| Municipal solid waste {CH}\| market for \| Alloc Def, S | 1,71555E-05 | kg |
| Municipal solid waste {RoW}\| market for \| Alloc Def, S | 1,21116E-05 | kg |
| Municipal solid waste {RoW}\| market for \| Alloc Def, S | 0,005397581 | kg |

**Table 6:** Viscose thread manufacture data in Sweden (Wendin, 2007).

| Viscose thread manufacture (SE) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Viscose thread | 1 | kg |
| **Materials/fuels** | | |
| Viscose fibre {SWE}, U | 1,22 | kg |
| **Electricity/heat** | | |
| Electricity, medium voltage {SE}\| market for \| Alloc Def, S | 17 | kJ |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Alloc | 0,211 | tkm |

**Table 7:** Viscose knitting and dyeing without pigment data in Sweden (Wendin, 2007).

| Viscose knitting, dyeing (/wo pigment) (SE) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Viscose knit | 12000 | ton |
| **Resources** | | |
| Water, unspecified natural origin, SE | 1800000 | m3 |
| **Materials/fuels** | | |
| Viscose thread manufacture (SE) | 13300 | ton |
| Soap {GLO}\| market for \| Alloc Def, S | 3480 | kg |
| Hydrogen peroxide, without water, in 50% solution state {GLO}\| market fo | 8400 | kg |
| Acetic acid, without water, in 98% solution state {RER}\| acetic acid prod | 12000 | kg |
| EDTA, ethylenediaminetetraacetic acid {RER}\| EDTA production \| Alloc D | 2400 | kg |
| Sodium chloride, powder {GLO}\| market for \| Alloc Def, S | 168 | ton |
| Sodium percarbonate, powder {GLO}\| market for \| Alloc Def, S | 48 | ton |
| Sodium hydroxide, without water, in 50% solution state {RER}\| chlor-alka | 12 | ton |
| Carboxymethyl cellulose, powder {RER}\| production \| Alloc Def, S | 1980 | kg |
| **Electricity/heat** | | |
| Electricity, medium voltage {SE}\| market for \| Alloc Def, S | 157,6 | MWh |
| Heat, onsite boiler, hardwood mill, average, SE/MJ/RNA | 47928672 | MJ |
| **Emissions to air** | | |
| Carbon dioxide | 379 | ton |
| Carbon monoxide | 301 | kg |
| Sulfur dioxide | 2384 | kg |
| Nitrogen oxide | 771 | kg |
| **Emissions to water** | | |
| Waste water/m3 | 1800000 | m3 |
| BOD5, Biological Oxygen Demand | 36 | ton |
| COD, Chemical Oxygen Demand | 414 | ton |
| Heat, waste | 86 | TJ |
| Hydroxide | 7,8 | kton |
| Suspended solids, unspecified | 85 | ton |
| **Waste to treatment** | | |
| Hazardous waste, for incineration {CH}\| treatment of hazardous waste, ha | 120 | ton |

**Table 8:** Viscose cutting and sewing data in Sweden (Wendin, 2007).

| Viscose cutting and sewing (SE) | Amount | Unit |
|---|---|---|
| **Product** | | |
| Viscose T-shirt | 1150 | kg |
| **Resources** | | |
| Water, well, in ground, SE | 520 | l |
| **Materials/fuels** | | |
| Municipal waste collection service by 21 metric ton lorry {GLO}\| market fo | 6 | tkm |
| Viscose knitting, dyeing (/wo pigment) (SE) | 1414 | kg |
| **Electricity/heat** | | |
| Electricity, medium voltage {SE}\| market for \| Alloc Def, S | 1995 | kWh |

**Table 9:** Viscose T-shirt retail data, small store, in Sweden (Wendin, 2007; EEF, 2009).

| Retail of T-shirt, Viscose, Small Store | Amount | Unit |
|---|---|---|
| Retail of T-shirt, Viscose, Small Store | 1150 | kg |
| **Materials/fuels** | | |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Allo | 468,05 | tkm |
| **Electricity/heat** | | |
| Electricity, low voltage {SE}\| market for \| Alloc Def, S | 15000 | kWh |

**Table 10:** Laundry detergent data for the both of the T-shirts (Smulders et al., 2007).

| Laundry detergent | Amount | Unit |
|---|---|---|
| **Product** | | |
| Laundry detergent | 1 | kg |
| **Materials/fuels** | | |
| Alkylbenzene sulfonate, linear, petrochemical {GLO}\| market for \| Alloc D | 0,2 | kg |
| Zeolite, powder {GLO}\| market for \| Alloc Def, S | 0,5 | kg |
| Sodium perborate, monohydrate, powder {GLO}\| market for \| Alloc Def, S | 0,1 | kg |
| Polycarboxylates, 40% active substance {GLO}\| market for \| Alloc Def, S | 0,05 | kg |
| Sodium sulfate, anhydrite {RER}\| market for \| Alloc Def, S | 0,15 | kg |

**Table 11:** Washing data for both of the T-shirts in Sweden (Wendin, 2007; Electrolux, 2016; EC, 2010).

| Use phase of T-shirt Washing | Amount | Unit |
|---|---|---|
| Use phase of T-shirt Washing | 1150 | kg |
| **Materials/fuels** | | |
| Tap water {Europe without Switzerland}\| market for \| Alloc Def, S | 483 | ton |
| Laundry detergent | 163 | kg |
| **Electricity/heat** | | |
| Electricity, low voltage {SE}\| market for \| Alloc Def, S | 6535,1 | kWh |
| **Waste to treatment** | | |
| Wastewater, average {CH}\| treatment of, capacity 4.7E10l/year \| Alloc De | 483 | m3 |

**Table 12:** Drying data for both of the T-shirts in Sweden (Wendin, 2007).

| Use phase of T-shirt Tumble dryer | Amount | Unit |
|---|---|---|
| Use phase of T-shirt Tumble dryer | 1150 | kg |
| **Electricity/heat** | | |
| Electricity, low voltage {SE}\| market for \| Alloc Def, S | 47940,1 | kWh |

**Table 13:** Waste scenario data for both of the T-shirts in Sweden (SCB, 2013; EcoInvent, 2016).

| Waste scenario | Amount | Unit |
|---|---|---|
| **Waste scenario** | | |
| MSW Incineration (SE) \| Textile (T-Shirt) | 1 | kg |
| **Materials/fuels** | | |
| Municipal waste collection service by 21 metric ton lorry {CH}\| processing | 60 | kgkm |
| **Separated waste** | | |
| MSW textile incineration w/ fly ash extraction (CH) \| Avoided electricity a | 100 | Textile |
| **Remaining waste** | | |
| Municipal solid waste {SE}\| treatment of, incineration \| Alloc Def, S | 100 | % |

**Table 14:** Textile incineration data in Sweden for both of the T-shirts (Wendin, 2007; EcoInvent, 2016).

| Textile waste treatment (MSW incineration) | Amount | Unit |
|---|---|---|
| **Waste treatment** | | |
| MSW textile incineration w/ fly ash extraction (CH) \| Avoided electricity a | 1 | kg |
| **Avoided products** | | |
| Heat, for reuse in municipal waste incineration only {SE}\| market for \| Allc | 3,58 | MJ |
| Electricity, for reuse in municipal waste incineration only {SE}\| market for | 1,78 | MJ |