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Comparative Life Cycle Assessment of Jeans

A case study performed at Nudie Jeans

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Comparative Life Cycle Assessment of Jeans – A case study performed at Nudie Jeans
Jämförande livscykelanalys på jeans – en fallstudie genomförd i samarbete med Nudie Jeans

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Abstract

Within the jeans production industry, large quantities of cotton, water and chemicals are consumed on a daily basis resulting in environmental issues decentralized around the world. An increased awareness about these environmental issues amongst companies, organizations and the consumers have initiated for environmental aspects to be considered within the jeans production processes. One such initiative is the introducing of CSR management into the business operations and strategy. In order to see how well the environmental targets and performance succeed with capturing the existing environmental issues more information about the specific products is required.

This thesis was conducted to evaluate and compare the environmental impacts of three jeans manufactured by Nudie Jeans from a life cycle perspective and to evaluate the environmental focus at Nudie Jeans. Accordingly the main purpose has been to evaluate the environmental performance of jeans at Nudie Jeans. The main purpose have been divided into the two sub-targets:

- To find out which of the three styles of jeans: Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions, manufactured at Nudie Jeans, that has the best environmental performance and why.
- To find out how well the prioritized environmental sustainability targets and measures represent their potential environmental impact.

The evaluation is based on nine main environmental aspects, assessed to be relevant and of interest for the given case. The LCA has been performed according to the methodology and guidance presented in the ISO 14040-standard to ensure a methodological structure with high credibility.

The studied products are the three styles of jeans: Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions. The main difference between the products can be found in what companies and in which countries the life cycle phases: cotton cultivation, fabric manufacturing and jeans production are conducted. The results of the study show that Grim Tim Conjunctions and Tilted Tor Dry Royal Embo have the best environmental performance and the worst environmental performance can be found in Lean Dean Lost Legend. The results are mainly caused by two main process contributors, the energy sources used for electricity and heating and the substances used in the dyeing, laundry and finishing processes.

A sensitivity analysis on the results gathered from the LCA shows that Nudie Jeans is to the largest extent focusing on the right environmental aspects. The focus on organic cotton cultivation and the promoting of repairs are highly reflecting the environmental importance within the subject, however, the measures and targets regarding energy usage could be improved to better represent its environmental importance.

Keywords
Life cycle assessment, jeans, CSR management, organic cotton

Sammanfattning

Varje dag konsumeras stora mängder bomull, vatten och olika typer av kemikalier inom textil- och klädestillverkningsindustrin för att kunna producera jeans av den mängd som efterfrågas idag. Detta har lett till att det idag är en utav världens mest miljöfarliga industrier som genererar en mängd olika miljöproblem runt om i världen. Samtidigt har medvetenheten kring dessa miljöproblem ökat hos flertalet klädföretag, organisationer och framför allt hos konsumenter vilket har lett till ett ökat tryck på jeansproduktionsprocesserna. Idag har en mängd olika miljömässiga aspekter inkluderats inom produktionsprocesserna för jeans, bland annat genom CSR arbete. För att se hur den ökade miljömedvetenheten har satt sina spår på jeansproduktionen krävs det mer information inom detta ämne.

Denna uppsats har utförts för att utvärdera och jämföra den miljömässiga påverkan jeans tillverkade av Nudie Jeans har utifrån ett livscykelperspektiv. Huvudsyftet med studien har därför varit att undersöka miljöprestandan av jeans tillverkade av Nudie Jeans. Huvudsyftet har delats upp i de två delmålen:

- Att ta reda på vilken utav de tre jeansmodellerna Lean Dean Lost Legend, Tilted Tor Dry Royal Embo och Grim Tim Conjunctions, alla tillverkade av Nudie Jeans, som presterar bäst ur ett miljöperspektiv.
- Samt att ta reda på hur väl Nudie Jeans miljömål och åtgärdsplan reflekterar den potentiella miljömässiga påverkan dessa mål skulle ha eller redan har.

Utvärderingen är baserad på nio huvudsakliga miljöaspekter som har valts ut som relevanta inom jeansproduktion. För att säkerställa att en metodik med hög tillförlitlighet har livscykelanalysen utförts enligt den metodik och vägledning som finns presenterad i ISO 14040-standarden.

De studerade produkterna är de tre jeansmodellerna Lean Dean Lost Legend, Tilted Tor Dry Royal Embo och Grim Tim Conjunctions. Materialsammansättningen av produkterna är i princip lika men det som skiljer jeansen åt är var i världen de olika livscykelprocesserna bomullsodling, tygtillverkning och jeanstillverkning sker. Resultaten i studien visar att jeansmodellerna Grim Tim Conjunctions och Tilted Tor Dry Royal Embo presterar bäst ut ett miljöperspektiv och sämst miljöpåverkan hittas i modellen Lean Dean Lost Legend. Resultaten beror främst på två huvudfaktorer, energikällan som används för elektricitet och uppvärmning samt the kemikalierna som används i färg-, tvätt- och efterbehandlingsprocesserna.

En känslighetsanalys gjord på resultaten från livscykelanalysen på de tre jeansmodellerna visar att Nudie Jeans till största delen fokuserar på rätt saker i deras CSR arbete. Nudies fokus på ekologiskt odlad bomull samt starka marknadsföring inom lagning av jeans styrks av dess negativa påverkan, däremot krävs det en omställning när det kommer till mål och krav kring energianvändningen i produktionsländerna.

Nyckelord
Livscykelanalys, jeans, CSR arbete, ekologisk bomull

Table of content

1. Introduction

The textile industry is one of the world's oldest industries for consumer goods and manufacturing (Sustainability of textiles, 2013) and today different types of clothes are one of the most sold product category in the world [1] (World Federation of Direct Selling Associations, 2017). Yet, there are a lot of sustainability issues connected to the textile and clothing industries that still are unsolved (Muthu, 2014; Sustainability of textiles, 2013). One of the well-discussed areas is the processes connected to jeans production; one pair of jeans alone require in average between 5 700 – 15 000 liters of water, 0.5 kg of chemicals and extensive amounts of energy (Amutha, 2017; Textile Exchange, 2014). Despite that almost every person in the developed countries owns a pair of jeans, and every year about 2 billion new pairs of jeans are produced (Amutha, 2017). One company that has acknowledged this is Nudie Jeans who tries to take action in order to make their jeans production processes more sustainable.

To be sustainable in the clothing producer area is however easier said than done. Textile and clothing supply chains are complex and extensive, and are often global and decentralized (Muthu, 2014). All steps in the supply chain include further sub-processes and several types of in- and outputs represented by raw materials, energy, water, chemicals, auxiliaries, human labor, finished products, emissions, wastewater and solid waste (Muthu, 2017). The textile industry is thus highly intertwined with many social, environmental, economic and governmental issues around the world (Muthu, 2017; Sustainability of textiles, 2013). Due to these sustainability issues there has however been an upswing in the engagement of reaching more sustainable clothes. Today several companies and organizations, together with Nudie Jeans, are highlighting the sustainability challenges that exist. Amongst these are for example The European Commission and the Brotherhood of St Laurence and St James ethics center, which both identify environmental, social and economical challenges within the clothing industry (Sustainability of textiles, 2013 and Diviney and Lillywhite, 2009).

In order to include responsible and sustainable practice in textile production and to create a more comprehensive sustainability status of a certain product, it is thus equally important to understand and acknowledge all stages in the life-chain of the product, as it is to assess all three sustainability pillars; environmental, social and economic impacts at each step of the life cycle (Diviney and Lillywhite, 2009; UNEP/SETAC Life Cycle Initiative, 2011; Curran, 2015). To implement these aspects into the business strategy and operations a good CSR management is useful (European Commission, 2018).

In order to examine the environmental performance of jeans and to see how well the CSR management or environmental targets represent their environmental importance the thesis have been conducted in cooperation with Nudie Jeans. The Swedish denim brand Nudie Jeans was founded 2001 by Maria Erixon, who today owns the company together with Joakim Levin and Palle Stenberg (Nudie Jeans, 2017). The products at Nudie Jeans are sold in over 50 countries around the world and are especially popular within the home city of Gothenburg. Nudie Jeans thus has stores located all around the world but the Head Office is located in Gothenburg.

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[1] 2016 the clothing industry represented number four on the most sold product category list, after wellness, cosmetics & personal care, household goods & durables (World Federation of Direct Selling Associations, 2017)
[2] The UN's SDGs are available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

From the Head Office all aspects of the business are covered, amongst these design & product development, production, sales, marketing, supply chain management finance, HR and IT (Nudie Jeans, 2017). The field of sustainability is also managed at the Head Office where the main responsible persons, the Sustainability Manager and Environmental Manager are located and active.

Based on Nudie's sustainability report (Nudie Jeans, 2017) it is clear that environmental and social sustainability issues are by far two of the most highlighted, and prioritized areas within the company. Sustainability is highlighted as being the essence of Nudie Jeans and the core values are identified as the concerns for human rights, development, security and anti-corruption. Until today Nudie Jeans have been an active company within the field of sustainability and they work with several social and environmental sustainability organizations such as Amnesty Sweden, Fair Wear Foundation and Textile Exchange.

To ensure environmentally good and socially fair cotton cultivation has been one of the main sustainability targets at Nudie Jeans and 2012 the entire denim collection was produced with organic cotton. Another very highlighted aspect at Nudie Jeans is the importance of prolonging the lifetime of garments, which is done by offering free repairs, second-hand selling of Nudie products and recycling of worn out products. Today Nudie Jeans are trying to prove that fashion based on products that live longer, have higher quality and an increased number of repairs, reuse and recycling are the keys to sustainable and profitable business. This report will therefore evaluate the products manufactured by Nudie to see how well their products represent their visions.

2. Aim and Objectives

Textile production and especially jeans production processes imply many environmental, social and economic sustainability issues to deal with. Nudie Jeans is working on improving their sustainability performance connected to all three sustainability areas and has put up several sustainability goals for their suppliers to follow. But how well do their sustainability goals represent the large environmental issues in jeans production and how well do their jeans perform today? The main purpose of the study is to evaluate the environmental sustainability performance of jeans at Nudie Jeans and to give suggestions of improvements regarding the identified environmental issues connected to jeans production. The purpose is achieved by conducting a comparative Environmental Life Cycle Assessment (E-LCA) of three styles of jeans manufactured by Nudie Jeans and the three styles under study are *Lean Dean Lost Legend*, *Tilted Tor Dry Royal Embo* and *Grim Tim Conjunctions*.

The results from the E-LCA will be used to fulfill two sub targets of the study. The first sub target is to decide which of the three jeans styles that has the best environmental performance and to identify success factors and negative contributors in the product's life cycle. This will be achieved by comparing the three styles of jeans and by identifying environmental hotspots. The second sub target is to evaluate the existing environmental sustainability goals at Nudie Jeans to see if the environmental focus is on the right aspects in the product life cycle in order to find possible measures for improvements. This will be achieved by comparing the results from the E-LCA with the existing environmental sustainability goals at Nudie Jeans.

Since the study is case-specific for Nudie Jeans and the products under study are jeans manufactured by Nudie Jeans the main target group of the study is Nudie Jeans. The results can both be used in the internal sustainability work at Nudie Jeans and as a communication tool. The study will however be of value for external audiences as well. The results of the study will first of all be of value for the general jeans consumer to see how well the products perform from an environmental point of view in comparison to other jeans. The results can thereby be used on a more general level with the purpose to see how well jeans perform in an environmental perspective in cases where the suppliers actively highlight and work on their sustainability issues. Lastly the datasets created for the LCA models can be used to get general data about organic cotton cultivation, fabric manufacturing and jeans production. The data can be improved further as the performance improves at the suppliers or be customized for other suppliers' conditions.

The research questions for the study are:

- Which of the three styles of jeans manufactured at Nudie Jeans have the best environmental performance and why?
- How well do the prioritized environmental sustainability measures and goals represent its potential environmental impact?
- How do Nudie perform from an environmental perspective?

3. Outline of the Thesis

The following chapters in this thesis include the theoretical framework, research design and methodology, an LCA according to the ISO 14040-standard and its results, an analysis of the environmental sustainability work at Nudie Jeans and the results from the study.

Chapter 4: Theoretical Framework, presents the sustainability issues connected to textile and jeans production, the main concepts of CSR (corporate social responsibility) management in general and the specific CSR management at Nudie Jeans, and lastly a brief analysis of similar studies.

Chapter 5: Research Design and Methodology, includes a description of the research design of the thesis and the methodologies used: LCA according to the ISO-14040 standard and how the analysis of the environmental targets and measure at Nudie Jeans was conducted.

Chapter 6: Environmental LCA of three styles of jeans at Nudie Jeans and *Chapter 7: Analysis of CSR work at Nudie Jeans* stand for the results of the thesis. Chapter 6 presents the four phases of an LCA study according to the ISO 14040 standard: Goal and Scope, LCI, LCIA and Interpretation. Chapter 7 covers the analysis of Nudie Jeans' sustainability report with its main results.

Chapter 8: Discussion and Conclusion, is the final chapter and consists of a discussion about the limitations of the results, reflections and conclusions based on the LCA study and the sustainability analysis, and further suggestions.

4. Background

To get an introduction to the main subjects of the thesis Chapter 4 will contain: a description of the main sustainability issues connected to the textile industry in general and jeans production in particular, the concepts of corporate social responsibility (CSR) management, how Nudie Jeans work with CSR and finally a literature review on previous studies within life cycle assessments of textiles and jeans.

4.1 Sustainability issues in the textile industry and jeans production

Denim fabric is one of the most used fabrics of all times and has been accepted by people of all ages, classes and genders (Roshan, 2015). From the eighteenth century until today the strong and lasting fabric has been used to produce trousers, clothes and awnings for all types of people (ibid.). Denim has had both social and cultural influence on consumers and is considered as an expression of youth independence, freedom and a symbol of opposition (ibid.). The denim fabric has shown that it is here to stay. However, this fantastic, strong and rebellious fabric is not only sunshine and flowers. Denim fabric and the entire jeans production process is, as the rest of the textile and clothing industries, part of a long and complex production chain starting in the cultivation of cotton ending with a problematic waste management system, see **Figure 1**.

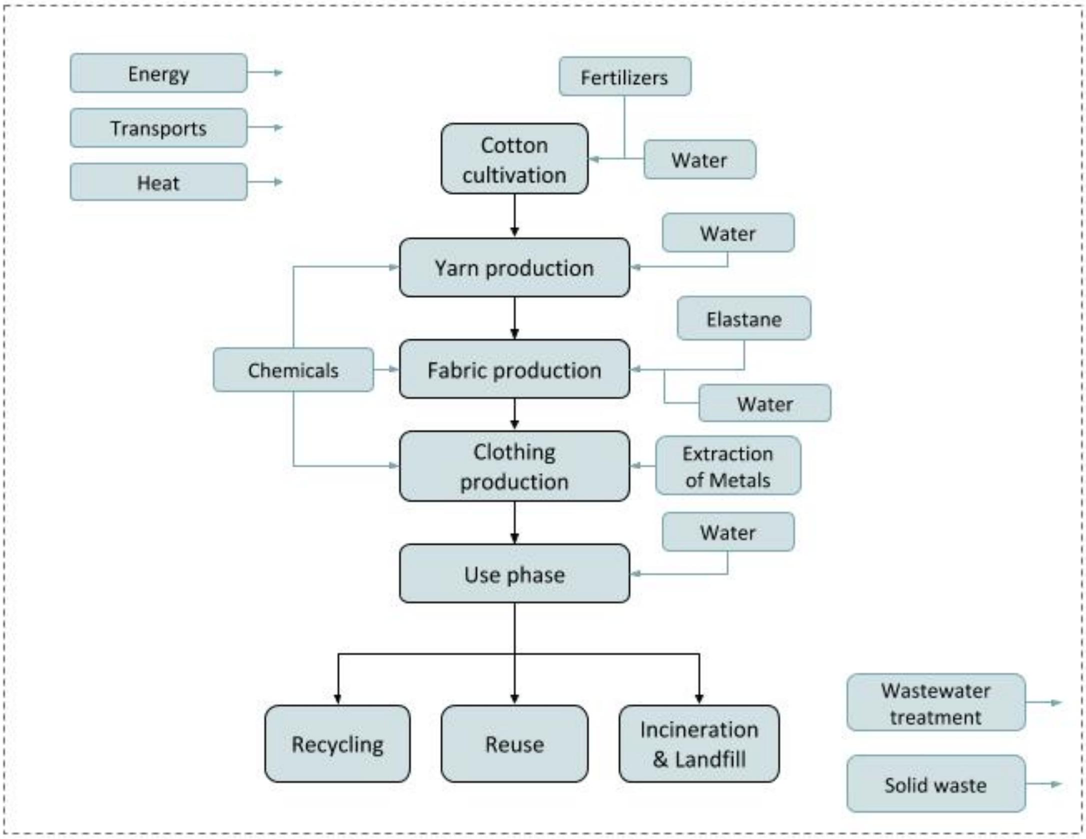

Figure 1: System flowchart of jeans. Boxes marked with a black frame represent the main supply chain of jeans, the boxes with a blue frame represent the raw material inputs, water flows, energy flows, transportations, heat and the generation and management of solid waste and wastewater.

The clothing industry is dominated by so-called fast fashion, the opposite to the long-term perspective that is representing the definition of being sustainable (Köksal et al., 2017). Today's fashion industry is based on rapid changes in styles and models where the apparel consumers expect change every new season and have a demand for new products on a frequent basis. This leads to an increased pressure on apparel retailers to achieve lower costs and shorter lead times to be able to produce more products than ever before. The production processes have therefore been outsourced to developing countries where poor labor conditions and huge environmental problems can be found. The life cycles of textiles and clothes are thus often complex, extensive, global and decentralized (Muthu, 2014). The steps in the supply chain include sub-processes, chains of stakeholders and all types of in- and outputs represented by raw materials, energy and water, which result in emissions to air, land and water (Muthu, 2017). Today the textile industry is representing one of the world's most polluting industries (Bin et al., 2017). The textile industry is thus highly intertwined with a lot of social, economic and environmental issues around the world (Muthu, 2017 and Sustainability of textiles, 2013).

The production of jeans starts with cotton cultivation where extensive amounts of water and pesticides are added to enhance the yields (Roshan, 2015). The harvested cotton is then sent to facilities for spinning and dyeing of threads and weaving of fabric. These processes both includes further use of water and the adding of chemicals. The finished fabric is then sent to cutting, sewing and finishing facilities where more chemicals are added to get the desired look and quality of the finished pair of jean. The produced jean is after production sent to a store where it is sold, used, washed and then thrown away (often incinerated). In addition large amounts of energy is consumed, waste is generated and transports is occurring (Köksal et al., 2017). Jeans could thereby, if not managed correctly, be one of the most environmental unfriendly products around the world.

4.2 Corporate Social Responsibility management in the textile industry

Corporate Social Responsibility (CSR) is defined by the European Commission (2018) and refers to when companies take responsibility for their impact on the society. To be socially responsible implies that a company not only follows the law, but also goes above legal obligations in order to integrate social, environmental, ethical, consumer and human rights concerns into their business operations and strategy. Simplified CSR means that a company or organization includes economic, social and environmental responsibility within their operations through measures like:

- The business is managed in a way that ensures profitability.
- The product is safe and not a hazard for the consumer.
- The company acts in a way that is sustainable in long-term thinking.
- The company promotes the business', the customers' and the suppliers' awareness on their affect on the environment.
- The company manage their raw materials in a resource efficient way.
- The employees have a good working environment.
- The neither employees nor customers are discriminated.
- Employ volunteers from other groups who are discriminated in the society.

However, the existing pressures from customers regarding diverse clothes with more styles at a lower price, makes it difficult to implement CSR rules in clothing factories (Księżak, 2016).

At the same time there is an increased awareness of sustainability amongst customers where more customers are willing to pay more for sustainable textiles and clothes (Bin et al., 2017). Despite the difficulties the increased awareness amongst customers has lead to that several clothing companies have started to implement CSR measures in order to reduce the negative environmental and social impacts. Except from Nudie Jeans we find fast fashion companies such as the companies included in the H&M group (H&M group, 2017b) and Lindex (Lindex, 2017) and the more luxurious companies Fillipa K (Fillipa K, 2016) and Louis Vuitton (LVMH, 2016).

Within the fashion industry there are different styles and clothes that are produced, which all require different conditions both when it comes to CSR management and other aspects. Lowson (2003) has divided garments into three different classes to represent the conditions; basic, seasonal and short-season products. Basic garments are the most standard clothes, to these products clothes that are sold constantly through the whole year are included, such as the standard jean. These basic products do also represent the products that have the best opportunity for minimizing costs and implement sustainability measures since they do not change in style that often and thereby are easy to predict, which means that they do not have to be quickly delivered to the market. Denim jeans, with durable fabric and predictability in style thus have all the best conditions to become sustainable.

4.2.1 Corporate Social Responsibility at Nudie Jeans

The corporate social responsibility (CSR) work at Nudie Jeans is managed and controlled from the Head Office, primarily by the CSR manager. The CSR management at Nudie Jeans has its base in the UN sustainable development goals (SDGs[2]) and the GRI[3] standards, and is every year presented in a sustainability report (Nudie Jeans, 2017). The sustainability report includes the main sustainability targets and measures relevant for the business conducted at Nudie Jeans, which have been identified through a mapping of the biggest impacts in the value chains according to the GRI standards. Nudie Jeans has also conducted what they call a materiality analysis where all relevant GRI standards have been related to the supply chain specific for Nudie Jeans. Through the materiality analysis the four main focus areas: *sustainable materials*, *sustainable production*, *sustainable products* and *This is Nudie Jeans* have been identified as the main sustainability areas and are today representing how Nudie Jeans is working with CSR. See

[2] The UN's SDGs are available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[3] The Global Reporting Initiative (GRI) is an international independent organization that helps companies, governments and organizations to understand and communicate their sustainability impacts. More information at: https://www.globalreporting.org/Pages/default.aspx

Table 1: Materiality analysis conducted by Nudie Jeans, adopted from Nudie's sustainability report (Nudie Jeans. 2017).

Nudie's focus areas	Priority topics	SDG	Identified GRI standards
Sustainable Materials	Design 1. Material & Certifications 14. Animal welfare	15	301: Material 303. Water
Sustainable Production	7. Fair Wear Foundation Code of Labor Practice 2. Transparency 4. Chemicals 5. Training 8. Living wages 6. Energy & Water	1, 5, 6, 8, 10 & 12	303: Water 302: Energy 306: Effluence and waste 401: Employment 402: Labor management relations 403: OHS 404: Training & education 405: Diversity & equal opportunities 406: Non discrimination
Sustainable Product	9. Repair, Reuse 3. Recycle 10. Transport	12	407: Freedom of association 408: Child labor 409: Forced or compulsory labor 413: Local community 414: Supplier social assessment
This is Nudie Jeans	13. Internal sustainability work 11. Communication 12. Collaboration	17	401: Employment 418: Customer privacy 205: Anti-corruption 306: Effluence and waste 405: Diversity & equal opportunities 406: Non- discrimination
	Non-material topics: 15. Socio economic compliance, 16. Biodiversity		

As seen in the results from the materiality analysis Nudie Jeans includes all three of the sustainability areas: economy, society and environment into their CSR work. In total Nudie Jeans has based their sustainability goals on eight of the 17 SDGs where three of them have a specific environmental focus: SDG number 6: *Clean water and sanitation*, SDG number 12: *Responsible consumption and production* and SDG number 15: *Life on land.* These three sustainability goals have been identified as the most relevant to include for Nudie Jeans and work as the basis for the environmental work within the CSR management.

Based on the SDGs and the three sustainability areas the main overarching environmental targets at Nudie Jeans are:

- *The life cycle perspective.* To ensure that the products are produced with a life cycle perspective where the responsible is on Nudie Jeans all the way from raw material extraction to the end-of-life management.
- *Move from fast to slow fashion*: To show that timeless garments with the help of repairs in order to prolong their lifetime are as profiting as the dominating fast fashion industry, but more sustainable.
- *Circularity*: At the end-of-life phase of a product make sure that the products are included in a circular system where the fibers can be reused.

The results from the materiality analysis have been the base for the analysis of the environmental performance of Nudie Jeans later in the report (see Chapter 7).

4.3 Literature Review of previous LCA studies on jeans

Apparel products are relatively common products in the application of LCA, and there are several LCA studies on jeans that can be found. A few of these studies are “The life cycle of a jean” conducted by Levi Strauss & Co (2015), “Environmental assessment of Swedish fashion consumption” conducted by Roos et al. (2015) and “A Comparative Life Cycle Assessment of Denim Jeans and a Cotton T-Shirt: The Production of Fast Fashion Essential Items From Cradle to Gate” conducted by Hackett (2015) which together represent the typical applications of LCA on jeans. Looking at these previous studies the most common application of LCA is of comparative structure, where the majority of the studies represent a comparison between jeans and other apparel products. Furthermore, most studies represent the general jean, which means that the majority of LCA studies represent jeans that are produced under non-sustainable conditions.

Even if the majority of the produced jeans are manufactured under non-sustainable conditions more and more companies have started to highlight these environmental and social issues. Thus, during the recent years more companies have started to implement sustainability measures into their operations, one of these companies is Nudie Jeans. In order to improve their environmental impact Nudie Jeans conducted a comparative LCA of three pairs of jeans during 2015 (Wendin, 2015). The study did however only include the production of jeans, from cotton cultivation (cradle) to the finished pant (gate) but did not include the impacts generated from use or the end-of-life phases.

As mentioned before comparative LCAs are a very common application. However, the comparisons are often between different types of apparel products and not between different types of jeans. With one exception, the study conducted by Levi Strauss & Co (2015) who compared three styles of jeans manufactured by Levi Strauss. These type of studies makes it possible to identify important key points in the product’s supply chains in order to see how different production choices and sustainability measures affect the impact of the jean. The study made by Levi Strauss is however based on the specific conditions and the specific supply chains at Levi’s, which results in fulfilling a more general purpose but is not adaptable on the jeans manufactured by Nudie. Therefore to evaluate the potential impact of the jeans manufactured at Nudie Jeans a new study has to be conducted with Nudie specific conditions.

5. Research Design and Methodology

To answer the research questions (see Chapter 2) an Environmental Life Cycle Assessment (E-LCA) of the three styles of jeans manufactured by Nudie Jeans has been performed. The results from the LCA study have both been used to answer which of the three styles of jeans that have the best environmental performance, and as a tool to evaluate the environmental goals and measures at Nudie Jeans. The study has been divided into three main parts (see **Figure 2**).

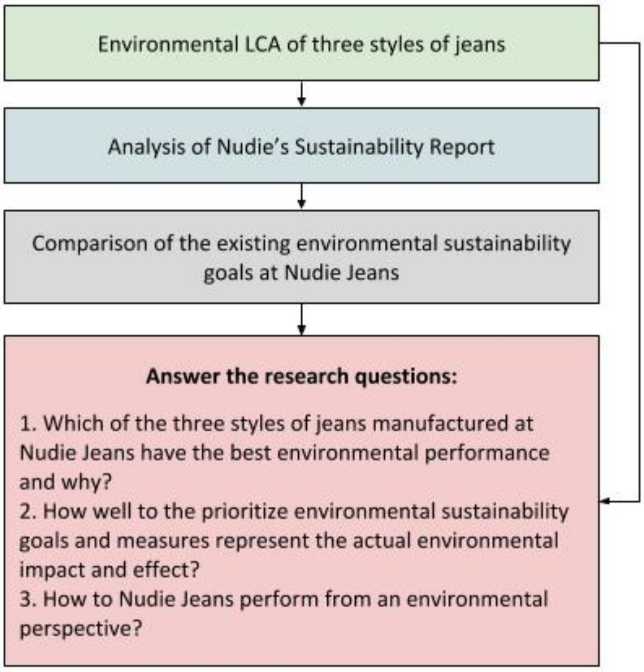

Figure 2: Illustration of the research design of the study

The first part is represented by a comparative E-LCA performed according to the ISO 14040-standard (ISO14040: 2006) where the results have had the main purpose to identify important environmental impacts and hotspots of the three styles of jeans. The second part is represented by an analysis of the latest Sustainability Report at Nudie Jeans with the purpose to identify key environmental sustainability goals and measures at Nudie Jeans. The third and last part has been to use the results from the E-LCA of the three styles of jeans and the identified environmental sustainability goals to evaluate the importance of the highlighted goals and measures to fulfill the main purpose of the study; evaluate the environmental performance at Nudie Jeans.

In order to get a better picture of the general methodologies of E-LCA the main concepts of LCA is presented together with a description of its main characteristics in section 5.1. This section only presents the basic methodologies for E-LCA, for specific methodological choices regarding the E-LCA conducted in this study please see Chapter 6. In section 5.2 a description of how the analysis of the environmental sustainability goals and measures have been performed is presented and lastly in section 5.3 a description of the methods for data gathering are presented.

5.1 Environmental Life Cycle Assessment

Environmental Life Cycle Assessment (E-LCA) is a method used to evaluate the potential environmental impacts and the used resources of a specific product or service throughout its life cycle, from extraction of raw material (cradle) to waste management (grave). This broad system approach gives the method a holistic and comprehensive scope of study, which helps avoiding problem shifting from one phase of the life cycle to another, from one geographic boundary to another, or from one environmental problem to another (Finnveden et al., 2009). The system approach thus captures all possible environmental impacts of a product which includes all responsible stakeholders into one consistent framework independent on where in the life cycle the impacts appear (Guinée et al., 2004).

There are two main approaches on how to conduct an E-LCA, consequential or attributional. The attributional LCA approach describes the environmental performance for a specific system at a specific time in the past, present or the future while the consequential LCA approach describes the environmental performance of a system where the in- and outputs changes after the demands of the functional unit (Finnveden and Moberg, 2005). For example, an attributional LCA is good to use when answering the question; which product has the best environmental performance, while the consequential system approach best answers the question; what are the consequences of choosing this product.

Environmental LCAs have been used for a relatively long time but has during the last decades developed further in terms of methodology, databases, consistency and thereby the quality and reliability of the results (Finnveden et al., 2009; Guinée et al., 2004). Today the tool is seen as a reliable method to adopt when evaluating the environmental performance of products and services (Finnveden et al., 2009) and is even standardized internationally by the International Organization for Standardization (ISO) in ISO 14040: 2006 and ISO 14044: 2006. The 14040 standard include principles and frameworks for how to conduct an E-LCA, and the 14044 standard include requirements and guidelines for the four stages in E-LCA: Goal and scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation (See **Figure 3**).

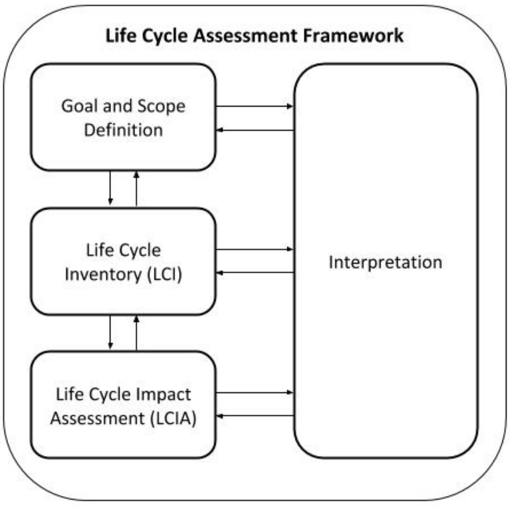

Figure 3: The four stages of LCA (Adopted from ISO 14040: 2006)

5.1.1 Goal and Scope Definition

The first step in E-LCA is the definition of goal, scope and boundaries for the study. The ISO 14040 states that the goal definition should include a description of intended application, why the study is conducted, intended audience and if the results are supposed to be disclosed to the public in the form of comparative statements.

The scope of the study should, as stated in the ISO 14040 standard: "be sufficiently well defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal" (ISO 14040: 2006, p.11). To ensure this statement the definition of goals and scope includes a description of the studied product system and the function of the product system(s), definition of the functional unit, system boundary, allocation procedures, data requirements, impact categories and methodology for impact assessment, assumptions, limitations and the audience of the study.

A system or a product can have several functions and the one selected for the study depends on the goal and scope. Most LCAs are performed to compare two or more product systems, which only is possible, or relevant, if the function of the two products is the same (Curran, 2015). For example the comparison of the two products a car and a train per se will probably show that the train has the largest impact, but when comparing the function "moving from place A to place B" the result may be different. The functional unit (FU) thus assures that the functions of the compared products are the same (Curran, 2015) and provides a reference to which the inputs and outputs are related (ISO 14040: 2006).

5.1.2 Life Cycle Inventory

The Life Cycle Inventory (LCI) phase is where all impacts connected to the specific product are assembled and quantified. Included in the quantification are all relevant in- and outputs for a specific product in each step of its life cycle (ISO 14040: 2006) necessary to meet the goals of the defined study (ISO 14044: 2006). This implies data collection of energy usage, raw material inputs and environmental releases to air, land, and water throughout the entire life cycle of the specific product or system (Curran, 2015).

Ideally all quantitative (and some qualitative data) should be collected for each unit process included in the system boundary. To ensure the quality, validity and transparency of the study there should be validation for using the specific data and each collected data should relate to the unit processes, the reference flow and to the functional unit. Furthermore, the collected data should be based on a systematic and consistent product system, fulfill the desired data quality in alliance with the application of the study and keep the level of aggregation of inputs and outputs consistent with the goal of the study. (ISO 14040: 2006)

In the LCI phase one of the most common difficulties is when a system yields more than one useful product, so-called multi-functional processes (Curran, 2015). When a process generates more than one useful product the flows of in- and outputs and the total environmental burden have to be *allocated* between these products (ibid.). For example, the production of meat also generates the co-product milk which both are desired products generated from the same system. The environmental impacts generated from the "cow-system" thus have to be divided between the two products meat and milk. This can be done in several ways where the ISO standard (ISO 14040: 2006) outlines a hierarchy of how to address co-production allocation:

(1) If possible, one should always try to avoid allocation through; dividing the unit process into sub-processes and collected in- and outputs in relation to these sub-processes, or; expanding the systems to include the additional functions of co-products.
(2) If not avoid allocation is possible the second best choice is to divide the input and output flows between the products according to physical relationships.
(3) If neither avoided allocation and allocation through physical relations are possible one should use other relationships to determine the allocation e.g. economic value.

It is however important to distinguish between co-products and waste, since the environmental burden only should be allocated to the useable co-products. The allocation procedures presented above is applicable to re-use, material recovery and energy recovery situations as well. (ISO 140044: 2006)

5.1.3 Life Cycle Impact Assessment

Following the ISO-standard (ISO 14044: 2006) the third phase in LCA is the Life Cycle Impact Assessment (LCIA). In the LCIA phase the impacts on human health and the environment associated with the in- and outputs from the LCI are assed (Curran, 2015). The purpose with the LCIA is thus to help to better understand the results and the environmental significance from the LCI (Finnveden et al., 2009; ISO 14044: 2006).

The LCIA consist of three mandatory steps (ISO 14044: 2006): The first step is to identify the impact categories, category indicators and characterization models where the impact categories chosen for the study should represent a set of environmental issues relevant for the specific product and to the defined goal and scope of the study. The second step is the classification step, in which each LCI result is assigned to the selected impact category relevant for the LCI result. The last step is the characterization step, in which the category indicator results are converted into the same units and all results are aggregated within the same impact category to form a numerical indicator result.

After these three mandatory steps there are several optional additional elements that can be included in the study; normalization, grouping, weighting and data quality analysis. Since these steps are not included in this thesis they will not be described further[4].

5.1.4 Life Cycle Interpretation

The last step of an E-LCA is the interpretation phase (ISO 14044: 2006), a systematic way to identify, quantify, check and evaluate the information and results gathered in the LCI and LCIA (Curran, 2015). The phase should according to the ISO-standard (ISO 14044: 2006) include three elements; an identification of significant issues from the LCI and LCIA phases; an evaluation of the completeness, sensitivity and consistency of the analysis; and finally a conclusion together with limitations of the study and further recommendations.

[4] For more information about the optional steps of LCIA see part 4.4.3 in ISO-14044: 2006.

5.2 Method for analysis of Nudie's Environmental Sustainability Goals.

In order to analyze the environmental performance at Nudie Jeans the sustainability report from 2017 (Nudie Jeans, 2017) has been used to identify the existing environmental sustainability targets and measures. In Nudie's sustainability report Nudie has identified all sustainability targets and measures with the help of a materiality analysis based on the UN Sustainable Development Goals and the GRI standard on sustainability reporting. Through the materiality analysis Nudie has identified 16 so-called priority targets where each priority target has been given a priority number between 1 and 16, one is prioritized highest and 16 lowest (see **Table 1** in section 4.2.1). Within each of the 16 priority topics there are multiple sustainability targets or measures addressed by Nudie Jeans in order to capture the identified priority topics. For example, in the priority topic *Material & Certification* one of the targets is that all products produced by Nudie Jeans should be made out of 70 percent sustainable material and another that all cotton products should be produced by organic cotton.

As mentioned there are 16 different priority topics relevant for the business conducted at Nudie Jeans, however, in order to capture the purpose of the study, which has a specific environmental sustainability perspective only environmental targets and measure have been of interest from the materiality analysis. The 16 priority topics have thus been narrowed down to only including six of the priority topics, as can be seen in **Table 2**.

Table 2: The identified environmental priority topics from the materiality analysis conducted by Nudie Jeans, adopted from Nudie's sustainability report (Nudie Jeans. 2017).

Nudie's focus areas	Priority topics	SDG	Identified GRI standards
Sustainable Materials	1. Material & Certifications	15	301: Material 303. Water
Sustainable Production	4. Chemicals 6. Energy & Water	6 & 12	303: Water 302: Energy 306: Effluence and waste
Sustainable Product	9. Repair, Reuse 3. Recycle 10. Transport	12	407: Freedom of association 408: Child labor 409: Forced or compulsory labor 413: Local community 414: Supplier social assessment

Within the six environmental priority topics 19 environmental sustainability targets or measures have been identified (more information about each target and measure is found in chapter 7). These targets and measures have been analyzed and evaluated in terms of how well they represent their potential environmental impact. Thus, how large is the potential environmental of each target/measure and how well is this impact represented in the priority order that the priority topic has been given by Nudie Jeans.

To evaluate the potential environmental improvement of each environmental measure or target five main sensitivity analyses have been performed on the processes: cotton cultivation, residential laundry of jeans, recycling & second-hand selling, transportation and energy usage (presented and explained further in section 6.4.3 Sensitivity analysis). Based on the results from the sensitivity analyses the potential environmental improvement has been compared to the priority order of the specific target/measure. If the target or measure is prioritized high at the same time as the potential environmental improvement from the sensitivity analysis also is high the priority area is evaluated to have the right environmental focus. However, if the sensitivity analysis shows that the potential environmental improvement is high and the priority level is low Nudie Jeans is evaluated to have the wrong focus within this specific area. The analyses of each environmental sustainability area together with a concluding table of the results from the analysis are presented in Chapter 7.

5.3 Data collection Strategy

The data that is used in the E-LCA is to the greatest extent collected from Nudie Jeans and six of their suppliers; The fabric manufacturers *"Italian Fabric Producer"* located in Italy, the fabric manufacturers *Bossa* located in Turkey, the Tunisian jeans producer *Denim Authority*, the cutting and sewing facility *Bobo* located in Italy, the Italian laundry facility *Everest*, the finishing company *GG Productions* located in Italy[5] and lastly the Swedish warehouse facility *Korallen*. The data has primarily been collected through custom-made data collection forms where questions regarding the facilities yearly production data have been in focus. Since the LCI phase is an iterative process (ISO 14044: 2006) the gathered data has been adjusted according to complementing data through email conversations. Where data has been considered to be unrealistic or where data has been lacking assumptions have been made according to smaller literature studies on similar cases.

As mentioned, each data collection form has been custom made after the type of production and activity of the suppliers. But all forms have included questions regarding:

- Total yearly production and yearly production of the product under study.
- Total yearly energy consumption and what type of energy sources that have been used for the different processes.
- Total yearly water consumption, what the source of water has been and how the water usually is treated after use.
- Transportation data within and outside of the facility.
- And lastly, the generation of waste and spillage at each facility.

Please see Appendix 1 for a general data collection form.

The collected data is handled in Microsoft Office's Excel (Microsoft, 2016) and modeled in the LCA software SimaPro (PRé Consultants, 2018). The amounts and types of material, energy and water have been based on the answers given by the suppliers in the data collection forms while the processes behind the in- and outputs have been based on generic datasets from the databases ecoinvent 3.3 (Ecoinvent, 2016), US Input and Output Database (CEDA, 2002) and Agri-footprint version 3.0 (Agri-footprint, 2017). For further information about datasets and methodological choices please see Chapter 6.

[5] Information about Bobo and GG productions has been collected via the logistic company Idea Mode (2018).

6. Environmental LCA of three styles of jeans

An environmental LCA of the three styles Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions has been conducted. In this section the specific methodological choices of the LCA are presented, the LCI results from each style of jean described, the LCIA is presented and lastly the main results together with a sensitivity analysis are included.

6.1 Goal and Scope definition

The goal of the environmental Life Cycle Assessment (E-LCA) has been to identify and to evaluate the potential environmental impacts of three different styles of jeans at Nudie Jeans, from a life cycle perspective. The results have been used to identify environmental hotspots throughout the supply chain in order to find out which of the processes and life cycle phases that generates the highest and lowest environmental impacts. The application of the LCA results will primarily be by Nudie Jeans, which means that the intended audience for this specific LCA is Nudie Jeans.

In this study a so-called attributional LCA approach has been chosen (further explanation in section 6.1.4) and the LCA is of comparative structure, however, none of the processes have been excluded due to similarities. The aim has been to include all processes, from organic cotton cultivation to the end-of-life management, so that the potential environmental impact represents the entire life cycle, and thus the whole product.

6.1.1 Function and Functional Unit

The three styles of jeans have the same basic function "to be pants", with the purpose to warm or to cover legs. The products are thereby switchable items in terms of just being pants. The main differences when talking about jeans are the desired look and that different pants can generate different feelings of comfort for different users. But since the products are all jeans offered by the same company the difference of the styles are assumed to be minimal. Furthermore, according to Nudie Jeans the three styles of jeans that are examined are assumed to have the same life length which according to a study made by Granello et al. (2015) represent 200 use cycles (or 200 days of wearing a pair of jeans).

The functional unit is thus **one pair of an average sized jean manufactured by Nudie Jeans and consumed in Sweden, over its full lifetime of 200 use cycles** where the average sized jean is represented by the total weight of all produced jeans of the same style divided by the total number of the same jeans style.

6.1.2 System Boundaries

The system boundary for the examined products reaches all the way from raw material extraction to final waste management of the products, and in each process included in the system different types of material, energy, water and emissions flows in and out from the system are included, see **Figure 4**. Fabric manufacturing, production of jeans, residential laundry of clothes at home, transportation and the recycling scenario are all included in the foreground of the study, and are primarily based on site-specific data. Cotton production, together with all other material production (elastane, chemicals, washing agents, packaging materials etc.) are placed in the background of the study where the type and amount of material primarily are based on site-specific data but the production processes are entirely based on generic data.

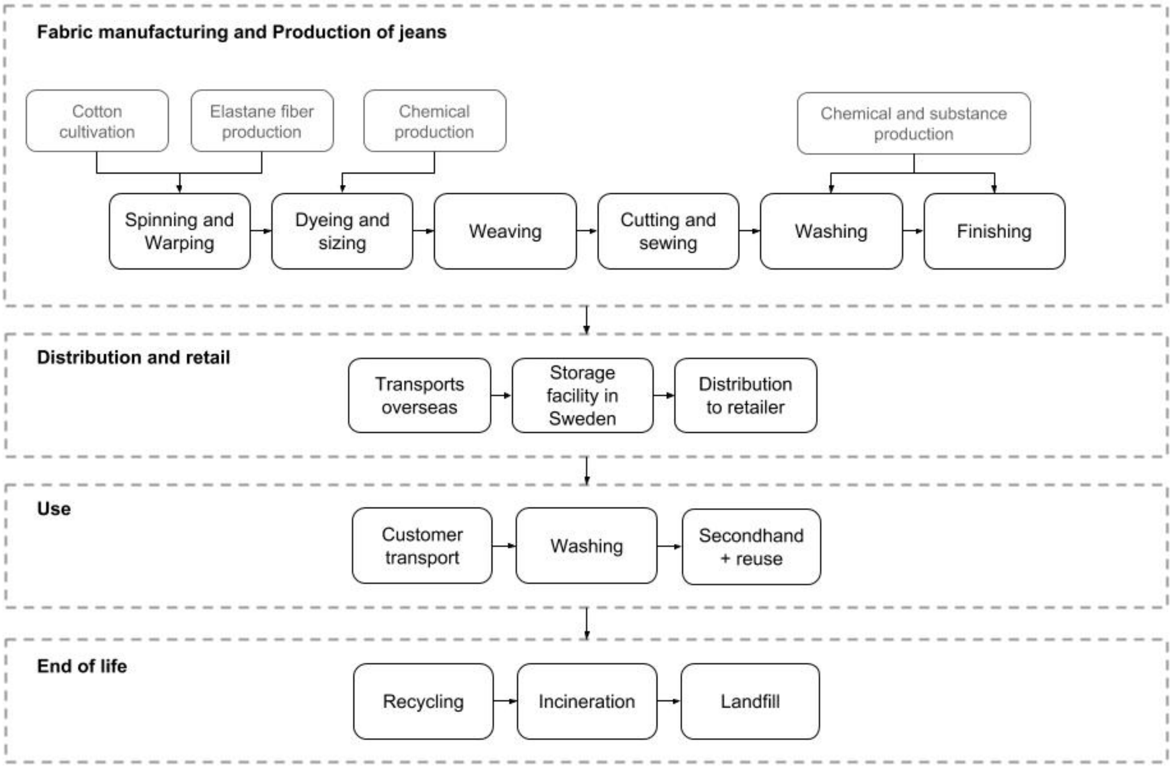

Figure 4: General flow-chart of the processes included in the life cycle of jeans, including foreground (black) and background (grey) division.

The system boundary connected to nature thus has its cradle at raw material extraction of cotton and ends at the emissions to land, air and water at the waste management in the end-of-life stage of the products, where all impacts along the way are included.

Geographically the production processes of the studied products are spread around different parts of the world. The raw material cotton is extracted in India and Turkey, the fabric manufacturers are located in Italy and Turkey, the jeans are sown in Italy and Tunisia while the finished pants are stored and sold in Sweden. The geographic system boundary for raw material extraction and the production of jeans have therefore been assessed on a global level, more specifically India, Turkey, Italy and Tunisia. The usage and disposal phases have however primarily be focusing on Swedish data. Regional data have been used as far as possible for the five different countries, but where regional data has been missing the global average have been used.

All site-specific data is collected during 2018 and represent circumstances at the suppliers during 2017. Regarding generic data the data is as updated as possible and primarily not older than 10 years old, but if the same technology is used or has the same conditions in general this is more important than the time frame.

The life cycle of infrastructure, machines, vehicles, roads, buildings, the designing of products, administrative work business travels etc. are not included in the study and thus excluded from the models in SimaPro.

6.1.3 Allocation Procedures

The allocation procedures used for the foreground processes included in the study are mainly based on the physical relation: *mass,* since the production data from the suppliers have been available in relation to total weight of yearly produced products. Some exceptions have been made but since these represent a minority they are documented separately in the LCI chapter (section 6.2).

In the LCI process the datasets used has been limited to only come from the three databases: Ecoinvent version 3.3 (Ecoinvent, 2016), US Input and Output Database (CEDA, 2002) and Agri-footprint version 3.0 (Agri-footprint, 2017), which all uses economic allocation in their existing datasets. The Input Output database allocates the environmental burdens based on the economic value in the US (CEDA, 2002). In the datasets from ecoinvent 'system model allocation, default' allocates the environmental burdens based on average supply of products from market activities and the economic revenue in Europe (Ecoinvent, 2016). The agri-footprint datasets are available in three different libraries in SimaPro, allocation based on mass, energy and economy (Agri-footprint, 2017). To keep a consistency with the choice of datasets and to minimize the risk of including too varying datasets with different system boundaries the allocations in agri-footprint datasets are based on mass.

The main weakness with choosing economic allocation for the datasets is that the value of products depends on the economic market, which can change dramatically all independent on the mass or other physical relations of the in- and outputs (Curran, 2015). But since the products under study are specific products where the result should represent the environmental impact, as it is today, the economic value will still represent the "right" economic values of the current situation.

All allocation procedures in agri-footprint are applied without the use of cut-offs, except from three processes, where one is animal manure (Blonk Agri-footprint BV, 2015). Since animal manure is used as an input in the LCI the allocation procedure for this process will shortly be explained here. Animal manure is considered as a residual product in the animal production system thus the environmental burden from animal production is not included in the manure processes. Only emissions from application of manure in the agricultural system are included.

In situations where the life cycles of different products merge into each other (such as when incineration in one system provides heat for another system) the materials in the second system that would have been produced with another type of energy can be avoided with the help of the energy produced in the first product system. In this study these types of issues have been handled through the so-called Polluter Pays (PP) principle (ISO 14040 and ISO 14044). Furthermore, all transportations have been allocated to the producer e.g. the transportation of cotton is allocated to the cotton cultivation process and the transportation of fabric to the fabric manufacturer etc.

6.1.4 Life Cycle Inventory modeling framework

As mentioned before, an attributional modeling framework has been applied in the LCI, because it is the best-suited approach for the purpose of the study. The choice of choosing an attributional approach over a consequential system approach has been made since the LCA is focusing on analyzing the potential environmental impact of currently existing processes and producers. The results from the LCA do not aim at giving propositions for changes in the current process, which often is the case when adopting a consequential approach. In this case an attributional LCA gives sufficient information about the environmental impacts of the studied system.

The methodology for the LCI phase has included data collection, modeling of the different supply chains and a calculation of the environmental impacts. The LCI was started with deciding which data sets that were important to include in the study, after this the collection of data was initiated (all collected data are documented in tables in Appendixes 2-4). The last step of the LCI phase was to use the collected data in order to create models for the supply chains. During this process complementary inventory data was collected, both in terms of complementary site-specific data from the suppliers, but also general data for some of the inputs, such as raw material extraction. Since the LCI process is an iterative process, and several data collection forms has been delayed for different reasons, the steps of the LCI haven't been conducted in sequence but rather simultaneously, along with the collected data.

During the LCI six key life cycle phases was identified for jeans; *cotton cultivation*, *fabric manufacturing*, *production of jeans*, *distribution*, *usage* and *end-of-life*. These life cycle phases in turn include further processes, which are described in the LCI phase in section 6.2. For all these life cycle stages data have been collected and sorted in the four areas: material usage, energy usage, water usage and transportation. All datasets are presented in the Appendixes 2-5.

6.1.5 Data Quality

Since the objects of study are three specific products manufactured by Nudie Jeans and the collected data as far as possible should be site-specific the data has been collected from the suppliers of the different production stages; *fabric manufacturing*, *jeans production* and *distribution*. The data should thereby be representative for the studied products. Where site-specific data hasn't been available for different reasons, or where phases in the life cycle aren't specific for the products, average data representing similar practices has been used. Generic data has primarily been used in the life cycle phases *cotton cultivation*, *usage* and *end-of-life*. When generic data has been used country specific data has been prioritized, and if no country specific data has been available a global average has been chosen to represent the processes. However, technological conditions and other basic preconditions have been prioritized over geographic boundaries and reliable, reviewed and acknowledged references have been used as far as possible.

All data that has been used that is not gathered through the data collection forms from the suppliers (see part 5.3) are documented separately in the LCI phase in section 6.2.

All data concerning raw material extraction in the different life cycle stages has been defined as non-specific for the jeans under study and has therefore been collected from the LCA inventory databases Ecoinvent 3.3, Agri-footprint 3.0 and the CEDA database USA Input and Output, prioritized in that order. For example, the conditions of the cotton cultivation are site-specific since cotton is cultivated under certain conditions in specific countries where the basic prerequisites such as the need for irrigation, fertilizing etc. may differ between countries. The cotton seeds on the other hand, or the extraction of manure used, are assumed to be non-specific and thereby taken from the LCA inventory databases.

When using LCA inventory datasets from several databases it will always be problematic to ensure that all data represent the same system boundaries. The USA Input output database for example contains data from entire economic sectors in the US (CEDA, 2002) and has thereby the advantage of including an entire economy. The disadvantage is however that the result may not be specific enough to fulfill the research question or is too site-specific for the US. In ecoinvent it is stated that the database contain data from ‘various sectors’ such as production, transport, production of chemicals with a main base of European and global data (Ecoinvent, 2016). This doesn’t mean that one database is better than the other it just means that the mixing of different databases can be problematic and that different databases are suited for different purposes. To avoid having too many different databases the choice of datasets have been prioritized in the order: 1) ecoinvent, 2) agri-footprint and lastly 3) USA Input Output.

The reason to why the prioritization order is looking like it does is because the ecoinvent database has a European and global perspective (Ecoinvent, 2016), which represent the scope of this study very well. The agri-footprint database complements ecoinvent when it comes to data regarding crop-cultivation and animal production systems (Agri-footprint, 2017), the database has therefore been included so that the cotton cultivation step is represented in a fair way. Datasets representing dying detergents in the fabric manufacturing stage is lacking in the two databases ecoinvent and agri-footprint therefore there was a need to include a third database. The USA Input Output database both included the needed processes and was the most similar database in terms of allocation procedures and system boundaries, so even if the inputs and outputs are represented in economic terms this was chosen. Since the large majority of the used datasets comes from ecoinvent, the negative effects of mixing databases are minimal.

6.1.6 Life Cycle Impact Assessment Method

The impact categories chosen for the LCA in this study are based on a report from Thinkstep (2016) on the Environmental Footprint Category Rules (PEFCR). The report has been developed on the behalf of the Sustainable Apparel Coalition (SAC) and does therefore represent the impact categories relevant for the textile industry. Of the total nine recommended impact categories four have been assessed here: climate change, freshwater eutrophication, marine eutrophication and terrestrial acidification. The impact categories ozone depletion and photochemical ozone formation, particulate matter, ionizing radiation have been excluded since these do not represent the most severe environmental impacts connected to textiles (Textile Exchange, 2014; Muthu, 2014). The toxicity categories may be important to include due to the large use of chemicals within the textile industry, however these data often yield results that are unstable due to inadequacies in the characterization methodologies (Thinkstep, 2015).

The impact categories have been complemented with three additional impact categories specific for cotton cultivation: water consumption, abiotic (fossil) depletion and land use (Textile Exchange, 2014) to ensure that the most important impact categories are included according to the ISO standard (ISO 14040: 2006).

The LCIA method that has been used in the study is the ReCiPe Midpoint (H) 2016 impact assessment method. The method was created by several important actors[6] within LCIA and includes both midpoint and endpoint indicators (ReCiPe, 2016). The choice has been to only look at midpoint level indicators since the endpoint level indicators becomes too broad, e.g. human health, ecosystem quality and resource scarcity. In accordance to the purpose of the study it is sufficient to stop at midpoint level.

[6] The specific actors are RIVM, Radboud University, Norwegian University of Science and Technology and PRé Consultants

The ReCiPe (2016) assessment model consists of 17 sets of midpoint levels, and standardized models from characterization and classification. Ten of the total 17 midpoint indicators have been chosen (see **Table 3**) since they best resemble and have a direct link to the identified impact categories. The remaining categories: ozone depletion, human toxicity, photochemical oxidation, particulate matter and terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation and metal depletion have been excluded since there is missing a direct connection between these midpoint indicators and the desired impact categories. In **Table 3** the assessed impact categories is presented together with their units and their corresponding environmental issues.

Table 3: Description of the chosen impact categories. The impact categories presented in the first column are the ones identified from Thinkstep (2015).

Impact Category	ReCiPe Midpoint (H) Indicator	Unit	Description
Climate Change	Climate Change	Kg CO_2 eq.	Climate change or global warming refers to the effects on climate caused by human emissions in the form of greenhouse gases (GHG): carbon dioxide (CO_2), methane (NH_4), water vapor (H_2O), nitrous oxides (N_2O), ozone (O_3), chlorofluorocarbons (CFCs) and hydrofluororcarbons. GHG's absorbs radiation from the sun, which leads to increased temperatures in the atmosphere (Rockström et al., 2009; Goedkoop et al., 2008). Climate change is thus relevant in all systems that uses fossil based energy sources, transportation and land use. The characterization and classification factors in the ReCiPe 2008 method is based on CO_2 equivalent factors from the IPCC report 2007 (Goedkoop et al., 2008).
Terrestrial acidification	Terrestrial acidification	Kg SO_2 eq.	The release of inorganic substances, such as sulfates, nitrates and phosphates, to the atmosphere changes the acidity of the soil. Almost all plants have an optimum of acidity and a serious deviation from this optimum is thus harmful for several species. The terrestrial acidification potential assessed with the characterization and classification factors in the ReCiPe 2008 method is expressed in SO_2-equivalents and is therefore area independent. (Goedkoop et al., 2008)
Eutrophication	Freshwater eutrophication	Kg P eq.	Eutrophication can be expressed as the increased nutrient levels in the aquatic environment (Rockström et al., 2009; Goedkoop et al, 2008). Emissions of nitrogen (N) and phosphorus (P) are two of the main causes to eutrophication since they represents the substances which limits the yield the aquatic biomass (Rockström et al., 2009). Since the use of fertilizers often results in leakage of N and P to the attached water bodies this impact category is relevant for the LCA study. In freshwaters P is the limiting nutrient and in marine waters N plays the limiting role, the characterization and classification factors in the ReCiPe 2008 method is thus based on P equivalents for freshwater eutrophication and N equivalents for marine eutrophication (Goedkoop et al., 2008).
	Marine eutrophication	Kg N eq.	
Land Use	Agricultural land occupation	m^2a	The land use impact category in ReCiPe 2008 refers to the damage on ecosystems due to the effects of occupation and transformation of land (Goedkoop et al., 2008). Different areas have different spices diversity and not all types of occupation have the same effect on biodiversity and the type of land-use is therefore important to include. The land-use impact category has been included since jeans production requires crop cultivation. There are several links between how land is used and the loss of biodiversity but in the ReCiPe 2008 method two main mechanism are used; (1) occupation of a certain area over a certain time and (2)

	Urban land occupation	m^2a	transformation of a certain area of land. Agricultural land occupation is divided into various types of agriculture and urban land occupation is divided into three types of usage: continuously built, discontinuously built and green areas. Both impact categories are measured as the amount of agricultural area and urban area respectively that is occupied (m^2) times the estimated years of occupation (t), creating the unit m^2a for the midpoint characterization and classification factors. (Goedkoop et al., 2008)
	Natural land transformation	m^2	Natural land transformation refers to when land is transformed from one type of land use state to another: from natural to non-natural, from non-natural to natural, from non-natural to non-natural and from natural to natural. In ReCiPe the transformation from natural to non-natural land is characterized with a positive characterization factor (environmental damage) while transformation from non-natural to natural land has a negative characterization factor (environmental improvement). The last two transformations have no meaning in the ReCiPe method since no affect is assumed to occur and has therefore the characterization factor 0. The characterization and classification factors are expressed in m^2 (Goedkoop et al., 2008).
Water Consumption	Water depletion	m^3	Water scarcity is both a local and a global issue (Rockström et al., 2009). The global manipulations of the freshwater cycles due to the massive use of freshwater have started to affect biodiversity, food and health security and ecological functioning all around the world. Water use is one of the most highlighted environmental impacts connected to jeans production and cotton cultivation and is therefore included in the LCIA. It is however difficult do decide which water usage that results in water shortages. The impact category assessed with the characterization and classification factors of the ReCiPe 2008 method is based on m^3 of amount of depleted water.
Abiotic depletion	Fossil depletion	Kg oil eq.	Fossil fuels refer to all resources that contain hydrocarbons such as coal, oil and gas. The midpoint characterization and classification factors used in the ReCiPe 2008 method are expressed in oil-equivalents based on the ecoinvent database 2007.

In normalization the aim is to put the results of an LCIA into some kind of context by applying a scale factor so that the results can be referred to a specific reference value (ISO 14044: 2006). In order to fulfill the aim of the study: to find environmental hotspots of the three jeans and to see if theses hotspots are in focus in the sustainability work at Nudie Jeans a normalization stage is unnecessary. Furthermore, following the ISO standard, weighting of the environmental impacts in a comparative LCA, which will be disclosed to the public, is not permitted (ISO 14040: 2006). The weighting step is thus excluded from the study and the LCIA ends at characterized midpoint level.

6.1.7 Sensitivity analysis

Sensitivity analyses have been conducted in cases when data have differed a lot between the three styles of jeans, when data gaps have occurred, or when certain assumptions have been made. Sensitivity analyses have also been conducted according to the environmental sustainability goals at Nudie Jeans so that the effects of the goals could be examined. More information about the specific sensitivity analyses can be found in section 6.4.3 Sensitivity analysis.

6.1.8 Assumptions and Limitations

To ensure that all significant parts of the studied system should be included in the results no initial cut-off criteria were set. During data collection several parts of the system have been excluded from the analysis of different reasons. All excluded parts are described in the list below together with the main assumptions that have been made.

- Thread that is used for the sewing is not included as a specific material input in the jeans production phase. The material in the thread is assumed to be cotton and is thereby included in the cotton input.
- The fabrics used in the three styles of jeans contain 1-2 percent elastane, a polyurethane fiber that is used to make denim fabric more flexible. However, elastane, or some other suitable substituting material, do not exist in the databases used in the study, therefore the choice has been made to exclude elastane and its impact entirely. Since elastane is produced by fossil fuels the total impact would be higher if the elastane was included, but since the elastane content only represents 1-2 percent of the fabric (which in turn represent 95-98 percent of the pant) this negative impact should theoretically be negligible in relation to the other impacts.
- The sewing and cutting company Bobo, located in Italy, is heated with natural gas but the yearly consumption is unknown. The total amount of natural gas for heating has therefore been estimated based on the natural gas consumption at the other facilities located in Italy. By looking at the yearly consumption of natural gas at the facilities and the total number of produced products a so-called "heat factor" has been created representing 0.53 m^3 per kg produced product. This heat factor is then multiplied with the total production at Bobo to create a yearly value for the natural gas consumption.
- All energy and heat gained at incineration in countries outside of Sweden are seen as non-useful residues and have therefore been excluded from the study.
- For the datasets about land occupation, land transformation, CO_2 uptake and energy calorific value included in the ecoinvent dataset for cotton cultivation a change factor has been used based on yields of raw cotton fiber per hectare.
- Water consumption in the cotton cultivation process has been based on Turkey and Indian specific rainfall and irrigation data from an LCA study on organic cotton cultivation conducted by Textile Exchange (2014). For simplification purposes, the water consumption in the cotton cultivation processes has been based on the assumption that all water, the average yearly amount of rainfall per hectare, in Turkey and India[7] is absorbed into the ground. The amount of rainfall absorbed by the plant is thus defined by the mass of the yields of cotton per hectare.
- The fertilizer "rock phosphate" that is used in the cotton cultivation process in Textile Exchange (2014) does not exist in the used databases. The "lime as fertilizers" dataset from the agri-footprint database has therefore been used instead. The P content in the added rock phosphate has been used to decide the amount of required lime assuming that the P content in limestone is about 500 ppm (Porder and Ramachandran, 2012).
- All transportation by truck is modeled with the ecoinvent dataset *"Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S"* with the assumption that all trucks are the size of 16-32 metric tons, except when transportation is occurring within the life cycle phases then all trucks are the size of 3.5-7.5 metric tons. Since the exact environmental classification of the transports within the three product

[7] Rainfall patterns and the amount of rain are collected and presented in the same report conducted by Textile Exchange (2014).

systems is unknown the worst-case scenario has been chosen, thereby EURO3 is the environmental classification used for all transports.

- The suppliers have provided the location of their facilities, which has been used as the base for the calculation of transportation distances. The transportation routes between suppliers are extracted from Google Maps where the shortest route always has been chosen.
- Storage of products in the different facilities is not included as separate inputs in the LCA model but is included in the total energy consumption of the facility. One exception is made: the storage at Korallen since storage is the only function of this facility.
- All denim fabrics have the width of 1,5 meter, which has been the reference point in the aggregation of collected data at the fabric manufacturers (Nudie Jeans, 2018).
- Since several of the required substances used in the dyeing and sizing process of fabric manufacturing and in the laundry processes of jeans production were not available in the databases, other substances with similar function or attributes have been chosen. The choice of the substituting substance has been based on the product descriptions provided by the chemical products supplier HT Fine Chemical Co (2018), the study *Study on chemicals used in the garment washing process* conducted by Mahfuz (2013) and the book *Applied Plastics Engineering Handbook* written by Kutz (2011). To see which substances that have been replaced please see section 6.2.1-6.2.3.
- If city specific data is required in the use phase Gothenburg has been chosen as reference, since most jeans per person is sold in Gothenburg.

6.2 Life Cycle Inventory

Inventories of the three styles of jeans are first presented separately (part 6.2.1-6.2.3) where the processes that differ between the three jeans, *cotton cultivation*, *fabric manufacturing*, *jeans production* and *distribution*, are included. After this the processes that are equal for all three styles, *use* and *end-of-life*, will be presented in part 6.2.4. This LCI chapter only includes the methodology behind the data collection and which in- and outputs that has been included, not specific datasets and amounts for all collected data, for this please see Appendixes 2-5.

6.2.1 Life Cycle Inventory of Lean Dean Lost Legend

The life cycle of Lean Dean Lost Legend is divided according to the life cycle phases identified in section 6.1.4: cotton cultivation, fabric manufacturing, jeans production, distribution, usage and end-of-life, see **Figure 5** for the process flow chart. The use and end-of-life phase will be handled separately in part 6.2.4. For information about specific datasets and amounts go to Appendix 2.

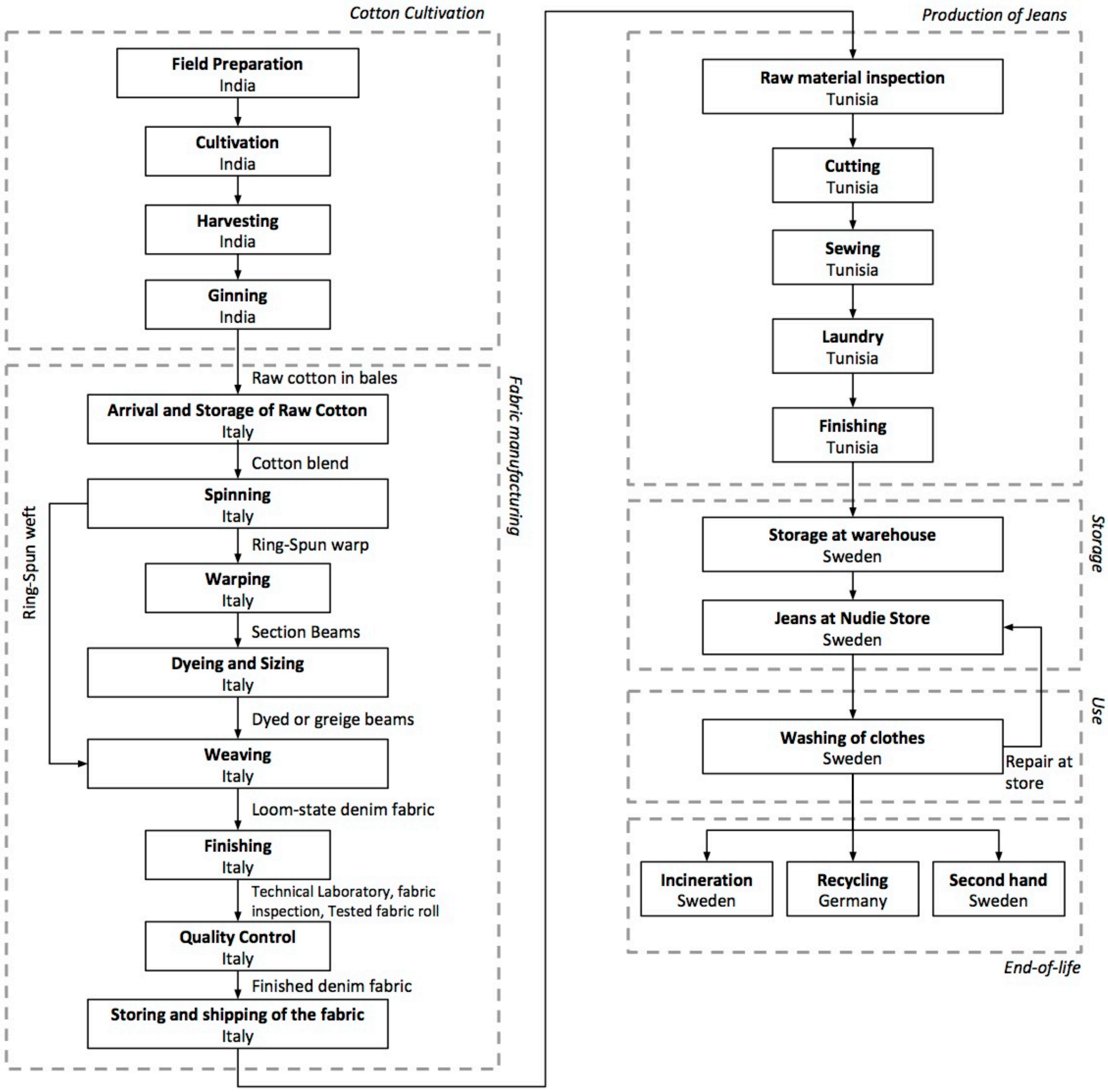

Figure 5: Flow chart of the life cycle phases and processes included for the product Lean Dean Lost Legend.

Cotton cultivation

Lean Dean Lost Legend is produced with the fabric RR 2716 Old Crispy, which consists of organic cotton cultivated in India. To estimate the impact generated from organic cotton cultivation the data inputs have been based on the study "*Life Cycle Assessment (LCA) of Organic Cotton*" made by Textile Exchange (2014). The ecoinvent dataset "*Cotton fibre {RoW}| cotton production | Alloc Def, U*" has been used as a reference to ensure that the dataset is as similar to the already existing raw material extraction processes as possible in terms of included aspects, so that the processes are easily exchangeable in the sensitivity analysis. Since the cotton is cultivated in India the datasets has primarily been based on country specific data from India. When country specific data was lacking the global average data[8] from the same report was used.

The cotton cultivation life cycle phase consists of the four main processes: field preparation, cultivation, harvesting and ginning (Textile Exchange, 2014). In field preparation the defined inputs are; ploughing, cottonseeds and arable land occupation, which all have been based on Indian specific values provided by Textile Exchange (2014). Arable land occupation is however adjusted according to the cotton fiber ecoinvent dataset to also include arable land transformation, carbon dioxide uptake and an energy gross calorific value.

The next step is cultivation, which consists of irrigation, fertilization and harvesting (Textile Exchange, 2014). The use of fertilizers is based on the global average amounts and types of fertilizers used in organic cotton cultivation given by Textile Exchange (2014). For simplification purposes the amount of added fertilizers have been aggregated to represent the total content of nitrogen and phosphorus, see **Table 4** and **Table 5**. The total amount of added nitrogen has been converted to manure from cows and the total amount of added phosphorus has been converted to the adding of lime.

Table 4: Total nitrogen content (kg) of the average required organic fertilizers per hectare in India, United States, China, Turkey and Tanzania. Data collected from Textile Exchange (2014).

Organic fertilizer	Weight (kg)	Nitrogen content (%)	Nitrogen content (kg)
Farm Yard Manure	7817	0,4	31,268
Compost	868	1,1	9,548
Cow dung	635	0,9	5,715
Neem cake	15	5	0,75
		Total:	47,281

Table 5: Total phosphorus content of the average required organic fertilizers per hectare in India, United States, China, Turkey and Tanzania. Data collected from Textile Exchange (2014).

Organic fertilizer	Weight (kg)	Phosphorus content (%)	Phosphorus content (kg)
Rock Phosphate	56	28 % (FAO, 2004)	56,68
		Total:	56,68

The need for irrigation depends on several preconditions such as temperature (climate), location and rainfall patterns (Textile Exchange, 2014). The volume of water added through irrigation and the volume of rain-fed water have been based on Indian specific data from Textile Exchange (2014). For more information about the methodology for water consumption data please see section 6.1.8 Assumptions. For the harvesting process 1 ha has been used according to Textile Exchange (2014).

When the cotton has been cultivated it is time for ginning of the raw cotton fiber. This process consists of the two data inputs transportation of the harvested cotton and the electricity usage and the process results in the three outputs cotton lint, cottonseeds and waste (Textile Exchange, 2014). The transportation includes transportation of the harvested cotton fiber, bale loading and bailing, and the type of transportation is assumed to be a smaller truck/tractor of

[8] *Average data* represent the average value collected from ten different organic cotton fields located around the world (Textile Exchange, 2014). Five cotton cultivation areas located in India, two areas located in Turkey, one area in the United States, one area in China and one area in Tanzania.

3.5-7.5 metric ton. The electricity consumption for ginning is based on the amount of energy required per yield of cotton fiber provided by Textile Exchange (2014). The amount of waste generated in the ginning process is relative to the yield of cotton lint and is thus based on data provided by Textile Exchange (2014). The gin waste is included as a waste output in the LCA model in the form of bio-waste to be composted.

In the production of cotton fiber (lint) there is also the production of cottonseeds. The environmental burden generated from cotton fiber is therefore divided between the two products cotton lint and cottonseeds. Since cotton lint is a relatively light weighted product in comparison to cottonseeds (see **Table 6**) allocation based on mass would not represent a fair division of the environmental burden since the largest part of the environmental burden would be allocated to a by-product. The environmental impacts from the inputs in cotton cultivation have therefore been allocated according to economic values of cotton lint and cottonseeds.

Table 6: Outputs from cotton production and the allocation of environmental burden based on mass and economic value (Textile Exchange, 2014).

Outputs	Weight (kg/ha)	Allocation - Mass (%)	Allocation – Economic value (%)
Cotton lint	406,8	40,4	**84**
Cottonseeds	598,9	59,6	**16**

The cotton fiber leaves the ginning process as cotton in bales ready to be used in the production of threads, textiles and then apparel products. In the case of Lean Dean Lost Legend the cotton cultivated in India is transported by vessel and truck to a fabric manufacturer located in Italy. Since the cotton cultivation phase is based on generic non site-specific data the location of the cotton cultivation field is unknown. The transportation of cotton has therefore been calculated with the start in Bombay, India, going via the Suez Canal to the harbor closest to the Italian Fabric Producer and then to the facility located in Italy.

Fabric manufacturing

The fabric used for Lean Dean Lost Legend, RR 2716 Old Crispy, is produced at a facility located in Italy and the datasets used is thus primarily country specific data for Italy.

The fabric manufacturing life cycle phase consists of the six main processes: spinning, warping, dyeing, sizing, weaving and finishing. The first phase in the manufacturing of fabric is the production of cotton threads, which is done through spinning and warping. The spinning and warping processes include two main inputs: organic cotton and electricity from the average Italian state-grid. The electricity is described as a total yearly value representing the facilities entire electricity consumption and is not process specific in the LCA model. In the spinning and warping processes there is also the generation of cotton spill. About 5 percent of the bought cotton is spilled each year, which thus represent an output of the system. The spill is included in the LCA model as a waste output in the form of textile.

From the warping process the threads are sent by truck 3 km to the facility for dyeing and sizing. In the dyeing and sizing process there are several substances required: the coloring agent pre-reduced indigo, caustic soda, sodium hydrosulfide, potassium permanganate (PVA) and potato starch. The amounts of required substances depend on the length of the fabric, which thus has been the base for calculating the inputs of the LCA model. Since pre-reduced indigo does not exist in any of the datasets a suitable substitute has been used to represent the impact instead, see **Table 10** in Appendix 2. The dying and sizing processes do also include inputs in the form of natural gas and water. The natural gas has been included as heat and the water is originating from wells. Furthermore, the water is modeled as a total yearly value for the entire facility and is thus not process specific in the LCA model.

Old Crispy is a denim fabric consisting of organic cotton (98%) and elastane (2%), which means that elastane, cotton threads and electricity represent the main inputs of the weaving process. The cotton threads are included through the spinning and warping process, elastane has been excluded from the LCA model entirely (see section 6.1.8 for more information why) and the electricity is included in the total yearly consumption.

The last process in fabric manufacturing is the finishing process, which in the LCA model is represented by the use of natural gas and water, which both already are modeled.

Data that are modeled as being general for the entire facility are, as mentioned before, the electricity and water consumption. But there is also the heating of the facility, which is included as heating produced from natural gas, and the generated waste. Outputs generated from the fabric manufacturing facility, except from cotton spill, are the fabric spill and waste in the form mixed packaging. These represent outputs of the system and are included in the LCA model as waste in the form of textile and packaging paper (since the majority of the mixed packaging is represented by paper). Another output of the system is the water that is polluted with different types of substances and fabric fibers. The management of the generated wastewater is included as management of the total amount of water that has been used in the facility, independent on if it has been in contact with chemical substances or not. The wastewater treatment is however only modeled as average European municipal wastewater treatment and the specific substances used in these processes are thereby not addressed as outputs.

Now the denim fabric Old Crispy is finished, controlled and ready to be sown into beautiful jeans. But first the fabric has to be transported from the Italian Fabric Producer located in Italy to the jeans producing company Denim Authority, located in Tunisia. The finished fabric is first transported by truck to Genoa, the harbor closest to the fabric manufacturers, where it continues its journey by vessel all the way to Africa, where it is transported by truck to Tunis, Tunisia.

Jeans production

The jeans production life cycle phase consists of the four main processes: cutting, sewing, laundry and finishing, which all occurs at the jeans producers Denim Authority located in Tunis, Tunisia. The datasets has thus primarily been country specific for Tunisia.

The cutting and sewing processes are in the LCA model represented by the inputs: denim fabric, zippers, buttons, rivets, waist tags, labels, electricity usage and a transportation distance on 250 km between the cutting facility and the sewing facility. The impact generated from the denim fabric is already included in the made process from the fabric manufacturing life cycle phase. The electricity is in the LCA model represented by the average global electricity sources (since Tunisian specific values were not available in the used databases). The zipper, button and rivet are made out of nickel free brass old copper. Since nickel free brass were not available in the used databases the ecoinvent dataset "*Brass {GLO}| market for | Alloc Def, S*" was adjusted to exclude all nickel contents to better represent the metal used at Denim Authority. In addition to metal recycled paper for the waist tags and woven cotton for the labels are added to Lean Dean Lost Legend. The cutting process also results in waste in the form of denim fabric, for each pant approximately 14 percent of the initial fabric is thrown away. In the LCA model the fabric spill is included as a waste output in the form of textile.

In the laundry process for Lean Dean Lost Legend the substances required are; Resine 3D (Noefielding NFC and Nearfinish 10X N), Dirty (Orange LG-L), Soaping Agent (Neareserve DSW), Spray PP Permangante, Neutralization Agent (META) and pumice. Two other main inputs are represented by water and electricity, which both have been modeled with global datasets. The amount of required substances depend on the amount of water used, since a certain concentration is desired. Since several of the required substances were not available in the databases other substances with similar function or attributes have been chosen, see **Figure 6**. For more information go to section 6.1.8 Assumptions and Limitations.

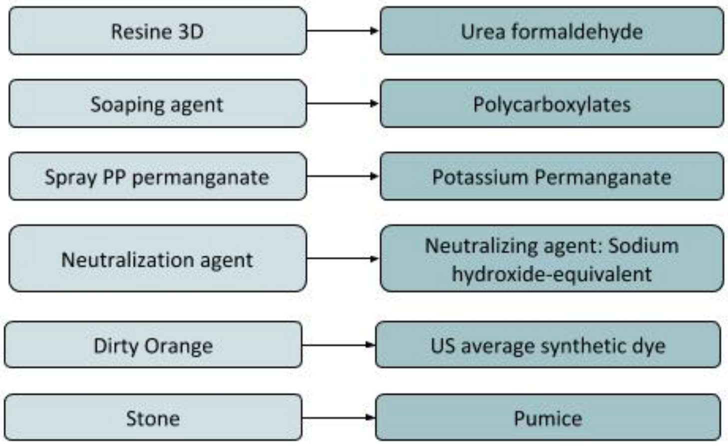

Figure 6: Illustration of substances used in the laundry process and its (eventual) substituting substance used in the LCA model.

As well as for the fabric manufacturing phase there are several data that are general for the entire facility and thus not process specific, these are: packaging material, waste, electricity, diesel and water.

Packaging used for the products at Denim Authority consists of biodegradable plastic containers and carton boxes. The finished jeans are packaged in loads of approximately 7 pairs per box and the plastic containers are assumed to be one container per pair of jeans. These reference points have been representing the base for the calculation of total amount of used packaging material at the facility.

Waste is according to the data collection form from Denim Authority consisting of plastic and paper, however, the amount of generated waste is unknown. Therefore, to include the impact from generated waste the amount has been based on the amount of waste generated at the other suppliers. From this a waste value represented by waste generated per kg of produced product is found and applied on the total production at Denim Authority. The total amount of generated waste has then been divided equally between plastic and paper. In the LCA model these are included as waste outputs in the form of packaging paper and polypropylene.

Electricity is represented by all electricity use at the facility except from electricity allocated for the laundry process, which already is included in the LCA model. The water usage is represented by water for other purposes than water for the laundry process. Both the electricity and water usage are modeled with global average datasets since Tunisian specific data is missing. The usage for diesel is unknown; therefore only the product “diesel” has been included in the system, not the combustion of the diesel and thereby not the largest negative impact generated from the diesel consumption.

Wastewater management is, as for the fabric manufacturing life cycle phase, only included as management of the total amount of water that has been used in the facility and the process is modeled according to average European municipal wastewater treatment. Thus, the specific substances used in these processes are thereby not addressed as outputs.

The finished pair of Lean Dean Lost Legend is now ready to be used and is therefore sent to the storage facility located in Sweden. Since the jeans production facility is located in Tunisia the jeans are first transported by truck to the nearest harbor, there they are loaded on a boat and shipped to the harbor in Genoa, Italy where the jeans again is transported by truck to the storage facility Korallen located in Borås Sweden. At the storage facility the only impact allocated to the pant Lean Dean Lost Legend is the heating of the facility and the electricity consumption. The heating is originating from district heating and electricity is from Swedish average electricity sources. From the storage facility the pants are distributed to the cities located around Sweden ready to be sold, see section 6.2.4 for information about how this distance has been calculated.

6.2.2 Inventory of Tilted Tor Dry Royal Embo

The life cycle of Tilted Tor Dry Royal Embo is divided according to the life cycle phases identified in section 6.1.4: cotton cultivation, fabric manufacturing, jeans production, distribution, usage and end-of-life, see **Figure 7** for the process flow chart. The use and end-of-life phase will be handled separately in part 6.2.4. For information about specific datasets and amounts used go to Appendix 3.

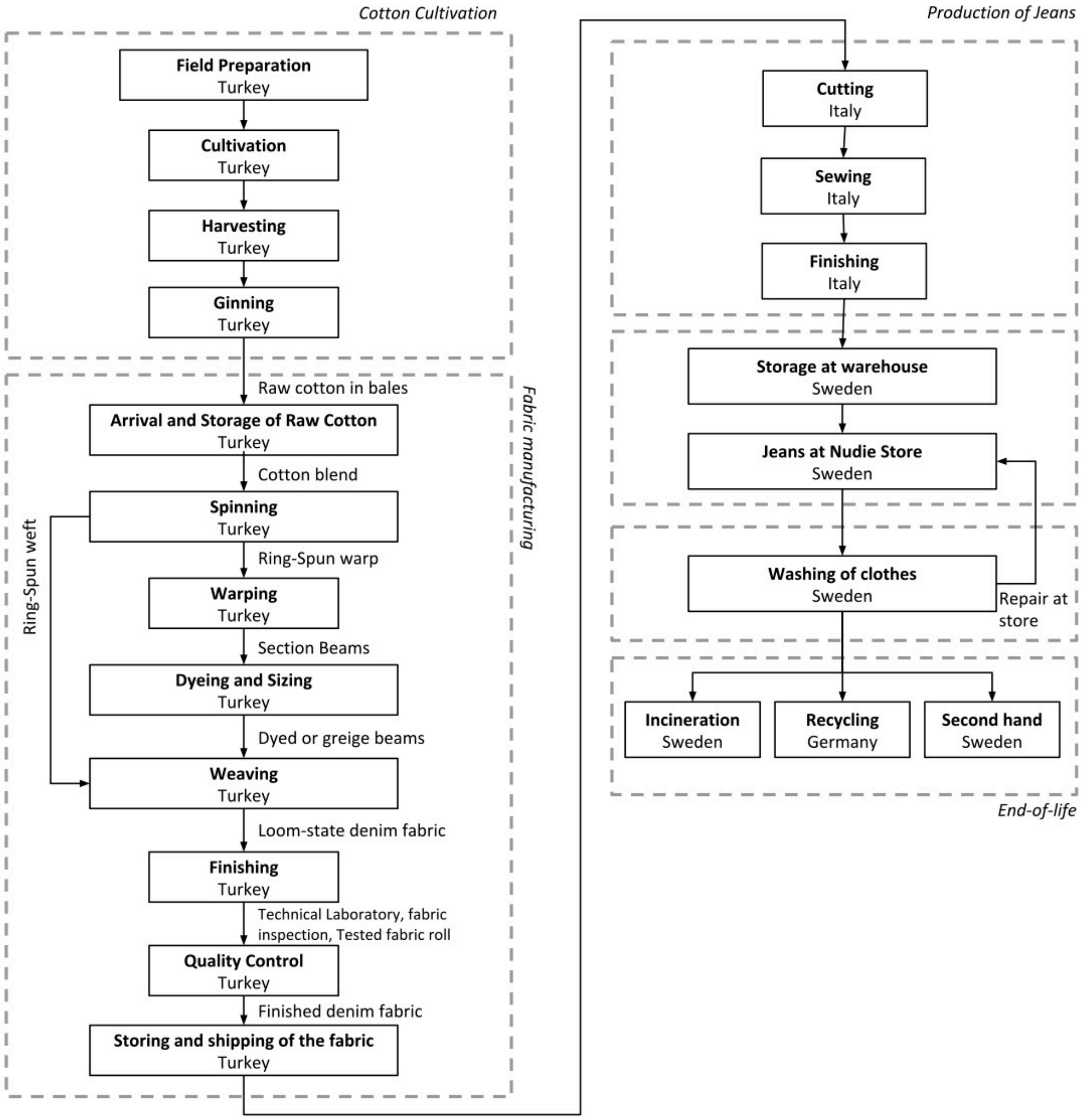

Figure 7: Flow chart of the life cycle phases and processes included for the product Tilted Tor Dry Royal Embo.

Cotton Cultivation

Tilted Tor Dry Royal Embo is produced with the denim fabric Organic Donner Indigofera, which consist of organic cotton cultivated in Turkey. As the impacts generated from cotton cultivation used in the LCA model of Lean Dean Lost Legend the cotton cultivation phase is based on the study conducted by Textile Exchange (2014) and the ecoinvent dataset "*Cotton fibre {RoW}| cotton production | Alloc Def, U*", with Turkey specific data. For more information about the data collection methodology in the cotton cultivation life cycle phase see section 6.2.1 (sub-section *Cotton Cultivation*).

The cotton is shipped in the form of bales from the field in Turkey to the fabric manufacturing facility located in Adana, Turkey. According to Nudie Jeans (2018) the cotton used for Tilted Tor Dry Royal Embo is coming from a company located in Akasya, Turkey, which has been used as reference point in the transportation data. Since both cotton cultivation and fabric manufacturing facility is located in Turkey the only type of transportation is by truck.

Fabric manufacturing

The fabric used for Tilted Tor Dry Royal Embo, Organic Donner Indigofera, is produced at a facility located in Turkey and the datasets used is thus primarily country specific data for Turkey. The fabric manufacturing life cycle phase for Tilted Tor Dry Royal Embo consists of the five main processes: spinning, warping, dyeing, sizing and weaving. The spinning and warping processes is the first process in the production of fabric, which includes the inputs organic cotton and electricity from the average Turkish state-grid. In the spinning and warping processes it is also the generation of cotton spill. About 13 percent of the bought cotton is spilled each year, which thus represent an output of the system. The spill is included in the LCA model as waste in the form of textile.

In the dyeing and sizing process there are several substances required: caustic sodium hydroxide, naturel indigo, acetic acid, three types of wetting agents, dispersing agents, sequestering agents and hydrosulfite. The dyeing process of threads is generally divided into several so-called dipping-processes in which the cotton threads are dipped into different baths of water. The amounts of required substances thus depend on the amount of water used in the processes, except from caustic sodium, which depend on the length of the fabric. The amount of substance is therefore calculated in relation to the provided amount of dyeing and sizing water. Since several of the required substances were not available in the databases other substances with similar function or attributes have been chosen, see **Figure 8**. For more information on how the substituting substances have been decided go to section 6.1.8 Assumptions and Limitations. The dyeing and sizing process is also requires electricity.

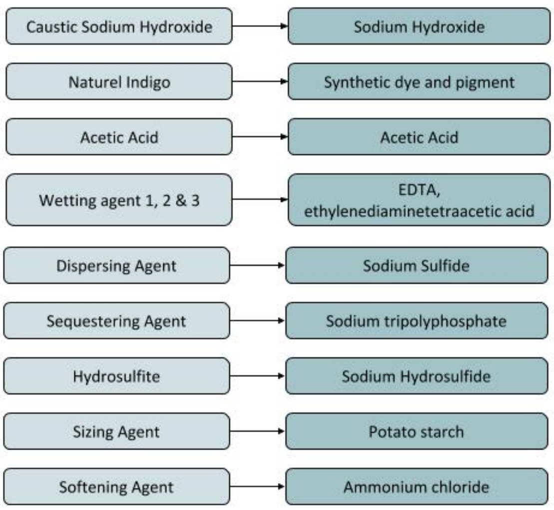

Figure 8: Illustration of substances used in the dyeing and sizing processes and its (eventual) substituting substance used in the LCA model.

Organic Donner Indigofera consists of organic cotton (99%) and elastane (1%), which means that elastane, cotton threads and electricity represent the main inputs of the weaving process. The impact from cotton threads is included through the spinning and warping process, elastane has been excluded (see section 6.1.8 Assumptions for further explanation) and the electricity is modeled with Turkish average data.

There are several inputs and outflows representing the fabric manufacturing life cycle phase that are categorized as non-process specific. First of all, the facility is heated with natural gas, which in this LCA is modeled with global average values for heating (with natural gas). There is also the non-process specific electricity consumption for lighting and other purposes, which is modeled with Turkish average data. The last input is the non-process specific water consumption, modeled with global average values. Regarding the outflows, except from the cotton spill generated in the spinning process there is the generation of "other waste" mainly consisting of plastics. The waste is modeled as a waste output in the model in the form of polyethylene/polypropylene products. Another output is the polluted wastewater, this has been modeled in the same way as in the fabric manufacturing life cycle phase for Lean Dean Lost Legend explained in section 6.2.1 thereby specific substances used in these specific processes are not addressed.

The finished fabric Organic Donner Indigofera is now done and ready to be sown into pants. The fabric is first sent by truck to storage facility located 200 km outside of the cutting and sewing facility where it is stored for some time. The fabric then continues its journey to the cutting and sewing facility Bobo located in Sant'Omero, Italy.

Production of jeans

The jeans production life cycle phase consists of the three main processes: cutting, sewing and finishing. For Tilted Tor Dry Royal Embo the processes are divided between two separate suppliers: Bobo who is doing the cutting and sewing work and GG Productions who is doing the finishing work and packaging. Both facilities are located in Italy and the datasets has thus primarily been country specific for Italy.

The first processes are the cutting and sewing of jeans. In this LCA model these are represented by the inputs: denim fabric, zippers and buttons, electricity and heating. The impact generated from the denim fabric is already included in the LCA model represented by the fabric manufacturing life cycle phase. The zipper used in Tilted Tor Dry Royal Embo is made out of nickel free metal and the material used for the buttons is made out of nickel free copper. Since nickel free metals were not available datasets in the databases used, the two ecoinvent datasets "*Brass {GLO}| market for | Alloc Def, S*" and "*Copper {GLO}| market for | Alloc Def, S*" were adjusted so that all nickel contents were removed from the processes to better represent the metals used at Bobo. The outputs of the cutting and sewing processes is represented by denim fabric spill, but the total amount is unknown, therefore the same amount provided by Denim Authority has been used to model the waste flow. Thus, approximately 14 percent of the initial fabric is thrown away. In the LCA model the fabric spill is included as a waste output in the form of textile.

The electricity usage at Bobo is modeled with Italian specific datasets based on data provided by the facility. The heating is according to Bobo coming from the energy source natural gas but the amount is unknown. To include the impacts generated from heating, and not exclude it entirely, the other facilities located in Italy have been used to create a heating value per produced product, see **Table 7**. This heating value has then been applied on the weight of produced Tilted Tor Dry Royal Embo to create a yearly heating value.

Table 7: Data representing yearly natural gas consumption and the production volumes at the Italian facilities: GG Productions, Everest and Italian Fabric Producer.

Company	Gas consumption (m^3/year)	Total production (kg/year)	Gas consumption (m^3/kg)
GG Productions	617	182961	0,0034
Everest	1400000	1428571,4	0,98
Italian Fabric Producer	5904871,8	10000000	0,59
		Average consumption:	**0,52 m^3/kg product**

Since Tilted Tor Dry Royal Embo is a non-washed style the pants are after the sewing process sent by truck directly to the finishing and packaging company GG Production in Acqualagna, Italy. In the finishing process the included inputs are: waist tags, booklets, packaging material, electricity and heating. The waist tags are produced by cotton and the booklet is made out of paper, which both have been modeled with global average values. The packaging used for the products at GG Production consists of cardboard boxes, which fit between 15-16 pairs of jeans per box. This number has thus been used as reference point for the calculation of total amount of used packaging material at the facility. The electricity is provided from the Italian state-grid and the energy source for heating is natural gas.

Now Tilted Tor Dry Royal Embo is finished and packaged and ready to be sent to Sweden for usage. The pants are as Lean Dean Lost Legend first transported by truck to the storage facility Korallen located in Borås, Sweden. At the storage facility the only impact allocated to the pant Tilted Tor Dry Royal Embo is the heating of the facility and the electricity usage. The heating is originating from district heating and electricity is from Swedish average electricity sources. From the storage facility the pants are distributed to the cities located around Sweden ready to be sold, see section 6.2.4 for information about how this distance has been calculated.

6.2.3 Life Cycle Inventory of Grim Tim Conjunctions

The life cycle of Grim Tim Conjunctions is divided according to the life cycle phases identified in section 6.1.4: cotton cultivation, fabric manufacturing, jeans production, distribution, usage and end-of-life, see **Figure 9** for the process flow chart. The use and end-of-life phase will be handled separately in part 6.2.4. For information about specific datasets and amounts used go to Appendix 4.

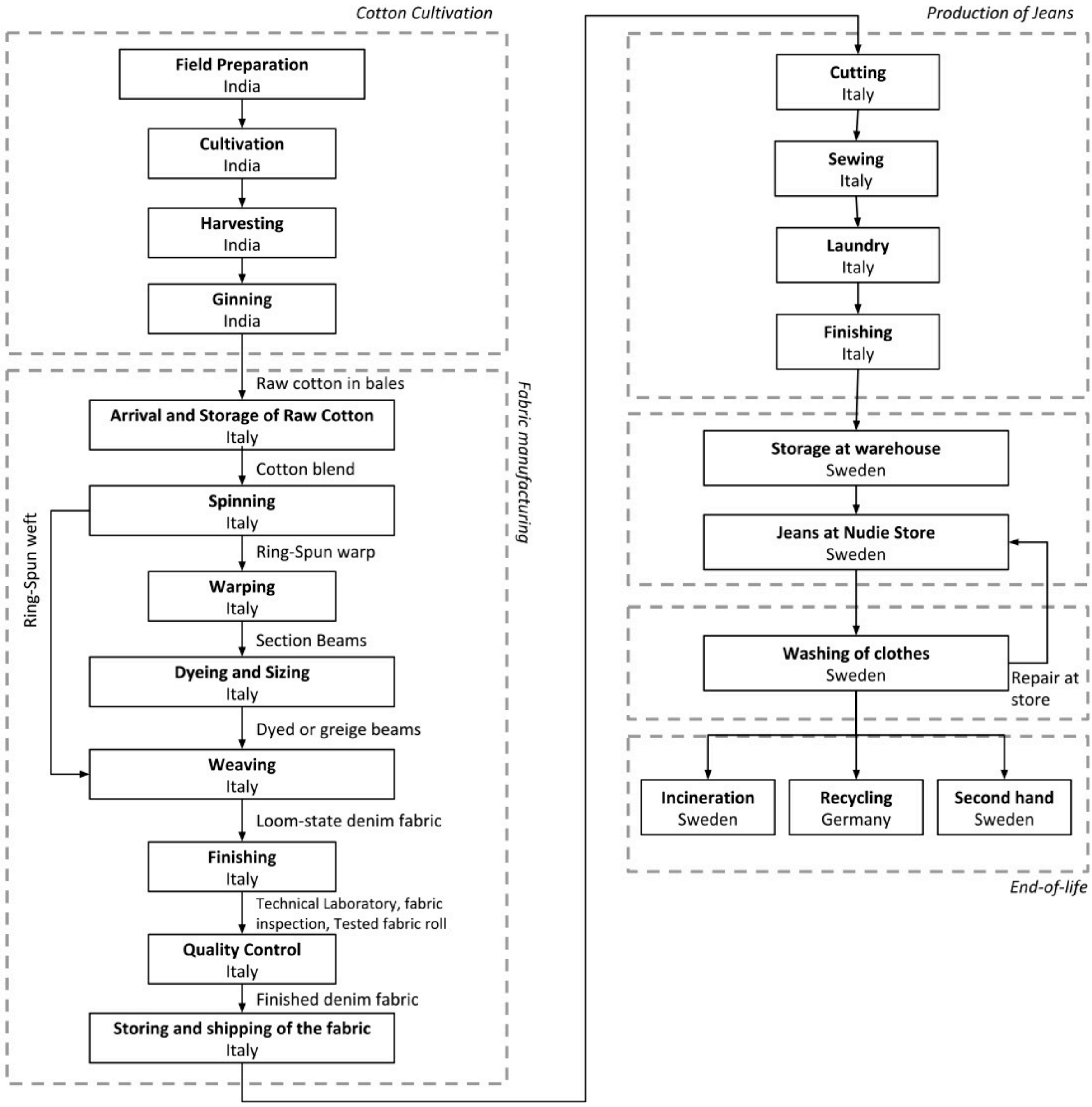

Figure 9: Flow chart of the life cycle phases and processes included for the product Grim Tim Conjunctions.

Cotton cultivation

Grim Tim Conjunctions is produced with the denim fabric RR 7216 Sioux Preshrunk, which consists of organic cotton cultivated in India. The cotton cultivation process is thus identical to the cotton cultivation process described in section 6.2.1 for Lean Dean Lost Legend. The cotton is thus, as for Lean Dean Lost Legend, also transported to the Italian Fabric Producer.

Fabric manufacturing
The fabric used for Grim Tim Conjunctions, RR 7216 Sioux Preshrunk, is produced at the same facility as the fabric RR 2716 Old Crispy. In the LCA model the processes for producing Sioux Preshrunk is thus identical to the processes in fabric manufacturing for Lean Dean Lost Legend. However, the specific input amounts have been adjusted to the relation of produced Sioux Preshrunk. For more information about the production of fabric see section 6.2.1 (sub-section *Fabric Manufacturing*).

What differs between the two fabrics Old Crispy and Sioux Preshrunk is that the finished fabric Sioux Preshrunk is sent by truck to the cutting and sewing facility Bobo located in Sant'Omero, Italy, via the storage facility 200 km outside the cutting and sewing facility.

Production of jeans
For Grim Tim Conjunctions the production of jeans consists of four main processes: cutting, sewing, laundry and finishing. The cutting and sewing processes are conducted at the cutting and sewing facility Bobo as Tilted Tor Dry Royal Embo. These processes are therefore identical to the cutting and sewing processes described in section 6.2.2. The values are however adjusted according to the production quantities specific for Grim Tim Conjunctions.

After the sewing process the pants are sent by truck to the laundry facility Everest located in Piombino Dese in Italy. In the finishing process several substances are added: pumice, pigments and salt. Since the specific pigments did not exist in the databases used the US general synthetic dye and pigment-manufacturing process was chosen. The laundry process is also represented by the inputs: heating, electricity and water. The heating of the facility is generated from the energy source natural gas, electricity provided by the Italian state grid and the water originates from wells.

Wastewater management is also one of the processes representing the washing of jeans and is included as the management of the total amount of water that has been used in the facility, independent on if it has been in contact with chemical substances or not. The process is modeled according to average European municipal wastewater treatment and the specific substances used in these processes are thereby not addressed as outputs of the system.

The washed pants are after the laundry process sent by truck to the finishing facility GG Productions located in Acualagana in Italy. The finishing and packaging processes of Grim Tim Conjunctions are thus identical to the processes described in *finishing process* in section 6.2.2 for Tilted Tor Dry Royal Embo. The values are however adjusted according to the production quantities specific for Grim Tim Conjunctions.

The jean Grim Tim Conjunctions are thereafter transported to Sweden for storage in a storage facility located in Borås. At the storage facility the only impact allocated to the pant Grim Tim Conjunctions is the heating of the facility and the electricity usage. The heating is originating from district heating and electricity is from Swedish average electricity sources. From the storage facility the pants are distributed to the cities located around Sweden ready to be sold, see section 6.2.4 for information about how this distance has been calculated.

6.2.4 Life Cycle Inventory of the processes that are equal to all three products

For the three pairs: Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions the use and end-of-life phases are modeled equally. The use phase is based on a study about consumer behavior regarding purchases, use and washing habits conducted by Mistra Future Fashion (Granello et al., 2015) and the end-of-life scenarios has been based on several references presented in the end-of-life process description. For information about specific datasets used in the use and end-of-life phases please see **Appendix 5**.

After the jeans production life cycle phase all three jeans styles end up at the storage facility located in Borås, Sweden, where the pants are distributed between the cities located around Sweden. The impact generated from this transportation is based on the average transport distances and the average loads of the transports based on data provided by Nudie Jeans (Nudie, 2018).

Use phase

The use phase consists of the two main processes: transportation of the jeans from stores to households and the residential laundry of jeans. The average transportation distance between store and household is in general between 2 and 15 km for the regular Swedish consumer, which gives the mean value of 8.5 km (Granello et al., 2015). The type of transportation is assumed to be either by car (45 %), public transport (28 %), cycling (6 %) or walking (20 %) according to data collected from the City of Gothenburg (City of Gothenburg, 2017) since most jeans per person and year is sold and used within Gothenburg. In the LCA model the impacts of the different transportation types are included according to the percentage of the total distance of 8.5 km, for example cycling and walking represent 26 percent of the distance and thus 2.21 km per FU. The impacts generated from cars represent the emissions from one car driving 3.83 km, public transportation is included as regular buses representing one person's impact traveling 2.38 km and the impacts from cycling and walking is assumed to be zero.

Residential laundry of jeans is the second process included in the use phase. The process is represented by the three inputs: water, energy and washing detergents. One laundry process at 40°C requires approximately 60 liters of water (VIA, 2018; Göteborg Energi, n.d.), 0,79 kWh of electricity (Swedish Energy Agency, 2014) and 50 ml of washing detergents (VIA, 2014). One pair of jeans is in general washed 200[9] times during its lifetime (Granello et al., 2015), which has been used as reference for the calculations. The environmental impact allocated to one pair of jeans has been based on the weight of one jean in relation to the general weight of "one washing load of clothes"[10].

In the process of residential laundry of clothes several chemical pollutants from the fabric manufacturing and jeans production processes, washing detergents used in the residential laundry process and cotton textile fibers from the garments will most likely end up in the wastewater that is generated from this process. The negative impacts from these specific substances are however not included in the LCA model. The eventual effects of this choice will be discussed further in section 8.1.

[9] One pair of jeans is in general washed every tenth time it has been used according to Granello et al. (2015).
[10] The general weight of one washing load of clothes is represented by 2,7 kg (Granello et al., 2015).

End of life

Jeans are discarded for different reasons, the most common ones are that the material or seams are broken, that the garment loses its shape or that people just get tired of them (Carlsson et al., 2011). At this end-of-life stage the jeans are thrown away in the regular garbage bin, turned in for recycling, or donated to second-hand stores. The ratio between the amounts of textile that goes to each disposal fraction (recycling, incineration and second-hand) is based on data about Swedish textile consumption behavior presented by Statistics Sweden (Statistics Sweden, 2016), H&M (H&M Group, 2017a), Lindex (Lindex, 2017) and KappAhl (KappAhl, 2017), (see **Figure 10**).

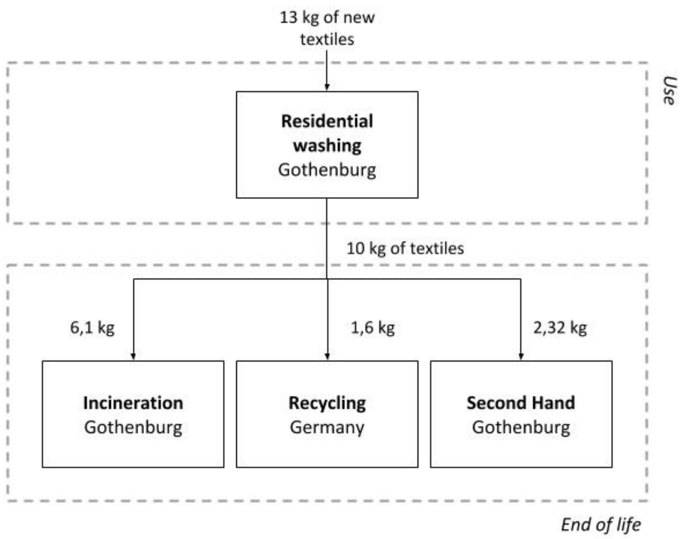

Figure 10: Cutout from the system descriptions of the three jeans styles representing the Swedish disposal alternatives and disposal amounts for bought textiles.

The effects of including recycling and second-hand use in the end-of-use scenario will be that the total impact of the jeans will be reduced, since the end-of-use model is based on avoided burdens where recycling of jeans means avoided production of rockwool, and the second-hand use replaces the production of one new pair of jeans. The end-of-life phase in this LCA model thus only includes the impacts generated from incineration[11]. The recycling and second-hand effects are however interesting and important parts to examine and has therefore been included in the sensitivity analysis in section 6.4.2.

The incineration scenario has been based on the dataset "*Waste incineration of textile fraction in municipal solid waste (MSW), EU-27*". The process has been adjusted to resemble Swedish incineration conditions and a transportation distance has been added. The generation of heat and electricity in the incineration process are included as avoided burdens according to avoided allocation procedure. The heat has been credited with Swedish average heating (non natural gas based) based on the energy content of 5.29 MJ per kg of cotton fabric and the electricity has been credited as Swedish average electricity according to the energy content of 1.78 MJ per kg cotton fabric (Roos et al., 2015). For more information about the specific datasets used please see **Appendix 5**.

[11] The model still represents the same percentage of clothes that is going to incineration today but the effects from recycling and second-hand use have been excluded.

6.3 Life Cycle Impact Assessment

The impacts generated from all the included in- and outputs are in this section aggregated into different impact categories depending on where they have an affect. The impact categories have been narrowed down to include the nine impact categories: climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation, urban land occupation, natural land transformation, water depletion and fossil depletion. The methodology for the LCIA is presented in section 6.1.6 within the Goal and Scope definition.

6.4 Life Cycle Interpretation

The aggregated results from the LCIA phase will in this chapter be presented for all three jeans styles within all of the nine identified impact categories. Results for each impact category and jeans style are then shown and described for all three jeans styles in parallel. The four main life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration as end-of-life phase) has been used to group the results. The chapter also includes a sensitivity analysis of the processes:

6.4.1 Results

The results are shown in **Figure 11** for the impact categories defined in the LCIA: climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, land use (agricultural land occupation, urban land occupation and natural land transformation), water depletion and fossil depletion. For information about the chosen impact categories please see sections 6.3 and 6.1.8.

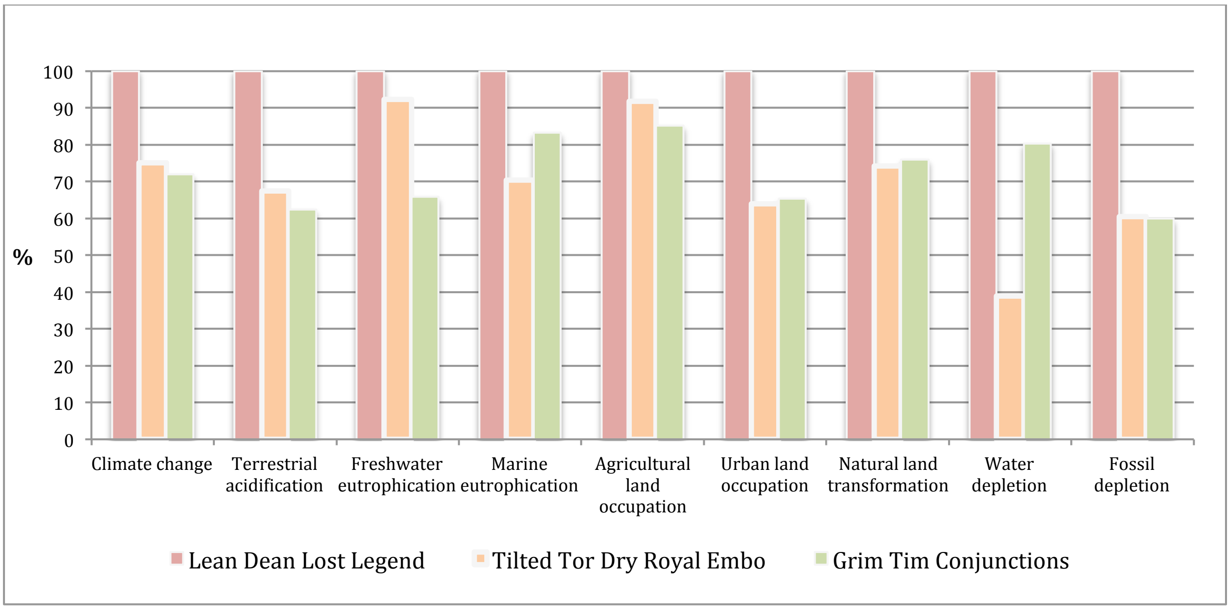

Figure 11: Characterized results of all impact categories for one pair (0.72 kg) of Lean Dean Lost Legend, one pair (0.63 kg) of Tilted Tor Dry Royal Embo and one pair (0.6 kg) of Grim Tim Conjunctions. The product with the highest environmental impact is shown as 100 % impact, and the other products in proportion to that value.

To give a comprehensive view of the results the graph shows the sum of potential environmental impact of the three studied jeans styles Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions. The columns describe the ratio between the three styles where the pant with the highest potential environmental impact has been given the value 100 %. As seen in **Figure 11** the style Lean Dean Lost Legend has the higher potential impact within all nine studied impact categories. Within the categories: freshwater eutrophication, marine eutrophication and agricultural land occupation the differences are the smallest. For the two other jeans styles it is not equally clear to see which one that performs best or worst from an environmental perspective. In order to get a better understanding of the differences **Table 8** shows the quantified results of the three styles of jeans.

Table 8: Specific results for the three styles of jeans: Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions within all impact categories, presented in unit per FU.

Impact Category	Lean Dean Lost Legend	Tilted Tor Dry Royal Embo	Grim Tim Conjunctions	Unit
Climate change	16,65	12,49	11,97	**kg CO_2 equivalents**
Terrestrial acidification	0,081	0,054	0,050	**kg SO_2 equivalents**
Freshwater eutrophication	0,0070	0,0065	0,0046	**kg P equivalents**
Marine eutrophication	0,031	0,022	0,026	**kg N equivalents**
Agricultural and occupation	2,61	2,39	2,22	**m2a**
Urban land occupation	0,24	0,155	0,159	**m2a**
Natural land transformation	0,0086	0,0064	0,0065	**m^2**
Water depletion	7,63	2,97	6,13	**m^3**
Fossil depletion	5,56	3,36	3,33	**kg oil equivalents**

It is still not clear which of the two styles that has the highest environmental performance. Grim Tim Conjunctions has a bit higher potential environmental performance within the five areas: climate change, terrestrial acidification, freshwater eutrophication, agricultural land occupation and fossil depletion but the differences are in fossil depletion, urban land occupation and natural land transformation are minimal. A conclusion of which of the two styles that are better or worse than the other is therefore not fair to draw at this point but should require a more thoroughly sensitivity analysis.

Climate Change

For the impact category climate change the results are relatively equal but Lean Dean Lost Legend stands out a bit. For all three styles the climate change impact is highly dependent on the energy sources used at the facilities for heating and electricity and the transportation types between the different facilities. Lean Dean Lost Legend is made out of cotton from India, the fabric is manufactured in Italy, sown in Tunisia and sold in Sweden, the supply chain thus includes several transoceanic transports and long transportation distances on land, which results in high amounts of CO_2 emissions. Grim Tim Conjunctions is on the other hand made out of cotton from India, produced in Italy and then transported by car to Sweden, which results in only one transport over seas and relatively short transport distances. Tilted Tor is a mix of them both, the cotton is cultivated and the fabric is manufactured in Turkey, the pant is sown in Italy and then sent to Sweden, which means that no sea travels are needed but some relatively long transportation distances are. As seen in **Figure 12** the transportations thus have had the expected impact.

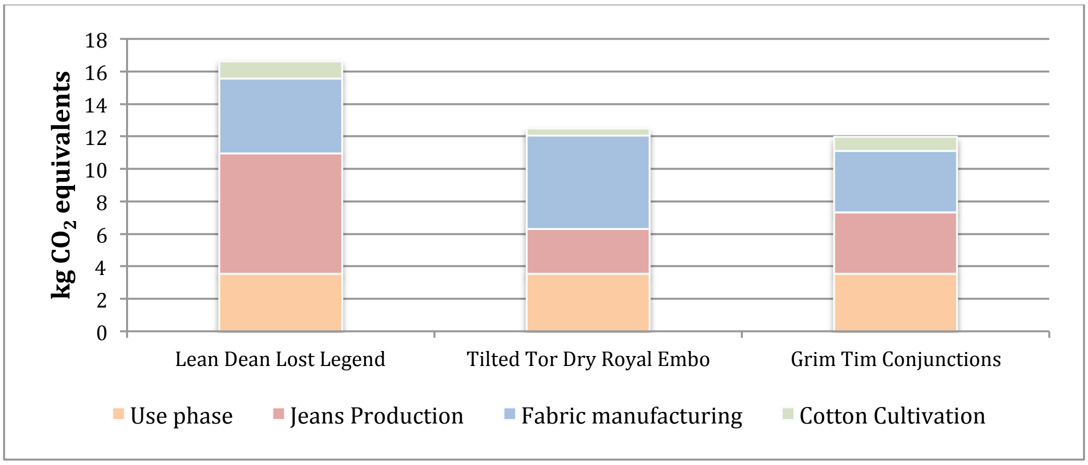

Figure 12: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category climate change.

The second reason to why the results are looking as they do is the choice of energy sources for electricity and heating. All facilities use natural gas as energy source for heating, one of the worst energy sources for heating from an environmental perspective. The electricity sources are based on the average use of energy sources in the countries Italy, Turkey and Sweden and the global average use of energy sources for the facility located in Tunisia. The energy sources used in the product's life cycle are thereby mainly from fossil based resources, which are resulting in high amounts of CO_2 emissions.

Terrestrial acidification

Terrestrial acidification is highly connected to the release of acidifying compounds such as sulfates, nitrites and phosphates (see **Table 3** in section 6.3). In turn, the release of acidifying compounds is connected to the combustion of fossil based energy sources, such as oil, coal and gas. The results for the terrestrial acidification category should therefore be relatively similar to the result of the impact category climate change. As shown in **Figure 13** this is also the case.

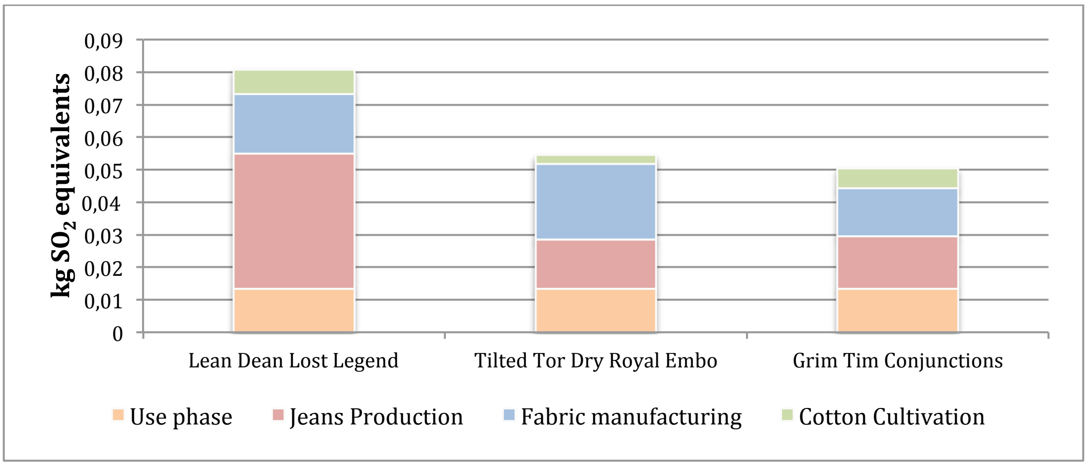

Figure 13: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category terrestrial acidification.

Eutrophication

The results on freshwater eutrophication are quite varying between the three styles of jeans, but what is clear, based on **Figure 14**, is that the jeans production phase for Lean Dean Lost Legend and the fabric manufacturing phase for Tilted Tor Dry Royal Embo have the highest potential environmental impact. The negative environmental effects from the jeans production phase come from the substances used in the laundry process, the extraction of metals used for buttons and zippers, transportation and the use of electricity and heat. For Tilted Tor Dry Royal Embo and the fabric manufacturing process the Turkish average electricity source the main contributing process.

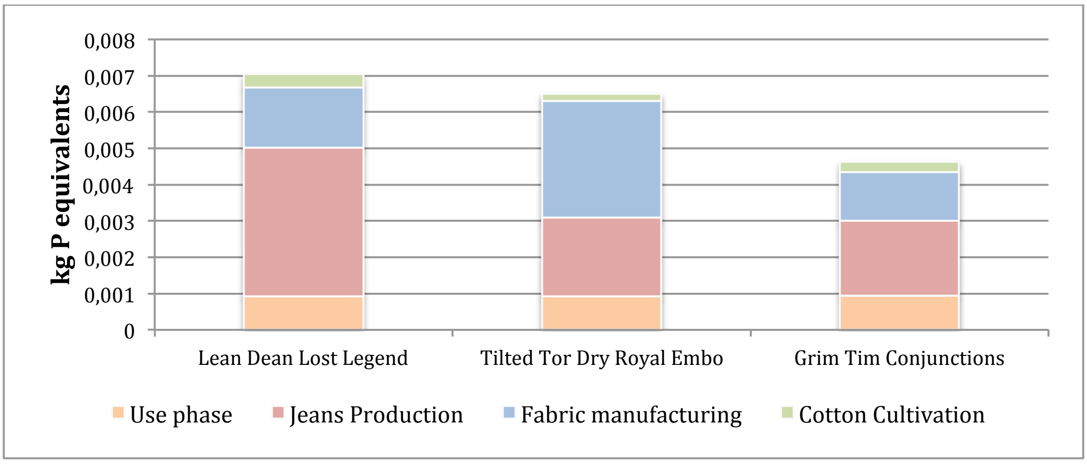

Figure 14: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category freshwater eutrophication.

The results on marine eutrophication differs a lot from the results from freshwater eutrophication, for all three jeans styles the use phase and the fabric manufacturing phase is the highest contributors (see **Figure 15**).

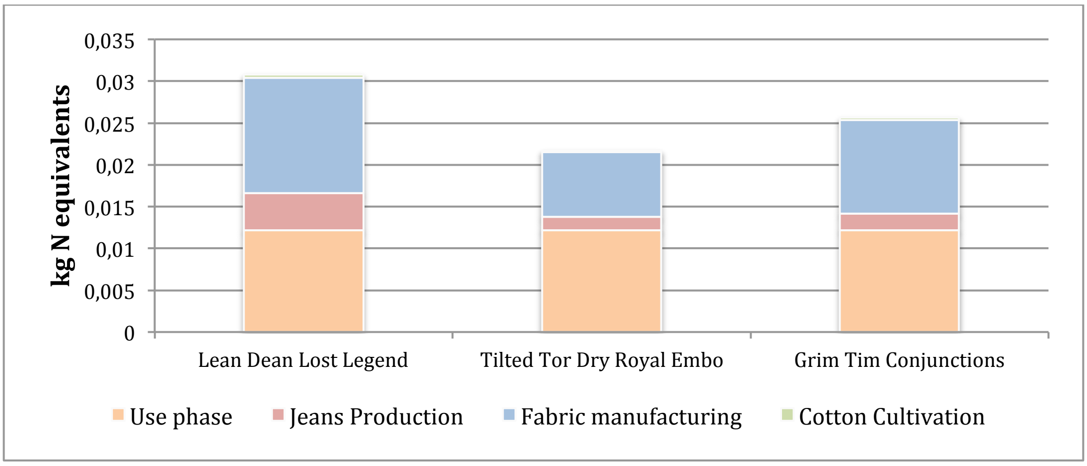

Figure 15: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category marine eutrophication.

The use of water in combination of chemical substances such as sodium hydroxide, ammonium chloride and potato starch is causing the highest environmental impact within the fabric manufacturing phase for the three styles of jeans, the results is thus shown most clearly in the wastewater treatment processes. The fossil fuel based energy sources for electricity usage, heat and transports are also contributing, but significantly lower than the contaminated water. Within the use phase the largest contributor can as well as for the fabric manufacturing phase be identified in water usage in combination with washing detergents, thus the washing of jeans.

Land use

The land use impact category consists of the three indicators: agricultural land occupation, urban land occupation and natural land transformation. In **Figure 16** the contribution of the four life cycle phases cotton cultivation, fabric manufacturing, jeans production and use on the impact category agricultural land occupation is shown.

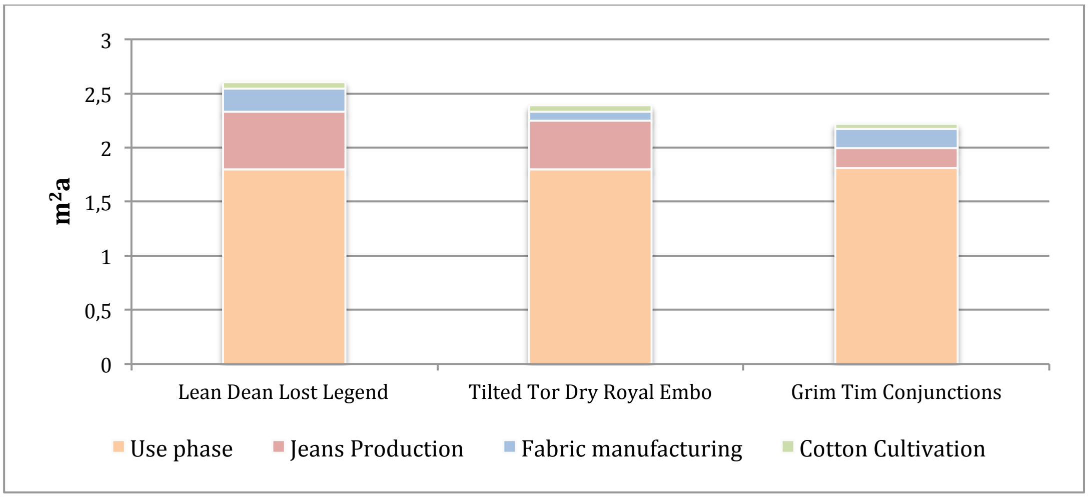

Figure 16: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category agricultural land occupation.

As seen in **Figure 16** the largest potential environmental impact within agricultural land occupation is found in the use phase of all three styles, where washing detergents is the main process contributor. The soap process used in the LCA model is mainly produced by palm oil, soybean oil and cottonseed oil which all three have large negative impacts on biodiversity and land use, which would explain the negative impact generated from the use phase. Furthermore, equal for the three jeans styles is that the jeans production facilities represent the second largest contributing life cycle phases. Within the jeans production facility the use of paper packaging materials represent the largest contributing processes, probably since it is made out of wood.

In contrast to the process contribution in agricultural land occupation the process contribution in urban land occupation vary a lot between the three pants, as seen in **Figure 17**.

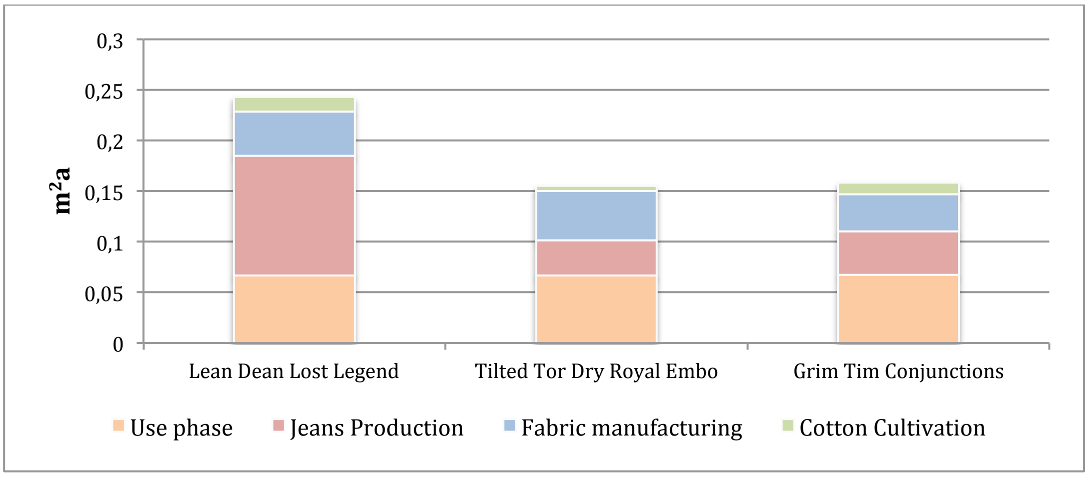

Figure 17: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category urban land occupation.

For Lean Dean Lost Legend the jeans production phase in Tunisia is representing the largest contributing process for the impact category, due to the use of potassium permangante and neutralazing agents in the laundry process. For Tilted Tor Dry Royal Embo and Grim Tim Conjunctions on the other hand the use phase represent the highest negative environmental impact. Overall for the impact category urban land occupation it is the substances used for dyeing, sizing, laundry and residential laundry that has the highest negative potential impacts on urban land occupation. This effect is most likely originating from the extraction of the substances since urban land occupation is determined by the total area that is occupied times the estimated time that it will be contaminated.

Proceeding to natural land transformation, which can be seen in **Figure 18**.

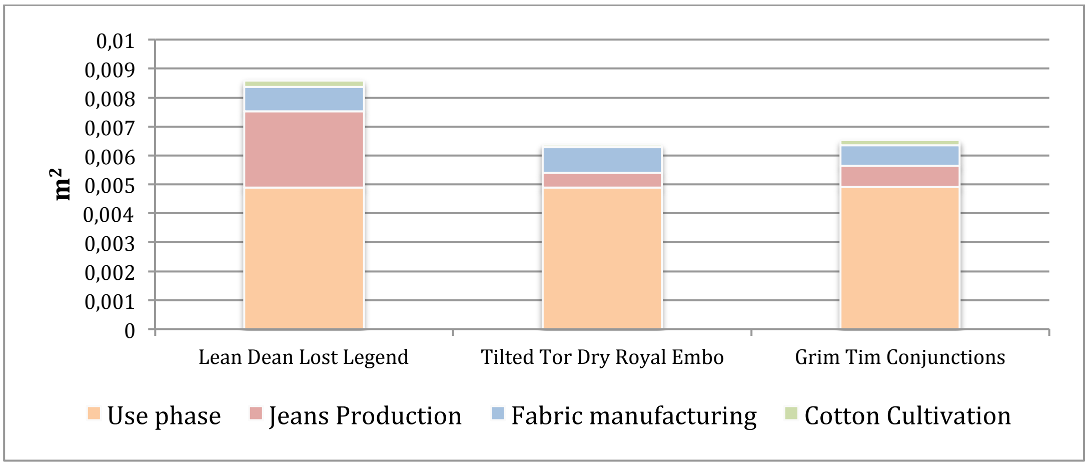

Figure 18: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category natural land transformation.

For natural land transformation, the largest negative impact can be found in the use phase for all three jeans, once again due to the use of washing detergents. Since the washing detergents used in the LCA model is based on oil made out of palm, cottonseeds and soybeans the effects on natural land transformation is quite expected. Lean Dean Lost Legend sticks out a bit when it comes to the jeans production facility in Tunisia, which has significantly larger impact than the jeans production phases form the other two jeans styles. The large negative impact is mainly caused by the use of diesel at the facility.

Water depletion

In the water depletion impact category there is no doubt that the cotton cultivation phase of the life cycle by far is the most contributing process. In **Figure 19** the contribution between the life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) is shown.

Figure 19: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category water depletion.

Organic cotton cultivation requires different amounts of added water dependent on temperatures, location and rainfall patterns but in average organic cotton cultivations around the world requires 15 000 m^3 of water (95% rain-fed and 5% irrigated) per hectare with a cotton fiber yield on 1835 kg (Textile Exchange, 2014). Based on the same study conducted by Textile Exchange (2014) the amount of rainfall per hectare is approximately 9900 m^3 in India with an average cotton fiber yield on 1130 kg, and 6300 m^3 in Turkey where the cotton fiber yield is 1835 kg. Of this rain water the cotton lint in India absorbs about 4000 m^3 per hectare and the cotton lint in Turkey 2800 m^3 per hectare[12]. The water consumption is thus smaller than the average water consumption.

Important to notice is that the amount of rain-fed water does not affect the natural water cycles in the same way as irrigation, since the water that lands on the field still will be going back to the same water bodies as it would have anyways, independent on the type of natural land use. The consumed water for irrigation on the other hand can affect the water cycles if the water is collected from a water source where the used water cannot return, this type of water use will thus result in water scarcity. If excluding the amount of water that is added to the soil through rainfall the total water consumption for the three jeans Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions are: 600 liter, 400 liter and 450 liter per FU respectively. This amount can appear as being very small, the water

[12] For information on how the water consumption is calculated please go to section 6.1.8 Assumptions and Limitations.

consumption at the fabric manufacturing and jeans production processes are therefore discussed further in *Chapter 8.1*.

Abiotic depletion – Fossil depletion

As for the impact category climate change the abiotic, or fossil, depletion is connected to the use of fossil fuels. Since all transportation runs on fossil fuels, the heat is coming from natural gas (except in Sweden) and the electricity is produced from fossil fuels the abiotic depletion also will be high in these processes. The transportation distances are longer for Lean Dean Lost Legend than for the other two jeans styles, which are shown in **Figure 20**. The Tunisian global average energy source used for assessing the electricity usage at the jeans production facility results in high amounts of fossil fuels, which explains the high process contribution from jeans production.

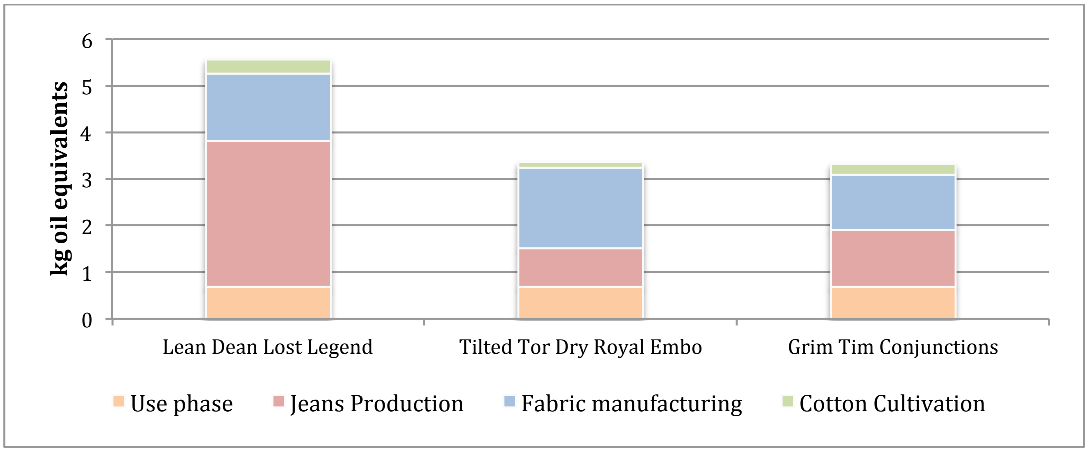

Figure 20: Contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration) on the impact category water depletion.

6.4.2 Concluding results

To summarize the results from the LCIA within the three specific jeans style a short summarize of each jeans style is presented in terms of the highest process contributors. The section only includes overall results, for quantified results go to Appendix 6.

For Lean Dean Lost Legend the life cycle phase that has the largest negative impact within all of the nine impact categories in average is the jeans production processes representing 36.3 percent of the total impacts. The second largest life cycle phase is represented by the use phase and stands for 28.7 percent. The third most impacting life cycle phase is fabric manufacturing with 19.7 percent and lastly cotton cultivation phase is found representing 15.4 percent of the total impacts. Tilted Tor Dry Royal Embo differs a bit from Lean Dean Lost Legend, where the use phase represents the largest impacting life cycle phases with 38.1 percent of the total average impact. Fabric manufacturing represent the second largest impact and stands for 30.1 percent and the third life cycle phase is the jeans production phase representing 19 percent of the total impact. Cotton cultivation comes last, as for Lean Dean, with its impact on 12.9 percent. Regarding Grim Tim Conjunctions the impact division between the life cycle phases is the same as for Tilted Tor Dry Royal Embo: use phase (38.4 percent), fabric manufacturing (22.9 percent), jeans production (22.2 percent) and lastly cotton cultivation (16.5 percent).

The transports has been included as sub-processes within each life cycle phase of the studied product systems, thus, each life cycle phase include the transport of the final produced product to the next life cycle stage. The transports are therefore not shown as separate process contributors in the graphs. The impacts generated from transports contribute 3, 7 and 4 percent of the total environmental impact for the three styles Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions respectively.

Overall the style Grim Tim Conjunctions has the best environmental performance of the three styles of jeans and performs 29.5 percent better than Lean Dean Lost Legend. Tilted Tor Dry Royal Embo is however not far behind performing 27.7 percent better than Lean Dean Lost Legend. Since the difference between the two styles Tilted Tor Dry Royal Embo and Grim Tim Conjunctions is so small a final conclusion on which of these two styles that performs best of worst is not fair to draw at this point. The negative impacts are mainly caused by two main process contributors, the energy sources used for electricity and heating and the substances used in the dyeing, laundry and finishing processes.

6.4.3 Sensitivity analysis

In the following section the results from the performed sensitivity analyses are presented. The results are only presented as percentage deviation of the original result.

Conventional vs. organic cotton cultivation

Organic cotton is used in all three of the studied products, and all other cotton containing products manufactured by Nudie Jeans for that part. To only manufacture products with organic cotton is placed high up on their priority list of sustainability measures. Since the choice of cotton is such an important subject for Nudie Jeans it would be interesting to see how large the environmental importance of the choice of cotton really is.

To evaluate the environmental importance within the nine impact categories the cotton cultivation processes *Cotton lint – India* and *Cotton lint – Turkey*, representing organic cotton cultivation in the LCA model, have been replaced with the ecoinvent dataset "*Cotton fibre {GLO}| market for | Alloc Def, S*" for conventional cotton cultivation in all three fabric manufacturing processes. To ensure that the organic cotton cultivation processes are as equal as possible in terms of system boundary and included processes the cotton processes *Cotton lint – India* and *Cotton lint – Turkey* have been adjusted to only include water for irrigation. In **Figure 21** the characterized results are shown for Lean Dean Lost Legend, **Figure 22** represents the results for Tilted Tor Dry Royal Embo and in **Figure 23** the characterized results for Grim Tim Conjunctions are presented.

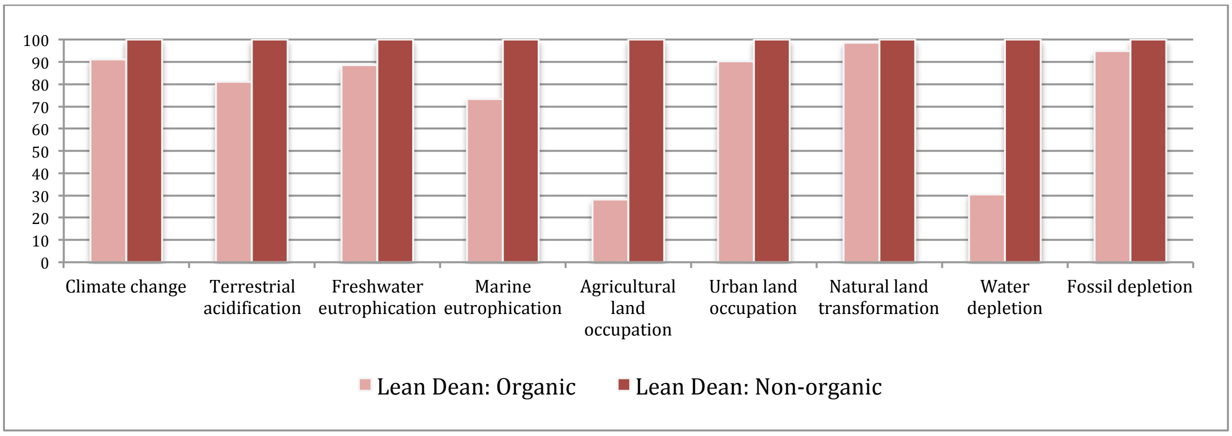

Figure 21: Characterized results of all impact categories from the "organic vs. conventional cotton" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

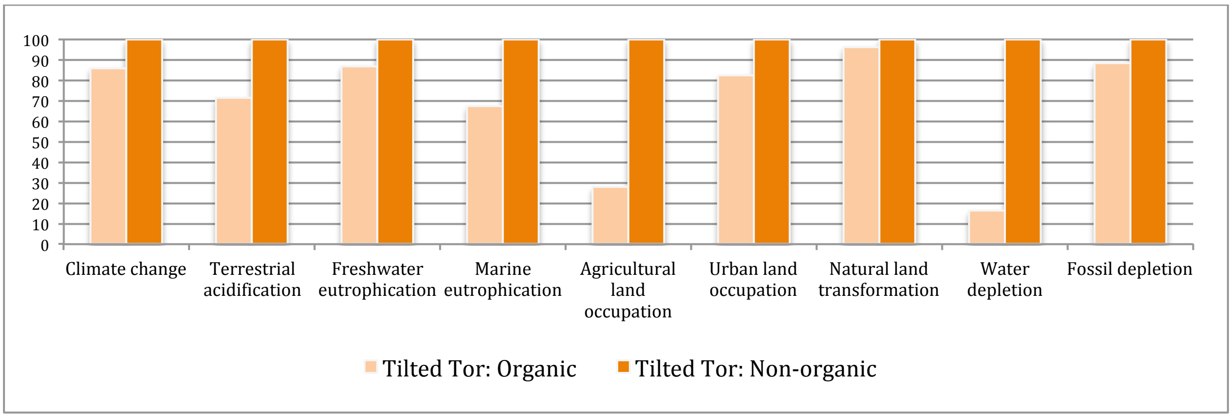

Figure 22: Characterized results of all impact categories from the "organic vs. conventional cotton" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

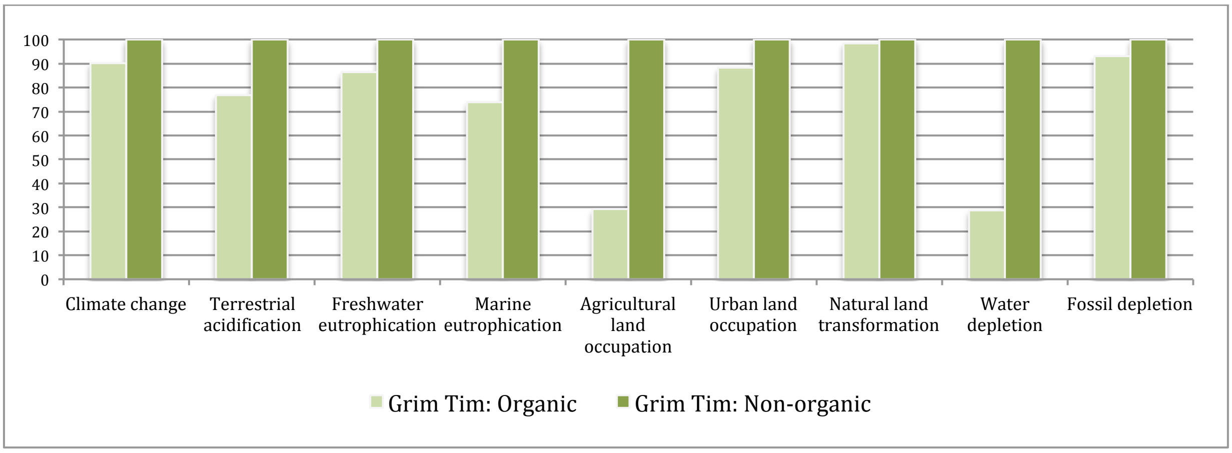

Figure 23: Characterized results of all impact categories from the "organic vs. conventional cotton" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

By replacing the organic cotton cultivation processes with the conventional cotton cultivation process it is clear that the use of organic cotton results in an overall higher potential environmental impact. The largest difference can be found in the impact categories: terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation, and water depletion. The two impact categories that stand out the most are water depletion and agricultural land occupation. By replacing the use of conventional cotton to organic cotton the environmental impact can reduce with 70-80 percent when it comes to water depletion and with around 70 percent when talking about agricultural land occupation.

Organically cultivated cotton in the regions studied by Textile Exchange (Textile Exchange, 2014) requires relatively little irrigation in addition to the occurring rainfall. But since the total water usage[13] in crop cultivation is highly dependent on climatic conditions and irrigation techniques it is not right to draw the conclusion that the low water use depends on the fact that the fields are cultivated under organic conditions or not. Some studies show the relation that organic cotton cultivation leads to less water consumption (Textile Exchange, 2014) while others implies the opposite (Wakelyn and Chaudhry, 2007). The water depletion impact category is thus more dependent on climatic conditions and irrigation techniques than the relation to the choice organic or conventional cotton cultivation.

Land occupation can also be a tricky impact category to assess and draw conclusions from since the effects on biodiversity almost are impossible to assess (Textile Exchange, 2014; Goedkoop et al., 2008). Organic cotton often has lower yields than conventional cotton cultivation, which means that more land is required to produce the same amount of conventional cotton (Wakelyn and Chaudhry, 2007). This effect is however not shown in the figures above. The unexpected result on agricultural land occupation could depend on the use of fertilizers and pesticides in the conventional cotton process since the agricultural land occupation midpoint indicator represents the total area that is occupied times the time it is assumed to be affected (see **Table 3** in section 6.3). For example, many of the artificial fertilizers used in conventional cotton cultivation consist of phosphorus that is extracted through mining. During this process several unwanted heavy metals are extracted and are included in the phosphorus fertilizers affecting the ground, which is not occurring in the use of manure from animals (Asp, 1999).

Change in behavior: airing instead of washing

Washing of jeans is according to Nudie Jeans an unnecessary process to a large extent, but how does this affect the environmental performance? In the sensitivity analysis washing of jeans is excluded entirely and exchanged with airing (a process with no inputs) to illustrate the impact of washing of clothes. The results are shown in the figures below. In **Figure 24** the effects on Lean Dean Lost Legend is presented, **Figure 25** presents the results for Tilted Tor Dry Royal Embo and **Figure 26** shows the results for Grim Tim Conjunctions.

[13] Water use is defined as the use of water by human activities such as water withdrawal, water release or other human activities that impact water flows and quality (Textile Exchange, 2014).

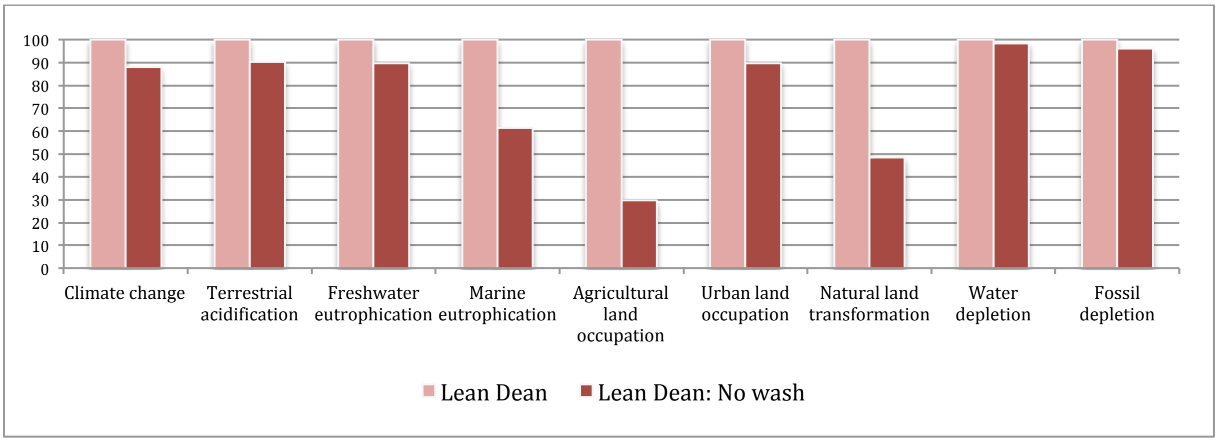

Figure 24: Characterized results of all impact categories for the "airing instead of washing" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

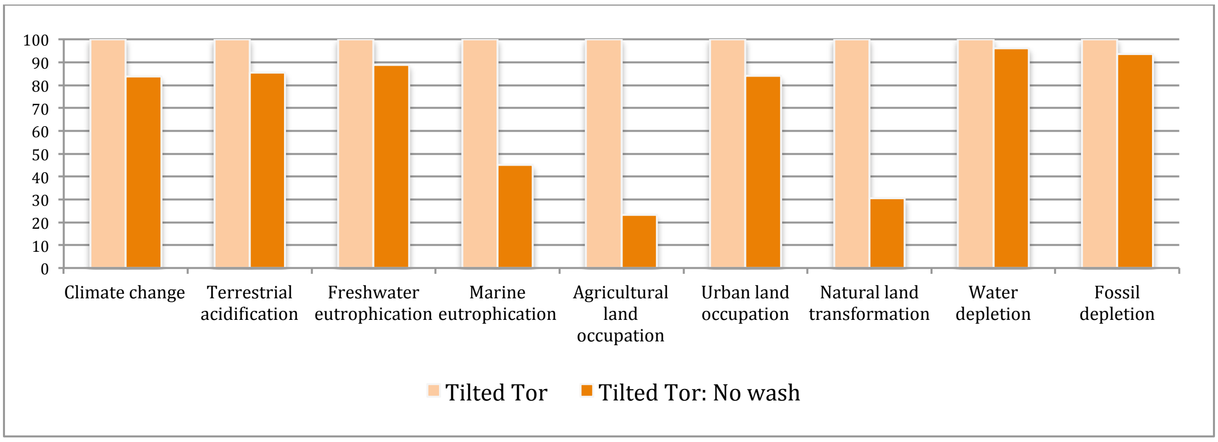

Figure 25: Characterized results of all impact categories for the "airing instead of washing" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

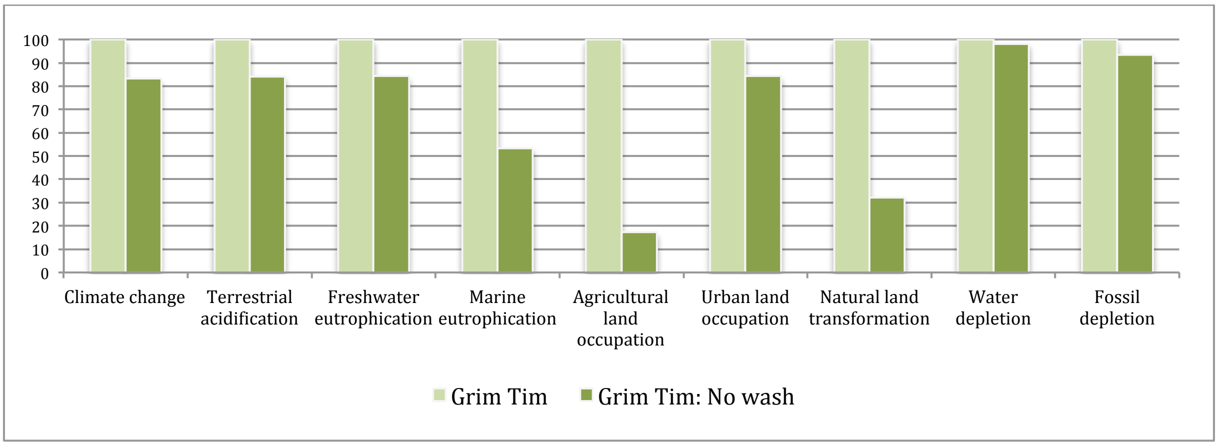

Figure 26: Characterized results of all impact categories for the "airing instead of washing" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

As seen in the figures the impacts are lowered in all of the nine impact categories for all three styles of jeans. The reduced impact of exchanging washing to airing does most likely depend on the excluding of energy usage, water usage and washing detergents, which all three have large effects on marine eutrophication, freshwater eutrophication and biodiversity loss.

The effect on water depletion is not presented that clear in the figure since water consumption at the cotton cultivation process stands for about 96, 87 and 96 percent of the total water consumption for the three pairs of jeans. The excluding of residential washing would however mean a reduction of 120 liters of water per FU. If excluding the cotton cultivation process and only looking at the life cycle phases: fabric manufacturing, jeans production and use phase this implies a reduction of 35, 31 and 51 percent of the total water consumption per pair of jeans.

Waste scenarios including recycling and second-hand

In the end-of-use phase in the reference scenario cut-offs at recycling and second-hand use have been used, and the only impact included is the impacts generated from the incineration process. This choice has been made since recycling or second-hand selling of jeans will lead to the avoided production of other materials and thus lower the total impact if avoid allocation with the help of avoided burdens were adopted. Since recycling and second-hand selling are two of the most highlighted environmental measures by Nudie Jeans the gained effects from recycling and second-hand are interesting to investigate further. The allocation approach used in the sensitivity analysis scenarios is thus to avoid allocation though avoided burdens.

The recycling scenario is based on a study about textile recycling conducted by the Swedish Environmental Protection Agency (Östlund et al., 2015). According to the study textiles can either be recycled through "down-cycling" or through "fiber-to-fiber" recycling. However, elastane-containing denim fibers cannot be transformed into new cotton fibers, therefore denim jeans are mainly transformed into insulation materials through down-cycling. The recycling scenario in the sensitivity analysis represents the avoided burden from production of rockwool insulation material, where 1 ton of jeans can replace the production of 720 kg of rockwool.

Recycling is assumed to occur at a recycling facility located in Germany, where several Swedish clothing companies send their collected textiles (Östlund et al., 2015). In the processes of insulation production it is assumed that the yield of production is 90 percent, the energy consumption is 3,68 kWh/kg and the heat demand is 1,9 MJ/kg. In the recycling scenario waste is generated and incineration is applied. Since incineration results in the co-product *heat* the system is credited with the amount of generated heat according to the "avoid allocation" principle (ISO 14044: 2006). The energy content in mixed cotton fibers is assumed to be 25 MJ/kg (Östlund et al., 2015).

Jeans that goes to second-hand replaces the need for production of new jeans. The second-hand process for the end-of-life scenario is thus represented as the avoided burden from the production of a pair of each jean: Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions respectively.

The incineration scenario is modeled in the same way as described in section 6.2.4. For information about the specific datasets used in the waste processes (incineration, recycling and second-hand selling) please see **Appendix 5.**

In the figures below the results from applying avoid allocation through avoided burdens for the pants Lean Dean Lost Legend (**Figure 27**), Tilted Tor Dry Royal Embo (**Figure 28**) and

Grim Tim Conjunctions (**Figure 29**) are shown. The scenario represents the following ratio: 77 percent of the bought clothes are thrown away each year, 18 percent of the bought clothes goes to second-hand stores, 12 percent to recycling and 47 is going directly to incineration. This scenario thus represents the already modeled division of waste management but includes the gains from recycling and second-hand selling.

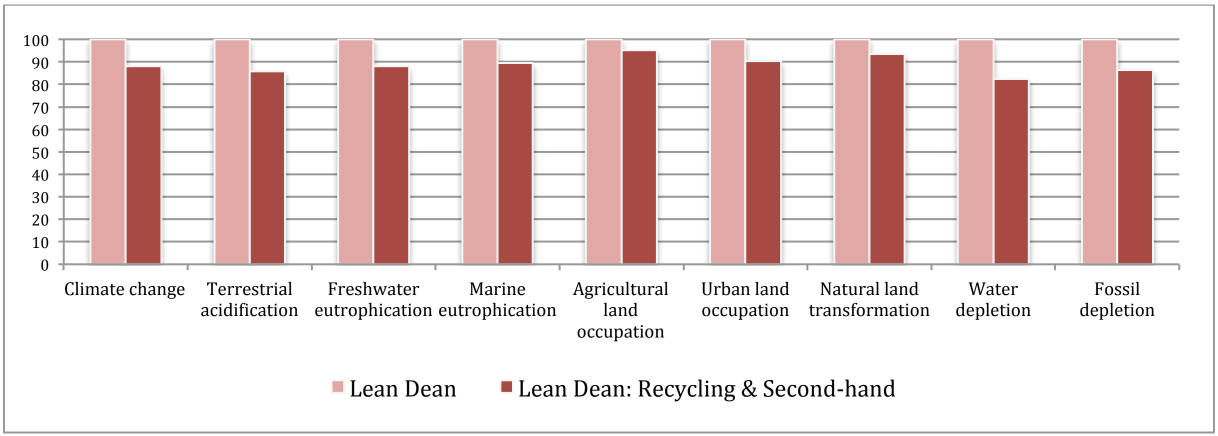

Figure 27: Characterized results of all impact categories for the "original life cycles including recycling and second-hand selling" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

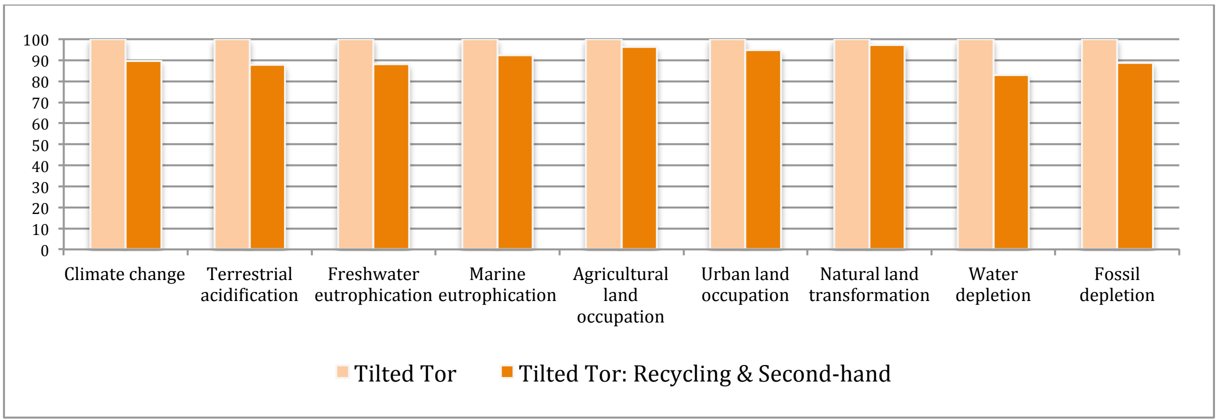

Figure 28: Characterized results of all impact categories for the "original life cycles including recycling and second-hand selling" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

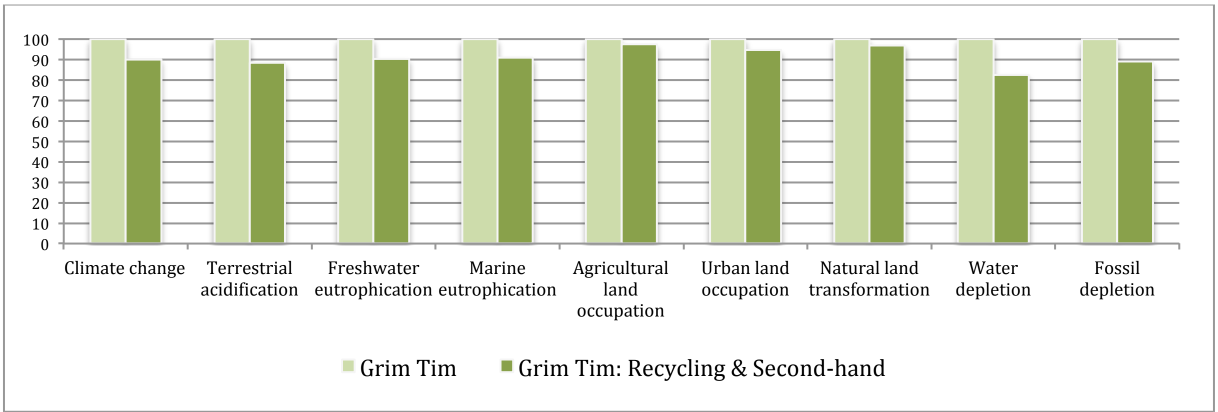

Figure 29: Characterized results of all impact categories for the "original life cycles including recycling and second-hand selling" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

In an ideal future with circular economy dominating the textile industry, all textiles products would be part of a circular system where no textile products goes directly to incineration from the consumer. If following the waste hierarchy with the rest we assume that in this ideal future zero percent of the produced pant goes to incineration, the majority goes to second hand and the broken clothes (20 percent) goes to recycling. Then the potential impact for the general produced jean could be reduced by almost 60 percent in the water depletion category and approximately 50 percent in the impact categories climate change, terrestrial acidification, freshwater eutrophication and fossil depletion, only by not throwing away the pant in the regular garbage bin (see **Figure 30**, **Figure 31** and **Figure 32**).

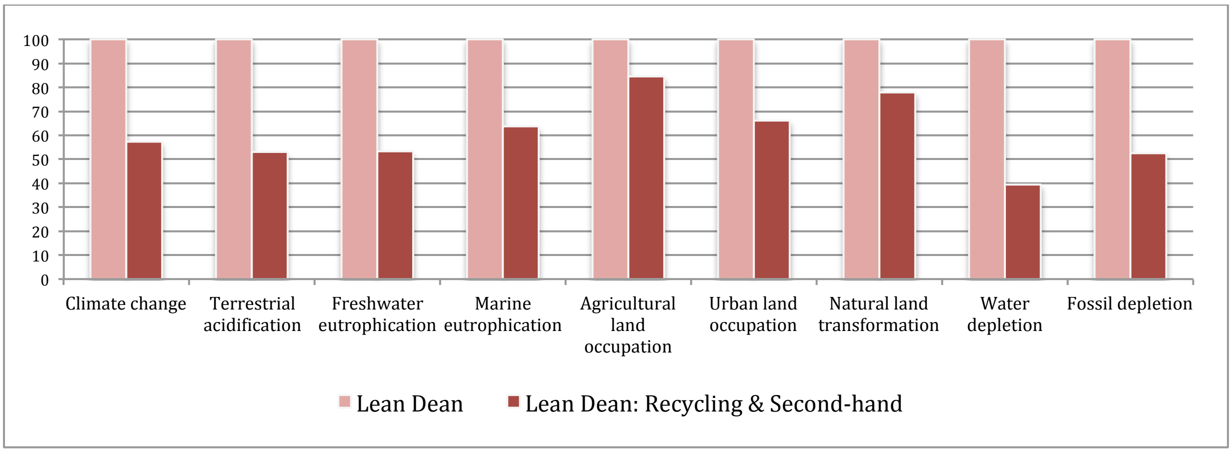

Figure 30: Characterized results of all impact categories for the "original life cycles compared to the ideal circular system" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

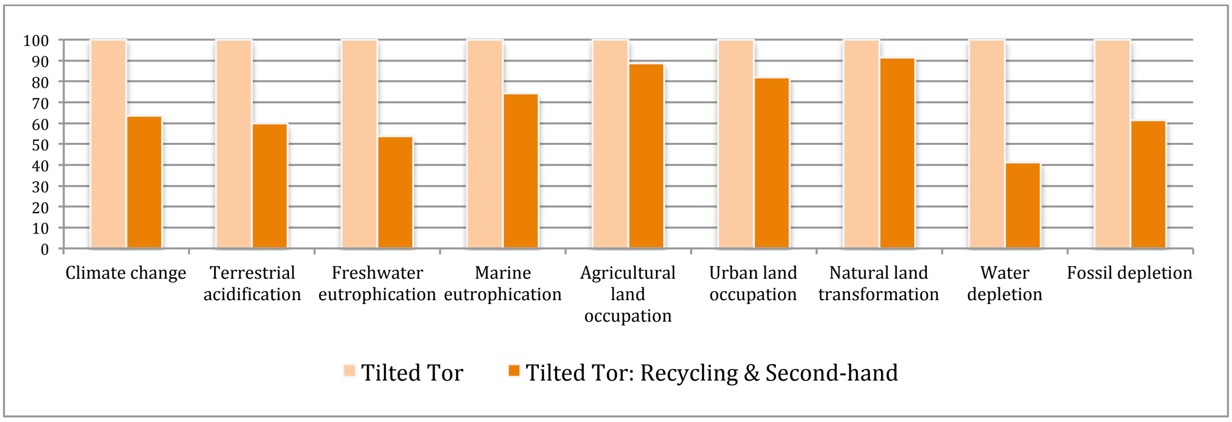

Figure 31: Characterized results of all impact categories for the "original life cycles compared to the ideal circular system" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

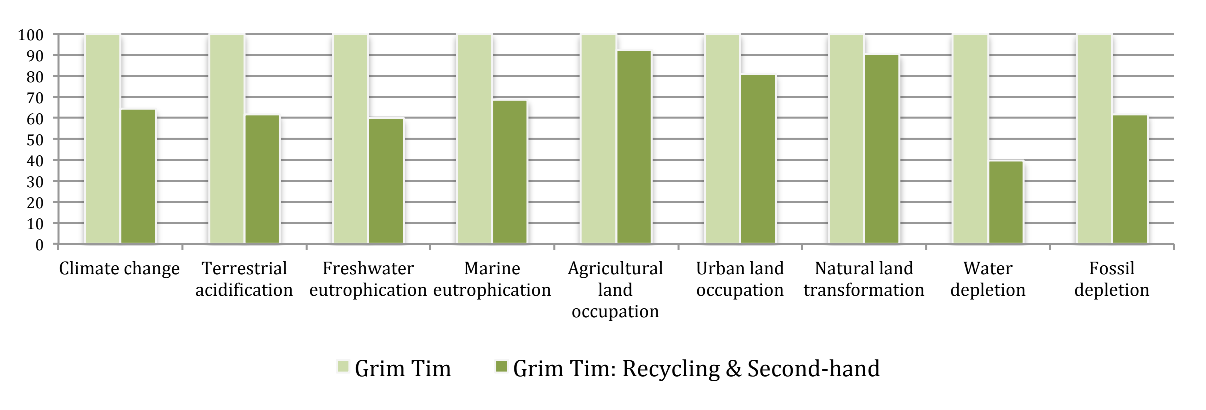

Figure 32: Characterized results of all impact categories for the "original life cycles compared to the ideal circular system" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

Mode of transportation

Nudie Jeans have in their sustainability report addressed the importance of exchanging truck transportation with train as far as possible (Nudie, 2017). So how important is the mode of transport? To illustrate the impact that is represented by the choice of transportation all transports by truck and vessel have been excluded from the LCA study and the results are shown in **Figures 34-36** for the three styles of jeans.

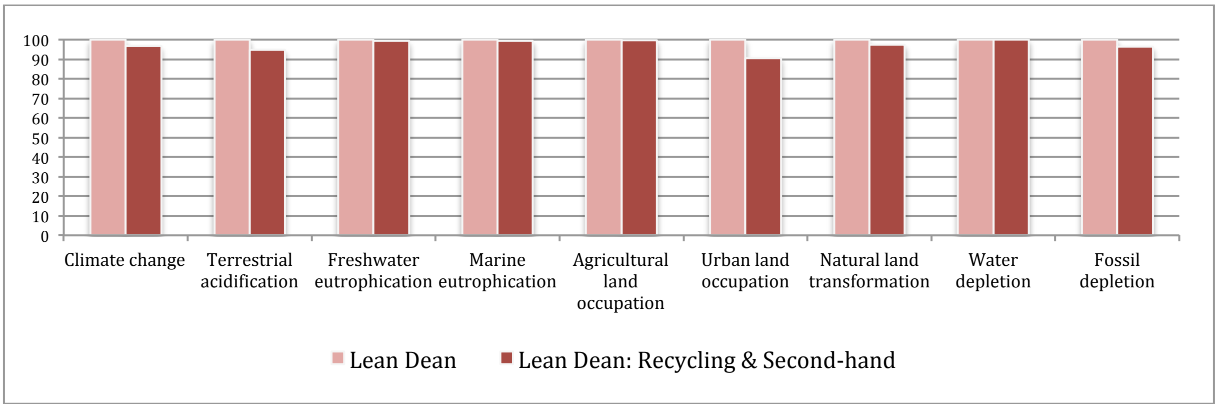

Figure 33: Characterized results of all impact categories for the "no trucks or vessel transportation" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

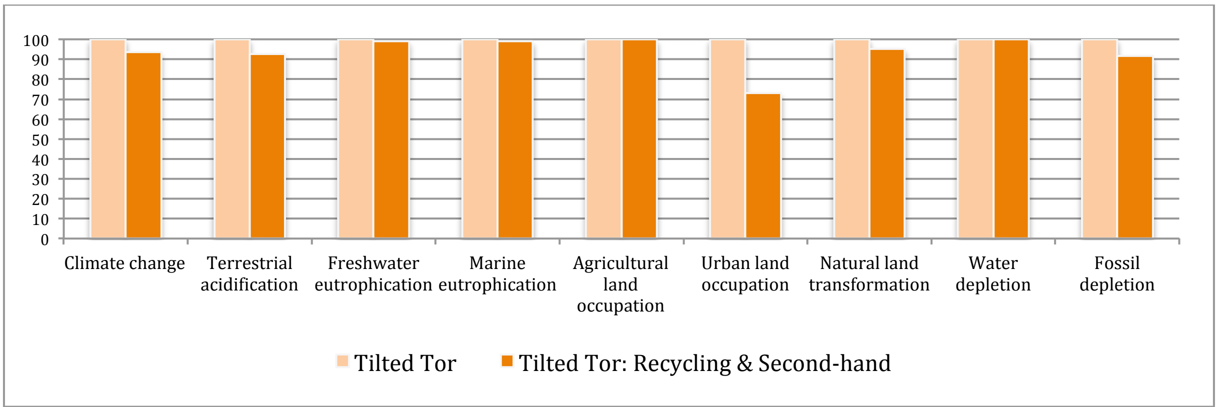

Figure 34: Characterized results of all impact categories for the "no trucks or vessel transportation" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

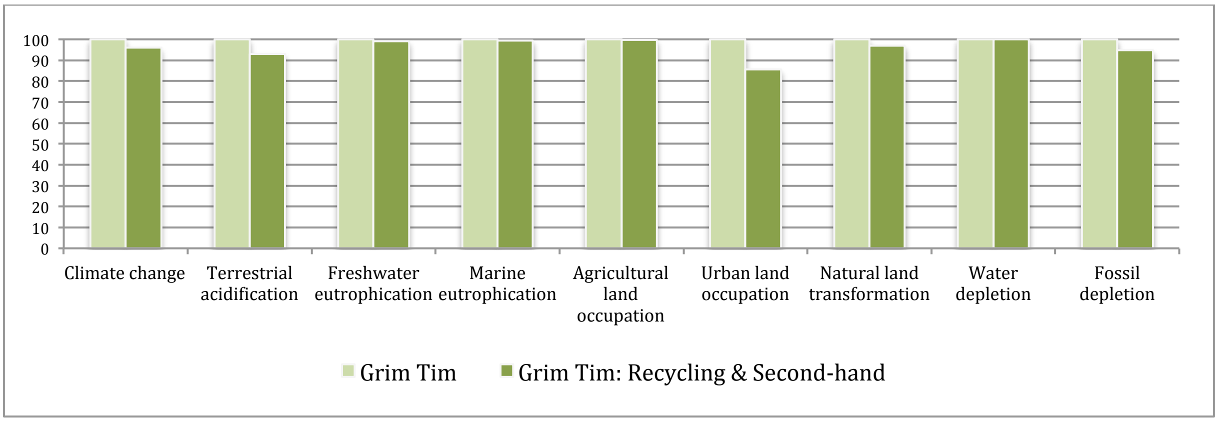

Figure 35: Characterized results of all impact categories for the "no trucks or vessel transportation" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

As seen in the figures the effects of excluding all transportation by truck and by vessel would not lead to that significant effects on the impact categories, only 2-6 percent in total for the three styles of jeans. The largest change can be found in urban land occupation where the reduction represents between 10-27 percent in the three styles. This reduction could be sourced to the non-need for roads or industries where the trucks are produced.

Energy sources

In the materiality analysis conducted by Nudie Jeans (see section 4.2.1) the choice of energy source is one of the priority topics within the CSR work at Nudie Jeans. The choice of energy source has therefore been one of the included aspects for the sensitivity analysis. In **Figure 36**, **Figure 37** and **Figure 38** the results from substituting all fossil fuel based resources in the fabric manufacturing and jeans production processes to wind and solar power within the life cycles of the three styles Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunction respectively are shown.

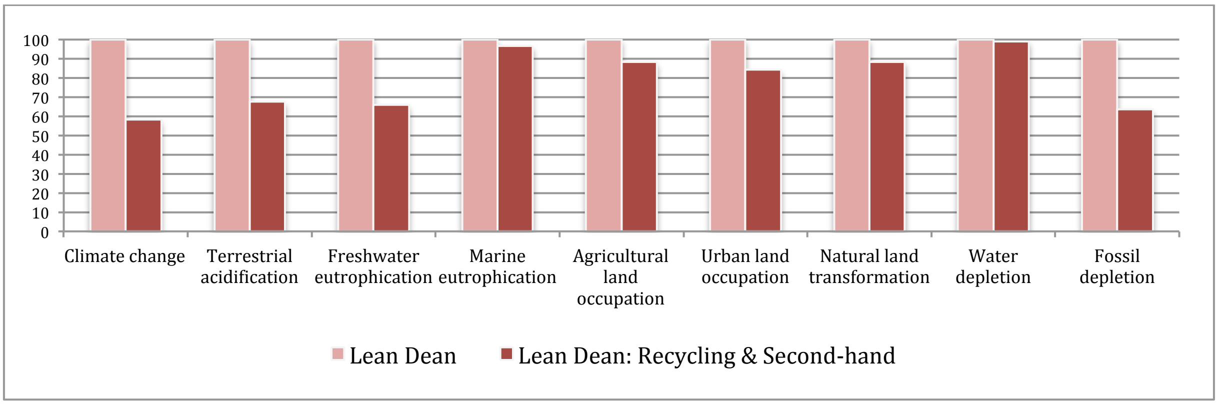

Figure 36: Characterized results of all impact categories for the "no fossil fuels" scenario for Lean Dean Lost Legend. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

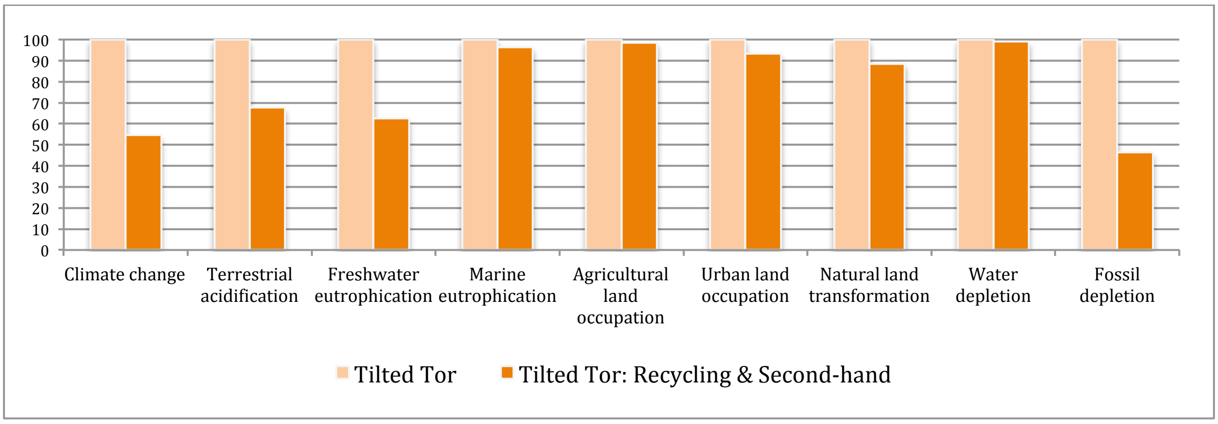

Figure 37: Characterized results of all impact categories for the "no fossil fuels" scenario for Tilted Tor Dry Royal Embo. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

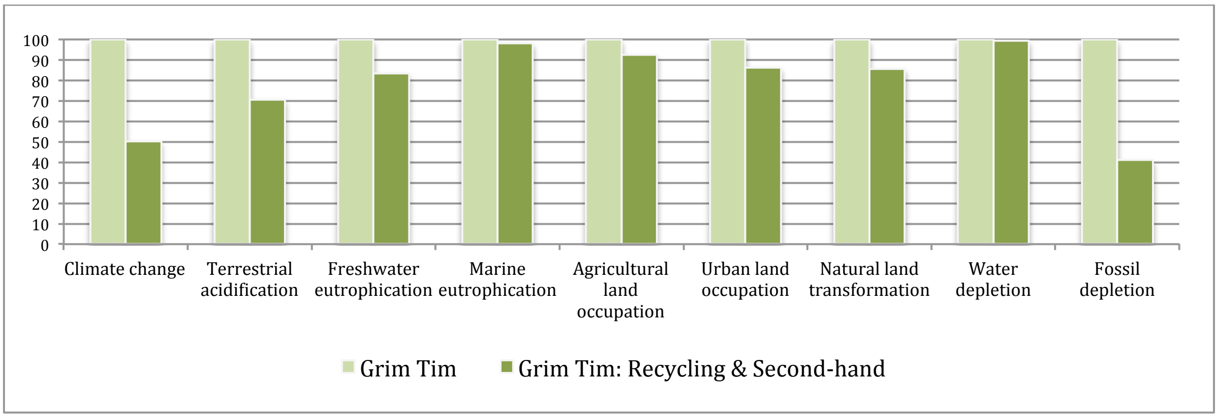

Figure 38: Characterized results of all impact categories for the "no fossil fuels" scenario for Grim Tim Conjunctions. The product with the higher environmental impact within each impact category and between each jeans style is shown as 100 % impact, and the other as a proportion of that value.

As seen in the figures the impacts are lowered in all of the nine impact categories for all three styles of jeans when substituting the electricity and heating sources to wind and solar power. The largest effects are shown in the impact categories: fossil depletion, climate change and terrestrial acidification. The climate change impact would be lowered with 42, 45 and 50 percent respectively for the three styles of jeans, and the fossil depletion category results in a reduction of 36, 54 and 59 percent. For the pant Lean Dean Lost Legend this would mean that the total CO_2 emissions would decrease by approximately 6 kg CO_2-equivalents.

7. Analysis of environmental sustainability goals at Nudie Jeans

Based on the Nudie Jeans Sustainability Report (Nudie Jeans, 2017) and the results from the LCA study on three styles of jeans at Nudie Jeans an analysis of the existing environmental sustainability measures of Nudie Jeans has been conducted. Each identified environmental measure is first described and then evaluated in terms of relevance to the identified impact effects from the sensitivity analysis conducted in section 6.4.3 Sensitivity analysis.

7.1 Cotton

Raw materials and different types of certifications represent the sustainability topic that is prioritized highest of all the 16 sustainability topics relevant for Nudie Jeans. All products should consist of at least 70 percent sustainable materials and be certified with different types of certifications depending on which type of material that is used. For cotton products the identified sustainability targets are that all products should be produced by 100 percent organic cotton and that the organic cotton used for the production is certified according to *Textile Standards (GOTS)*, the *Organic Content Standard (OCS)* and the *Us Department of Agriculture (USDA Organic)* depending on the origin of the cotton. (Nudie Jeans, 2017)

According to the sensitivity analysis conducted in organic vs. conventional cotton cultivation in section 6.4.3 the results showed that the organic cotton results in lower impacts in all impact categories. Despite uncertainties within the water consumption and land use effects the choice of organic cotton instead of conventional cotton is one of the most affecting measures that can be taken at a company selling cotton products.

7.2 Wastewater treatment and chemical restrictions

Chemical usage is one of the well-discussed issues within the textile industry, and especially within jeans production. Nudie Jeans has within their sustainability work placed the management of chemicals as the priority topic number 4. All suppliers should have proper wastewater systems where the larger suppliers preferably should have their own wastewater treatment plant and smaller suppliers have be connected to the municipality's wastewater treatment plants (Nudie Jeans, 2017). Furthermore, Nudie Jeans has based its regulations and sustainability targets on the Restricted Substance List (RSL), which all suppliers must sign and follow in order to comply with the European legislations and regulations on which chemicals that should or shouldn't be used (based on European REACH). From 2017 they also encourage their suppliers to become GOTS certified to increase the usage of GOTS certified chemicals. (Nudie Jeans, 2017)

Since chemical usage is one of the most highlighted issues connected to the industry it is reasonable for Nudie Jeans to focus on this subject. However, a conclusion based on this study cannot be drawn since the toxicity assessments within the impact categories have been excluded due to uncertainties.

7.3 Energy and water

When it comes to energy usage and water consumption Nudie Jeans states in the sustainability report that not enough data has been gathered to be able to draw any conclusions or set any specific targets within the energy and water consumption area. The energy & water priority topic is at the same time prioritized as the 6th most relevant sustainability topics for Nudie Jeans. Without any set targets or measures a few of the suppliers have, on their own initiative, started to change their energy sources to renewable energy sources and one of the suppliers have exchanged all of their electricity consumption from fossil fuels to wind power. (Nudie Jeans, 2017)

However, the sensitivity analysis conducted in section 6.4.3 shows that the replacement of the existing energy sources to only include renewable energy source is having the largest environmental improvement of all the measures. By only replacing the fossil fuel based energy sources within the two life cycle phases, *fabric manufacturing* and *jeans production* to wind and solar power the total potential environmental impact on climate change impact could be reduced by 6.5, 5.7 and 5.9 kg CO_2 equivalents, thus between 40-50 percent of the total impact. This is thus the measure that can improve the environmental impact of a pair of jeans manufactured by Nudie Jeans the most. Since a large improvement has been identified within the energy area the current priority order is thus wrong. Since Nudie Jeans has come so far within the current 1th priority topic (material & certifications) a rearrangement of the priority topics should be done. The energy & water topic could definitely be prioritized as number one in the future since the potential environmental improvement almost halves the environmental impact of the product.

7.4 Transportation

Transportation has the priority number 11 out of the total 16 sustainability topics. The measures identified by Nudie Jeans are to, as far as possible, replace transportation by truck with transportation by train and to avoid airfreight as much as possible by instead using sea freights. (Nudie Jeans, 2017)

As shown in section 6.4.3 Sensitivity analysis the effect of excluding all trucks are not that significant if looking at the effect per functional unit. Even for climate change, where the highest impact reduction can be expected the reduction of CO_2 equivalents is only 4-7 percent from the original life cycle. The highest effect can be seen in the impact category urban land occupation, probably since the need for roads and industries for the production of vehicles are reduced. Based on the sensitivity analysis the transportation topic should not be prioritized higher than it is today since there are areas that could reduce the total impact considerably more. But since transportation is based on fossil fuels this is a topic that has to be handled in due time and should not be forgotten.

Nudie Jeans also highlights the importance of replacing airfreights with sea freights as far as possible since about 91 percent of the transports from warehouse to customer are done by airfreights. The goal per se has the right focus since airfreights result in higher amounts of CO_2 emissions than sea freights (SSNC, 2017). No conclusions about airfreights can be drawn based on this study, however, based on the high amount of emissions that is caused by air freights the target should arguably be prioritized higher than 10th place.

7.5 Climate Compensation

Climate compensation is a very good option when further emission reduction measures can't be taken, and of course during the time implementations of the measures are done. Climate compensation should however not be seen as an alternative instead of other possible measures since climate compensation per se don't reduce the companies own impact (SSNC, 2018). A conclusion based on this study can however not be made.

7.6 Repair, reuse and recycle

The next environmental sustainability topics at Nudie Jeans are repair & reuse and recycle, which have the priority numbers 9 and 3 respectively. Within the field of repairs and reuse there are five measures identified. The first and most promoted measure taken by Nudie Jeans is the offering of free repairs in order to prolong the lifetime of the jeans. The second measure is to receive old jeans manufactured by Nudie and re-sell them to a new user. The third measure is to take care of the fabric from old and worn out jeans or jeans that for some reason can't be sold as jeans, and use these for repairing old jeans or manufacture new products such as backpacks, shorts or caps. The fourth measure is the free repair kit that is sent to people that has a long distance to the nearest repair shops and the fifth and last measure that also is highly promoted by Nudie Jeans is to, as far as possible, avoid washing of jeans. (Nudie Jeans, 2017)

As seen in the sensitivity analysis the total average environmental impact could be reduced by about 30 percent without any other environmental improvements, just by increasing the amount of reusing and repairs, since each reuse means one less new pair of jeans has to be produced. Furthermore, to take care of damage jeans, spill can be reduced at the facilities, which means that unnecessary impact from cotton cultivation and fabric manufacturing can be avoided. Recycling of cotton also reduces the impact but should, as stated in the sustainability report, be prioritized after the waste hierarchy stages reduce and reuse, since the denim fabric is down-cycled and will not replace the production of a new pair of jeans.

When it comes to the free repair kit all unnecessary material consumption can be questioned. If the person that receive his or her repair kit uses it once and then throws it away, the gain of repairing the pants can be questioned in relation to the impact generated from sending their jeans to the repair shops instead.

To, as far as possible, avoid washing of jeans has also been examined in the sensitivity analysis in section 6.4.3. According to the sensitivity analysis the impacts generated from the washing of jeans can reduce the total environmental impacts in all impact categories, which shows the significance of the environmental target.

7.7 Conclusion of the analysis

To conclude the analysis of the existing environmental targets and measures the results are presented in **Table 8.** Each measure has been assigned a color to represent how well the focus represents the environmental impact. Cells marked as green has the right prioritization according to its potential environment impact, red cells do not have the right prioritization according to the environmental performance and in the yellow cells conclusions cannot be made based on this study.

Table 9: Identification and analysis of the environmental sustainability goals at Nudie Jeans in relation to the results conducted from the LCA study. The numbers 1, 4, 6 and 10 in the table represent the priority order the topic has for Nudie Jeans. Green cells stands for right focus, orange for an uncertain conclusion and red cells for wrong focus.

Focus area at Nudie Jeans	UN SDG	Priority topic	Environmental measures	Right or wrong focus
Sustainable Materials	15	Material & Certifications (1)	100 % organic cotton Certifications 70% from sustainable materials	**Right focus:** Right focus area and right priority order according to potential environmental impacts
			Increase amount of recycled cotton	**Right focus:** Right focus area and right priority order according to potential environmental impacts
			Reused denim for patches, caps, shorts and backpacks etc.	**Right focus:** Right focus area and right priority order according to potential environmental impacts
Sustainable Production	6	Chemicals (4)	Proper wastewater systems The Restricted Substance List (RSL) GOTS certified	**No conclusion**
	6, 12	Energy & Water (6)	No measures or targets identified	**Wrong focus:** Wrong priority order in relation to the impact generated from these processes.
	12	Transport (10)	Replace truck by train Packs in effective ways and heavy loads	**Right focus:** Right focus area and right priority order according to potential environmental impacts
			Avoiding airfreight	**No conclusion**
			Climate Compensation	**No conclusion**
Sustainable Product	12	Repair and reuse (9)	Offering free repairs Reselling second-hand products Reusing worn out products	**Right focus:** Right focus area and right priority order according to potential environmental impacts
			Sends *Repair Kit* free of charge	**No conclusion**
			Avoid washing of jeans	**Right focus:** Right focus area and right priority order according to potential environmental impacts
		Recycle (3)	Collects Nudie jeans for recycling	**Right focus:** Right focus area and right priority order according to potential environmental impacts

8. Discussion

As Roshan (2015) states denim jeans are used all around the world, by all people of all ages, classes and genders. This means that jeans are consumed in large quantities every year all around the world. Lets say that all 7 billion people living on earth today would buy one pair of new jeans during one year, and that the production and usage of the bought pair of jeans would result in the same amount of CO_2 emissions as the average amount of the three jeans Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions. This would result in about 96 millions tones of CO_2 emissions, only in one year. This amount of emissions represents the same amount of emissions released when driving a car around the world 20 000 times[14] or almost twice as much as Sweden's total CO_2 emissions from 2016 (SSNC, 2018). This shows the importance of implementing environmental measures into the business operations and strategies in the production processes of jeans and textile. Luckily this is a trend that has started to show within several of the Swedish clothing companies. Nudie Jeans is only one of the companies that have started to implement CSR management within their business model. Both measures like the offering of free repairs and the reselling of second-hand products are promoting and contributing to the long-term thinking that is argued by Köksal et al. (2017) as one of the most essential factors in order to reach a sustainable clothing industry. The long-term thinking, and circularity thinking, can also be seen in several other companies around Sweden, H&M (H&M Group, 2017b), Lindex (Lindex, 2017) and KappAhl (KappAhl, 2017) who all have started to collect clothes for either second-hand use or recycling, which reduce the total impact significantly.

The results gathered from the LCA shows that 16.6, 12.5 and 12.0 kg CO_2-equivalents represent the total impact on climate change of the three jeans for Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions respectively. In comparison to other similar studies, with the same extent of the life cycle, the three jeans manufactured by Nudie Jeans ends up somewhere in the lower spectra. The general jean results in between 11.5 kg CO_2-equivalents (Roos et al., 2015) and 33.4 kg CO_2-equivalents (Levi Strauss, 2015). The negative impacts within the impact categories shown in the results from the LCA can be tracked down to three main contributing processes: energy source for electricity and heating, the transportation distances between the life cycle phases and the laundry and dyeing processes within fabric manufacturing and jeans production. Since the choice of energy source in the energy consuming processes within fabric manufacturing and jeans production alone stands for the largest total negative impact, an improvement within this field could reduce the total negative impact significantly. To reach a change within this area consumers may have to put higher pressure on the clothing companies, and the clothing companies have to put pressure on the suppliers to increase the amount of renewable energy or to change to suppliers located in countries where the access to renewable energy is available.

Looking closer to how well Nudie Jeans capture the environmental importance of their environmental targets we can see from the analysis in Chapter 7 that they have relatively good priorities. They have come far within many of the sustainability areas and only one of the environmental areas has been evaluated as "wrong focus". The energy sources used in the production processes should be reviewed and prioritized higher than they are today. Within the areas that conclusions can't be drawn based on this study further investigations should be done. For example, even if this LCA can't state that airfreights is bad, it is a given fact, and to still have 91 percent of the total transportations between the warehouse in Sweden to the

[14] Calculated according to Trafikverket (2018) numbers on carbon dioxide emissions from cars, trucks buses etc. where cars produced during 2016 and 2017 releases in average 123 g CO_2/km.

customers households is not the way to go if a company aims at becoming fully sustainable. Within this field, measures like placing warehouses closer to the customer or alternative shipments can be useful. For more information about the analysis please see Chapter 7. Analysis of environmental sustainability goals at Nudie Jeans.

The three environmental aspects: life cycle perspective, move from fast to slow fashion and circularity can be seen clearly in the environmental targets defined by Nudie Jeans. The clearest example is the repair shops, second-hand selling and recycling measures that are taken by the company. According to the sensitivity analysis measures within this field would mean very good opportunities to minimize the total environmental impact. If the same amount of clothes that is thrown away today instead of going to incineration would be reused or recycled the total impact of the three styles of jeans could reduce by between 30 to 40 percent, without any other sustainability measures. This is thus one of the most important aspects within the clothing industry where more companies have to start to take action. There are still difficulties within the recycling processes of jeans where most of the recycled products are down-cycled instead of becoming new garments and the consumers still require new and cheap clothes in a pace that is unsustainable, but if more companies would implement CSR management into their business strategies and actually conduct the identified measures the total impact could be improved significantly.

8.1 Uncertainties

As for all life cycle assessments there are always some uncertainties within the study and within the methodological choices. An LCA aims at providing a comprehensive view over the environmental impacts caused by the product. However, all types of impacts are not equally well covered, e.g. the methods for assessing land use, biodiversity, toxicity and some of the resource aspects such as freshwater use and elastane. Furthermore, the LCA methodology, as any other environmental tool, has its uncertainties.

Allocation is one of the most discussed methodological issues connected to LCA and is handled through the hierarchy of allocation procedures (found in section 5.1.2). The largest issue when talking about allocation is that the overall results should represent the same system boundary and in principal the same included aspects for all included processes. The allocation procedures in this LCA have therefore mainly been based on the mass relation of the produced products. Even if there are uncertainties with the choice of dividing the environmental burden based on weight a consistency in the methodological choices makes the results more coherent and reliable.

In this study all site-specific information have been gathered from the suppliers through data collection forms. When gathering data from suppliers many uncertainties and risks can occur, especially the risk of misinterpretation of the questions. To minimize this risk the data collection forms have been reviewed by a group of four students at KTH. But still, data uncertainties due to misinterpretations will still occur. Where questions have been raised further discussions about the requested data have been made with the supplier. In cases in which data is unreasonable or in cases where the suppliers don't sit on the specific data assumptions have been made. One example of this is the heating used for the sewing facility Bobo where the other Italian facilities have been used has a base for the heating used at Bobo. This type of assumption is of course affecting the results but not that significantly. The assumptions made on the use phase is however very important for the final results of the environmental performance, as can be seen in the figures presented in section 6.4. The use phase is entirely based on generic data where the consumer behavior is based on a study regarding Swede's general consumer behavior (Granello et al., 2011). These types of assumptions thus have a large impact on the results of the study and should be noticed by the one that reads the study. To minimize the uncertainties of assumptions made through the study reliable and reviewed studies have been used to base the assumptions or simplifications.

One of the largest uncertainties identified in the study is the impact on land use where the cotton cultivation process is not shown clear within any of the land use impact categories. Since one pair of jeans alone requires about 100 square meters[15] of agricultural land it is unrealistic that the use of washing detergents is resulting in more than twice as high impact within this specific impact category. The reason to this strange results could either be that there are errors in the calculations conducted or that there are errors in the data that has been used for the calculations. One explanation can also be that the effects on land use disappears somewhere in the aggregation step of the analyzed input data and is shown in some of the other impact categories. However, since the land use from cotton cultivation is not found in the results of the studied systems the impact on land use should be developed further before any proper conclusions can be drawn within this area.

Since average wastewater treatment processes has been used in all the life cycle phases that includes emissions to water the result may not reflect the site-specific conditions of the system. For example, in the residential laundry process the process most likely will result in emissions such as cotton or elastane fibers going to the wastewater treatment facility or the specific emissions generated from the washing detergents. These specific substances are however not included as outputs from the system due to simplification purposes with the model, which results in that the specific impacts from these substances are missing in the results. At the same time, the municipal wastewater treatment facility may reduce the impact from substances that don't exit the system through the wastewater and thereby reduce the impact further. Since the specific outputs and thus the impacts from these substances are excluded from the study and the fact that the average wastewater treatment facility both may be better or worse that the wastewater treatment facilities at the specific suppliers the potential impact generated from this LCA could be both higher or lower than the reality. For further investigations these aspects should be included as well to be able to draw more accurate conclusions about these processes.

The transportation datasets used in the LCA model are limited to only include transportation vehicles classified according to the EURO3 classification. This classification is representing the lowest environmental classification available in the ecoinvent database and may therefore not be representative in all transports within the supply chain of the three products. Transports within Sweden and maybe in some cases for Italy for example a classification of EURO5 would be more representative, while the EURO3 classification is better suited in the transports occurring in Tunisia, Turkey and India. Since the specific environmental classification of the vehicles used by Nudie Jeans and the suppliers is unknown the choice of only modeling the transports with this low environmental classification could result in that the potential environmental impact is lower in the reality. However, since transports, even if the worst case scenario has been chosen, only represent between 4-5 percent of the total environmental impact this choice should not be that significant for the final environmental impact of the three studied systems and thus to that significant for the results of the study.

[15] Based on the calculations that one pair of jeans requires between 0.75-0.8 kg cotton lint (based on data given by the suppliers in the data collection forms) and that the yield of cotton lint in the studied cotton fields is between 404-655 kg per hectare (Textile Exchange, 2014).

Nudie Jeans has different certification standards for organic cotton depending on which country the cotton is cultivated in (GOTS, USDA Organic and OCS) (Nudie Jeans, 2017). According to the GOTS standard no use of toxic, persistent pesticides and fertilizers are permitted in organic farming (GOTS, 2018) and according to the USDA Organic no synthetic fibers, sewage sludge, irradiation or genetic engineering may be used (U.S. Department of Agriculture, 2018). In the cotton cultivation processes in the LCA model however rock phosphate has been used as an input to the system, according to data gathered from Textile Exchange (2014). Rock phosphate is not classified as an organic fertilizer, which means that the results gathered from the LCA is not representing 100 percent organic cotton. The OCS standard that is the third used certification label by Nudie Jeans is developed by Textile Exchange and only ensures that the final material includes a certain amount of organic material. Since the organic cotton cultivation process created in this LCA study is based on a study conducted by Textile Exchange and that Nudie Jeans uses this specific certification label the use of rock phosphate is not entirely unrealistic. If the organic cotton used in the three jeans styles are cultivated with the help of rock phosphate is however unknown. If these farms don't include rock phosphate, according to the restrictions of organic cotton cultivation in GOTS and USDA Organic, the amounts of heavy metals and the effects on land use shown in the results (see section 6.4.1) probably are less in the reality.

Finally I would like to comment the water consumption at the facilities in the production phases: fabric manufacturing and jeans production. As seen by the results in section 6.4.1 the total water consumption (excluding rain-fed water consumption in the cotton cultivation phase) ends up at a total of 600, 400 and 450 liter per FU for the three styles Lean Dean Lost Legend, Tilter Tor Dry Royal Embo and Grim Tim Conjunctions respectively. Of this water consumption 220, 266 and 95 liters of water per FU represent the water consumed at fabric manufacturing and jeans production. In the study conducted by Levis Strauss (2015) the same processes results in a water consumption of 347 liters of water per produced pant, and in the study conducted by Roos et al. (2015) these numbers don't even show in compared to the water consumed at cotton cultivation. The results gathered from this study compared to results gathered from other similar studies do thereby not differ that much. The amounts are still smaller than the other studied, which could either depend on that the amounts that are provided by the suppliers at Nudie Jeans (and double checked) are misinterpreted or that the awareness at the suppliers within recycling of water or water saving techniques actually have reduced the water consumption.

8.2 Further suggestions

This study shows that there are a lot of opportunities for improvements within the life cycle of jeans. The results of the study can thereby both be used by Nudie Jeans as well as by other jeans producing companies and consumers that aim at improving their environmental performance. The aim was to capture the environmental performance at Nudie Jeans, to examine how well the products perform and how well the sustainability targets highlight the environmental importance. However, even if this study provides guidance within these areas some development opportunities have been identified.

First of all elastane should be included in the study. Since elastane is one of two raw materials used to produce the products this substance should definitely be involved if further studies are conducted. Even if elastane only stands for about 1-2 percent of the total weight of the pant, and that the impact theoretically should be negligible, the reality could differ.

Furthermore, some of the processes that are non-site specific in this study should be examined from the specific conditions at Nudie Jeans. For example, the use phase is now, as mentioned, entirely based on generic data. However, since Nudie Jeans is marketed as a conscious company when it comes to sustainability issues the consumer base may reflect this as well. More conscious consumers would lead to less impact generated from the use phase and thereby the entire result of the study. The cotton cultivation life cycle phase is also based on generic data (within the countries that Nudie Jeans uses in the three products). To get a result that even better represent the specific products manufactured by Nudie Jeans the life cycle phase of cotton cultivation should as well be site-specific. The water consumption at the fabric manufacturers and jeans producers should as well be examined further to see what the low water consumption depend on.

Last but not least, since this study has been narrowed down to only focus on the environmental sustainability issues all social and economic aspects have been excluded. This does not mean that social or economic sustainability issues do not exist within the textile and apparel industry. On the contrary, as can be seen in the materiality analysis (section 4.2.1) the majority of the priority topics are touching on social or economic issues such as fair labor conditions, fair living wages, the right training at the facilities and the importance of transparency throughout the supply chain. The majority of the sustainability issues connected to the business conducted at Nudie Jeans are thus social and economical and only six of the 16 stated sustainability areas (priority topics) are of environmental importance. This definitely highlights the importance of including social and economic aspects as well when doing this type of study. To include the social and economic aspects and thereby capture the entire sustainability impact of the three products a Social Life Cycle Assessment (S-LCA) and a Life Cycle Costing (LCC) could be conducted and added to the results from the E-LCA. To be able to capture the social impacts in the same extent as the environmental impacts has been captured in this E-LCA site-specific data would be required. By only using generic data from existing S-LCA databases the social impacts would only show country specific social risks within the different industries (cotton cultivation, apparel industry and textile production for example) and thereby not capture the conditions at the specific companies that Nudie Jeans uses. A risk assessment within the social area is already conducted by Nudie Jeans and thereby a more site-specific S-LCA would be necessary. This means that site-specific data has to be collected from the facilities. However, social data is often difficult to collect through data collection forms since the transparency of the supply chains often is limited and that social issues often are hidden from the public. Thus, to be able to reach the same level of detail and be able to do the same type of analysis on the social sustainability goals visits at the suppliers have to be conducted. Within the scope of this study visits at the different suppliers have not been possible to conduct but for further development of the analysis I would highly recommend to include both a S-LCA and a LCC to the E-LCA results to be able to capture the entire sustainability area.

8.3 Conclusions

From the study it is clear that the two jeans styles Grim Tim Conjunctions and Tilted Tor Dry Royal Embo have the best performance from an environmental perspective, at least within the specific impact categories chosen for this study. The difference between the two styles is minimal. Lean Dean Lost Legend has the worst environmental performance compared to the other two jeans styles but not the worst performance of all times looking on previous studies. The negative impacts depend on the two main aspects, energy sources for electricity and heating and the substances used for dyeing, laundry and finishing processes.

Nudie Jeans is definitely on the right path, where the majority of the sustainability targets and measures represent its environmental importance. The large focus on repairs, reuse, second-hand and recycling will play significant roles in the future when we are going towards more circular systems where Nudie Jeans definitely already are in the front row showing the way. Development opportunities are however seen within energy consumption at the production facilities.

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Appendix 1: Data collection form sent to suppliers

The questionnaires sent to the suppliers are customized after the specific production occurring at the facility, the questions on the questionnaires have thus differed depending on the type of production. All questionnaires include information regarding general production data, material and chemical usage, water consumption, water treatment, energy usage, and transportations. Below some general questions are shown to represent the questions in the questionnaires.

Q1. Is jeans/denim fabric the only type of product produced at the facility? If no, what other products are produced at the facility and how large share of the total production is represented by production of jeans/denim fabric?

Q2: What was the total production of jeans/denim fabric during 2017, given in total number of produced products and total weight of products?

Q3: What was the total production of the specific product X at the facility during 2017, given in total number of product X and total produced weight of product X?

Q4: What was the final weight of the finished product X and what was the content of the specific product X, split into percentages of weight?

Q5: What was the total amount (weight) of purchased cotton/denim fabric in 2017? Please estimate how much of the bought cotton/denim fabric that is spilled each year and explain how the spillage is handled.

Q6: What other materials are used in the finished product X (e.g. zipper, button, labels etc.), please specify type and weight of each material.

Q7: Are chemicals or other substances used in the production of the specific product X? If yes, which chemicals are used and how are the chemicals treated after use (please specify name and amount of each chemical)?

Q8: What is the total amount (weight) of solid spillage generated at the facility each year and what does this spillage, in the largest extent, contain of? Please specify how this waste is handled (treated on-site, sent by regular municipal waste management trucks etc.)

Q9: What was the total water usage at the facility during 2017 and what is the primary source of that water?

Q10: What was the total water usage for the specific processes X during 2017 (e.g. laundry, finishing)?

Q11: How is wastewater handled, is non-polluted water recycled, is polluted water treated on-site, is it sent to municipal or state-run wastewater treatment facilities, or is it not treated at all etc.?

Q12: What was the total use of electricity at the facility during 2017? If known, what source of energy is used for the electricity?

Q13: What was the use of other type of fuels (oil, coal, gas etc.) at the facility during 2017?

Q14: Is the facility heated? If yes, what type and amount of energy was used for heating during 2017?

Q15: Is the specific product X packaged before it is sent away? If yes, in what type of material is the product packaged, in what quantities are products packaged and what is the weight of the packaging materials used?

Q16: Is any transportation occurring between the different processes at your facility? If yes, please state type of transportation (truck, train etc.) and transport distance.

Q17: In what kind of vehicle (truck, ship train etc.) is the finished product X transported from the facility?

Appendix 2: Inventory data – Lean Dean Lost Legend

Table 10: Inventory data for the materials used in the processes: cotton cultivation, fabric manufacturing and jeans production, for the specific product system of Lean Dean Lost Legend. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly value allocated to the specific fabric *RR 2716 Old Crisp*y and the specific jean *Lean Dean Lost Legend*, thus not the entire production at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Material (In- and outputs)	Total yearly amount	Amount per pair	Reference of value	Modeled with/Dataset used
Cotton Cultivation	Field preparation (Inputs)	Arable land occupation	1 ha	0,0020 ha	Textile Exchange (2014)	Occupation, arable, organic Transformation, from arable, organic Transformation, to arable, organic Carbon Dioxide, in air Energy, gross calorific value, in biomass.
		Ploughing	1 ha	0,0020 ha	Textile Exchange (2014)	Ecoinvent 3: Tillage, ploughing {GLO}| market for | Alloc Def, S
		Cotton seeds	2 kg/ha	0,0040 kg	Textile Exchange (2014)	Ecoinvent 3: Cotton seed, for sowing {GLO}| market for | Alloc Def, S
	Cultivation (Inputs)	Manure	11531,95 kg/ha	23,12 kg	Textile Exchange (2014)	Agri-footprint: Manure, from cows, at farm/RER Economic
		Rock phosphate	313,6 kg/ha	0,63 kg	Textile Exchange (2014)	Agri-footprint: Lime fertilizer, at plant/RER Economic
	Waste (Outputs)	Waste	124,3 kg/ha	0,25 kg	Textile Exchange (2014)	Ecoinvent 3: Biowaste {RoW}| treatment of, composting| Alloc def, S
	Products (Outputs)	Seed	598,9 kg/ha	1,20 kg	Textile Exchange (2014)	Allocated 16 % of the environmental burden based on economic value
		Cotton Lint	406,8 kg/ha	0,82 kg	Textile Exchange (2014)	Allocated 84 % of the environmental burden based on economic value
Fabric Manufacturing	Spinning and warping (Inputs)	Organic cotton	22860,82 kg	0,84 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Cotton fibers from above made process "Cotton Lint – India"
		Elastane	443,22 kg	0,016 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Viscose fibre {GLO}| market for | Alloc Def, S
	Dyeing and Sizing (Inputs)	Pre-reduced indigo	147818 $ (1459,2 kg)	0,054 kg	Italian Fabric Producer (2018) & market value on pre-reduced indigo	USA Input Output Database: Synthetic dye and pigment manufacturing
		Caustic Soda	364,8 kg	0,013 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Sodium hydroxide, without water, in 50% solution state {GLO}|market for| Alloc Def, S
		Sodium Hydrosulfide	182,4 kg	0,0067 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Sodium hydrosulfide {GLO}|market for| Alloc Def, S
		PVA: Potassium Permanganate	291,84 kg	0,011 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Potassium permanganate {GLO}|market for| Alloc Def, S
		Potato Starch	729,6 kg	0,027 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Potato starch {GLO}|market for| Alloc Def, S
	Waste (Outputs)	Spill Cotton fibers	1085,89 kg	0,042 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Waste textile, soiled {GLO}| market for | Alloc Def, S
		Spill Mixed packaging	1402,79 kg	0,052 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Waste packaging paper {GLO}|market for| Alloc Def, S
	Products (Outputs)	Finished fabric RR 2716 Old Crispy	22161 kg	0,816 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Allocated 100 % of the environmental burden of the above processes

Life cycle phase	Process	Material (In- and outputs)	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Production of jeans	Cutting and sewing (inputs)	Denim fabric	8691,49 kg	0,82 kg	Denim Authority (2018)	Above mentioned process
		Zipper Brass[1]	76,73 kg	0,0072 kg	Denim Authority (2018)	Ecoinvent 3: Brass, Nickel free {GLO}|market for| Alloc Def, S
		Button Brass old copper, nickel free	24,08 kg	0,00226 kg	Denim Authority (2018)	Ecoinvent 3: Brass, Nickel free {GLO}|market for| Alloc Def, S
		Rivet Brass old copper, nickel free	9,59 kg	0,0009 kg	Denim Authority (2018)	Ecoinvent 3: Brass, Nickel free {GLO}|market for| Alloc Def, S
		Waist tag Recycled paper	45,4 kg	0,00426 kg	Denim Authority (2018)	Ecoinvent 3: Graphic paper, 100% recycled {GLO}| market for | Alloc Def, S
		Label Woven Cotton	7,78 kg	0,00073 kg	Denim Authority (2018)	Ecoinvent 3: Textile, woven cotton {GLO}|market for| Alloc Def, S
	Laundry (inputs)	Resine 3D Nofelding NFC 5% and Nearfinish 10X NF 5%	558,59 kg	0,052 kg	Denim Authority (2018)	Ecoinvent 3: Urea formaldehyde resin {GLO}| market for | Alloc Def, S
		Soaping Agent Neareserve DSW 1g/L	647,26 kg	0,061 kg	Denim Authority (2018)	Ecoinvent 3: Polycarboxylates, 40% active substance {GLO}| market for | Alloc Def, S
		Spray PP Permanganate 20g/L	12945,20 kg	1,21 kg	Denim Authority (2018)	Ecoinvent 3: Potassium permanganate {GLO}| market for| Alloc Def, S
		Neutralization Agent META 12g/L	7767,12 kg	0,73 kg	Denim Authority (2018)	Ecoinvent 3: Neutralising agent, sodium hydroxide-equivalent {GLO}|market for| Alloc Def, S
		Dirty ORANGE LG-L 0,05%	227,59 $	0,021 $	Denim Authority (2018)	USA Input Output database: Synthetic dye and pigment manufacturing
		Stone Pumice	7673 kg	0,72 kg	Denim Authority (2018)	Ecoinvent 3: Pumice {GLO}| market for| Alloc Def, S
	Packaging (Inputs)	Biodegradable plastic polybags	42,628 kg	0,0040 kg	Denim Authority (2018) and authors own data	Ecoinvent 3: Polylactide, granulate {GLO}|market for| Alloc Def, S
		Carton Box	1150,96 kg	0,11 kg	Denim Authority (2018)	Ecoinvent: Corrugated board box {GLO}|market for corrugated board box| Alloc Def, S
	Waste (Outputs)	Spill Fabric	1183,91 kg	0,11 kg	Denim Authority (2018)	Ecoinvent 3: Waste textile, soiled {GLO}|market for| Alloc Def, S
		Spill Paper	2237,97 kg	0,21 kg	Denim Authority (2018)	Ecoinvent 3: Waste packaging paper {GLO}|market for| Alloc Def, S
		Spill Plastic	2237,97 kg	0,21 kg	Denim Authority (2018)	Ecoinvent 3: Waste polypropylene {RoW}|market for waste polypropylene| Alloc Def, S
	Product (Outputs)	Lean Dean Lost Legend	7673 kg	0,72 kg	Denim Authority (2018)	Allocated 100 % of the environmental burden of the above processes

[1] The metal used for the zipper is assumed to be the same as the zipper used for the other examined jeans styles.

Table 11: Energy use within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Lean Dean Lost Legend. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly values allocated to the specific fabric *RR 2716 Old Crisp*y and the specific jean *Lean Dean Lost Legend*, thus not the entire energy usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Source of energy	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Cotton Cultivation	Irrigation	Electricity	145,22 MJ/ha	0,29 MJ	Textile Exchange (2014)	Ecoinvent 3: Electricity, low voltage {IN} |market for| Alloc Def, S
	Harvesting	Diesel	1 ha	0,0020 ha	Textile Exchange (2014)	Ecoinvent 3: Combine harvesting {GLO}| market for| Alloc Def, S
	Ginning	Electricity	231,88 MJ/ha	0,46 MJ	Textile Exchange (2014)	Ecoinvent 3: Electricity, low voltage {IN} |market for| Alloc Def, S
Fabric Manufacturing	Dyeing, Sizing and Finishing	Natural gas	1889,69 m^3	0,069 m^3	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
	Heating	Natural gas	13085,79 m^3	0,48 m^3	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
	Other processes	Electricity	126614,66 kWh	4,66 kWh	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
		Diesel	30,7 kg	0,0011 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Diesel {GLO}|market group for| Alloc Def, S
Production of jeans	Cutting	Electricity	1466,87 kWh	0,14 kWh	Denim Authority (2018)	Ecoinvent 3: Electricity, low voltage {GLO}|market group for| Alloc Def, S
	Sewing	Electricity	5221,53 kWh	0,49 kWh	Denim Authority (2018)	Ecoinvent 3: Electricity, low voltage {GLO}|market group for| Alloc Def, S
	Laundry	Electricity	24429,95 kWh	2,29 kWh	Denim Authority (2018)	Ecoinvent 3: Electricity, low voltage {GLO}|market group for| Alloc Def, S
	Other processes	Electricity	8859,63 kWh	0,83 kWh	Denim Authority (2018)	Ecoinvent 3: Electricity, low voltage {GLO}|market group for| Alloc Def, S
		Diesel	11028,81 kg	1,03 kg	Denim Authority (2018)	Ecoinvent 3: Diesel |market group for| Alloc Def, S
Storage at Korallen	Heating	District Heating	180,01 kWh	0,017 kWh	Kamgarn (2018)	Ecoinvent 3: Heat, district or industrial, other than natural gas {GLO}|market group for | Alloc Def, S
	Other	Electricity Green	30,71 kWh	0,0029 kWh	Kamgarn (2018)	Ecoinvent 3: Electricity, low voltage {SE}| market for| Alloc Def, S

Table 12: Water use data within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Lean Dean Lost Legend. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly values allocated to the specific fabric *RR 2716 Old Crisp*y and the specific jean *Lean Dean Lost Legend*, thus not the entire water usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Source of water	Happens with water after use	Total yearly value (L)	Liters /Pair	Reference of values	Modeled with/Dataset used
Cotton Cultivation	Irrigation	Ground water	-	137000 L/ha	274,66	Textile Exchange (2014)	Ecoinvent 3: Irrigation {IN}|market for| Alloc Def, S
Fabric Manufacturing	Total	Ground water	Partly treated on-site (in contact with chemicals) partly sent to municipal treatment (no contact with chemicals)	1578785,10	58,10	Italian Fabric Producer (2018)	Ecoinvent 3: Water, well, in ground, IT Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
Production of jeans	Laundry	Ground water and state grid	Partly treated with on site treatment and partly treated at municipal treatment facility	647259,77	60,74	Denim Authority (2018)	Ecoinvent 3: Tap water {GLO}|market group for| Alloc Def, S Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
	Other, in contact with products	Ground water and state grid		355678,55	33,38	Denim Authority (2018)	Ecoinvent 3: Tap water {GLO}|market group for| Alloc Def, S Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
	Other, not in contact with products	Ground water and state grid		127088,39	11,93	Denim Authority (2018)	Ecoinvent 3: Tap water {GLO}|market group for| Alloc Def, S Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S

Table 13: Inventory data for the transports between and within the processes: cotton cultivation, fabric manufacturing, production of jeans and transport to warehouse in Sweden for the product system Lean Dean Lost Legend.

Phase of transportation and Transportation destinations From	To	Means of transportation	Distance (km)	Tkm /year*	Tkm /Pair	Reference of value
Cotton Cultivation *Unknown, India*	**Ginning Process** *Unknown, India*	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}|market for| Alloc Def, S	90	101,7 /ha	0,20	**Distance and load:** Textile Exchange (2014). **Dataset:** Ecoinvent 3
Cotton Cultivation *Hyderabad, India*	**Fabric manufacturing: Harbor** *Genoa, Italy*	Transport, freight, sea, transoceanic ship {GLO}|market for| Alloc Def, S	8630	197288,89	7,26	**Location,** Distance and load: Italian Fabric Producer (2018) and Google Maps. **Datasets:** Ecoinvent 3
Fabric manufacturing: Harbor *Genoa, Italy*	**Fabric manufacturing: Facility** *Robecchetto con Induno, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	179	4092,09	0,15	**Location, Distance and Load:** Denim Authority (2018), Italian Fabric Producer (2018) and Google maps **Dataset:** Ecoinvent 3
Warping *Unknown, Italy*	**Dyeing & Sizing** *Unknown, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	3	66,48	0,0024	**Distance and Load:** Italian Fabric Producer, (2018) Denim Authority (2018) **Dataset:** Ecoinvent 3
Fabric manufacturing: Facility *Robecchetto con Induno, Italy*	**Fabric manufacturing: Harbor** *Genoa, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	179	3966,82	0,15	**Location, Distance and Load:** Denim Authority (2018), Italian Fabric Producer (2018) and Google maps **Dataset:** Ecoinvent 3
Fabric manufacturing: Harbor *Genoa, Italy*	**Jeans production: Harbor** *Tunis, Tunisia*	Transport, freight, sea, transoceanic ship {GLO}|market for| Alloc Def, S	896	19856,26	0,73	**Location, Distance and Load:** Denim Authority (2018) and Google maps **Dataset:** Ecoinvent 3
Jeans production: Harbor *Tunis, Tunisia*	**Jeans production: Facility** *Ras Jebel, Tunisia*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	82,4	1826,07	0,067	**Location, Distance and Load:** Denim Authority (2018) and Google maps **Dataset:** Ecoinvent 3
Cutting of jeans *Unknown, Tunisia*	**Sewing of jeans** *Unknown, Tunisia*	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}|market for| Alloc Def, S	250	2172,87	0,20	**Distance and Load:** Denim Authority (2018) **Dataset:** Ecoinvent 3
Jeans production: Facility *Ras Jebel, Tunisia*	**Jeans production: Harbor** *Tunis, Tunisia*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	81,4	624,58	0,059	**Location, Distance and Load:** Denim Authority (2018) and Google maps **Dataset:** Ecoinvent 3
Jeans production: Harbor *Tunis, Tunisia*	**Storage: Harbor** *Genoa, Italy*	Transport, freight, sea, transoceanic ship {GLO}|market for| Alloc Def, S	896	6875,01	0,65	**Location, Distance and Load:** Denim Authority (2018) and Google maps **Dataset:** Ecoinvent 3
Storage: Harbor *Genoa, Italy*	**Storage: Facility** *Borås, Sweden*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	2083,1	15983,62	1,50	**Location, Distance and Load:** Denim Authority (2018) and Google maps **Dataset:** Ecoinvent 3

* Except from the transport happening at farm in cotton cultivation that is provided in the form of tkm per hectare.

Appendix 3: Inventory data – Tilted Tor Dry Royal Embo

Table 14: Inventory data for the materials used in the processes: cotton cultivation, fabric manufacturing and jeans production, for the specifi product system of Tilted Tor Dry Royal Embo. Note that the total yearly value column for the fabric manufacturing and jeans production processe only represent the total yearly value allocated to the specific fabric *Organic Donner Indigofera* and the specific jean *Tilted Tor Dry Royal Embo* thus not the entire production at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Material (In- and outputs)	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Cotton cultivation	Field preparation (Inputs)	Arable land occupation	1 ha	0,0018 ha	Textile Exchange (2014), Bossa and Bobo	Occupation, arable, organic Transformation, from arable, organic Transformation, to arable, organic Carbon Dioxide, in air Energy, gross calorific value, in biomass.
		Ploughing	1 ha	0,0018 ha	Textile Exchange (2014)	Ecoinvent 3: Tillage, ploughing {GLO}| market for | Alloc Def, S
		Cotton seeds	35 kg/ha	0,12 kg	Textile Exchange (2014)	Ecoinvent 3: Cotton seed, for sowing {GLO}| market for | Alloc Def, S
	Cultivation (Inputs)	Manure	11531,95 kg/ha	40,90 kg	Textile Exchange (2014)	Agri-footprint: Manure, from cows, at farm/RER Economic
		Rock phosphate	313,6 kg/ha	1,11 kg	Textile Exchange (2014)	Agri-footprint: Lime fertilizer, at plant/RER Economic
	Waste (Outputs)	Waste	508,93 kg/ha	1,80 kg	Textile Exchange (2014)	Ecoinvent 3: Waste textile, soiled {GLO}| market for | Alloc Def, S
	Products (Outputs)	Seed	2544,64 kg/ha	9,02 kg	Textile Exchange (2014)	Allocated 16 % of the environmental burden
		Cotton Lint	1696,43 kg/ha	6,02 kg	Textile Exchange (2014)	Allocated 84 % of the environmental burden
Fabric manufacturing	Spinning and warping (Inputs)	Organic cotton	5912,85 kg	0,83 kg	Bossa (2018)	Cotton fibers from above made process "Cotton Lint – Turkey"
		Elastane	36,58 kg	0,0051 kg	Bossa (2018)	Ecoinvent 3: Viscose fibre {GLO}| market for | Alloc Def, S
	Dyeing and Sizing (Inputs)	Caustic Sodium Hydroxide	53,58 kg	0,0075 kg	Bossa (2018)	Ecoinvent 3: Sodium Hydroxide, without water, 50% solution state {GLO}|market for| Alloc Def, S
		Naturel Indigo*	397,05 $	0,0016 $	Bossa (2018)	USA Input Output Database: Synthetic dye and pigment manufacturing
		Acetic Acid*	1,29 kg	0,00018 kg	Bossa (2018)	Ecoinvent 3: Acetic Acid, without water, in 98% solution state {GLO}|market for| Alloc Def, S
		Wetting Agent -1, 2 & 3*	0,43 kg	6,03E-05 kg	Bossa (2018)	Ecoinvent 3: EDTA, ethylenediaminetetraacetic acid {GLO}|market for| Alloc Def, S
		Dispersing Agent*	0,20 kg	2,74E-05 kg	Bossa (2018)	Ecoinvent 3: Sodium Sulfide {GLO}|market for| Alloc Def, S
		Sequestering Agent*	0,078 kg	1,10E-05 kg	Bossa (2018)	Ecoinvent 3: Sodium tripolyphosphate {GLO}|market for| Alloc Def, S
		Hydrosulfite*	3,14 kg	0,00044 kg	Bossa (2018)	Ecoinvent 3: Sodium Hydrosulfide {GLO}|market for| Alloc Def, S
		Sizing Agent	3,84 kg	0,00054 kg	Bossa (2018)	Ecoinvent 3: Potato Starch {GLO}|market for| Alloc Def, S
		Softening Agent*	11,76 kg	0,0016 kg	Bossa (2018)	Ecoinvent 3: Ammonium chloride {GLO}|market for| Alloc Def, S
	Waste (Outputs)	Spill Cotton	739,11 kg	0,10 kg	Bossa (2018)	Ecoinvent 3: Textile, soiled {GLO}|market for| Alloc Def, S
		Other waste *Plastics*	205,59 kg	0,029 kg	Bossa (2018) & Idea Mode: Bobo (2018)	Ecoinvent 3: Waste polyethylene/polypropylene product {Europe without Switzerland}| market for waste polyethylene/polypropylene product| Alloc Def, S
	Product (Outputs)	Denim Fabric: Organic Donner Indigofera	5226 kg	0,67 kg	Bossa (2018) & Idea Mode: Bobo (2018)	Allocated 100 % of the environmental burden of the above processes

Life cycle phase	Process	Material (In- and outputs)	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Production of jeans	Cutting and sewing (Inputs)	Denim Fabric Organic Donner Indigofera	3927,19 kg	0,67 kg	Idea Mode: Bobo (2018)	Denim fabric from above made process "Organic Donner Indigofera"
		Zipper Metal, nickel free	27,72 kg	0,009 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Brass, Nickel free {GLO}|market for| Alloc Def, S
		Button Organic copper, nickel free	36,96 kg	0,012 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Copper, nickel free {GLO}|market for| Alloc Def, S
	Finishing (Inputs)	Waist tag Cotton	55,89 kg	0,005 kg	Idea Mode: GG Productions (2018)	Ecoinvent 3: Textile, woven cotton {GLO}| market for | Alloc Def, S
		Booklet Paper	100,60 kg	0,009 kg	Idea Mode: GG Productions (2018)	Ecoinvent 3: Paper, woodcontaining, supercalendred {RoW)| market for | Alloc Def, S
	Packaging (Inputs)	Cardboard	163,65 kg	0,053 kg	Idea Mode: GG Productions (2018)	Ecoinvent: Corrugated board box {GLO}|market for corrugated board box| Alloc Def, S
	Waste (Outputs)	Spill Fabric	2171,59 kg	0,099 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Municipal solid waste {TR}| treatment of, incineration | Alloc Def, S
	Product (Outputs)	Finished product: Tilted Tor Dry Royal Embo	6706,8 kg	0,60	Idea Mode: Bobo & GG Productions (2018)	Allocated 100 % of the environmental burden of the above processes

* The yearly value is calculated based on water allocated for dyeing process divided by four, assuming four main dipping processes.

Table 15: Energy use within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Tilted Tor Dry Royal Embo. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly value allocated to the specific fabric *Organic Donner Indigofera* and the specific jean *Tilted Tor Dry Royal Embo*, thus not the entire energy usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Source of energy	Source of energy	Total yearly value	Value per pair	Reference of value	Modeled with
Cotton cultivation	Irrigation	Electricity	13,25 MJ/ha	0,047 MJ	Textile Exchange (2014), Bossa (2018) & Idea Mode: Bobo (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Harvesting	Diesel	1 ha	0,0035 ha	Textile Exchange (2014), Bossa (2018) & Idea Mode: Bobo (2018)	Ecoinvent 3: Combine harvesting {GLO}| market for| Alloc Def, S
	Ginning	Electricity	966,96 MJ/ha	3,43 MJ	Textile Exchange (2014), Bossa (2018) & Idea Mode: Bobo (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
Fabric manufacturing	Spinning	Electricity	0,014 MWh	3,44E-06 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Warping	Electricity	0,028 MWh	6,91E-06 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Dyeing	Electricity	0,85 MWh	0,00020 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Sizing	Electricity	0,20 MWh	4,80E-05 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Weaving	Electricity	0,0089 MWh	2,17E-06 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
	Other	Electricity	28,0 MWh	0,0068 MWh	Bossa (2018)	Ecoinvent 3: Electricity, low voltage {TR} |market for| Alloc Def, S
		Natural gas	4767,36 m^3	1,16 m^3	Bossa (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
Production of jeans	Cutting & Sewing	Electricity	1272,21 kWh	0,41 kWh	Idea Mode: Bobo (2018)	Ecoinvent 3: Electricity, low voltage {IT} |market for| Alloc Def, S
	Finishing	Electricity	330,89 kWh	0,11 kWh	Idea Mode: GG Productions (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
	Heating	Natural gas	969,51 m^3	0,31 m^3	Idea Mode: Bobo (2018), Idea Mode: GG Productions (2018), Everest (2018) & Italian Fabric Producer (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
		Natural gas	6,23 m^3	0,0020 m^3	Idea Mode: GG Productions (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
Storage at Korallen	Other	Electricity Green	0,90 kWh	0,00029 kWh	Kamgarn (2018)	Ecoinvent 3: Electricity, low voltage {SE}| market for| Alloc Def, S
	Heating	District heating	5,29 kWh	0,0017 kWh	Kamgarn (2018)	Ecoinvent 3: Heat, district or industrial, other than natural gas {GLO}|market group for | Alloc Def, S

Table 16: Water use data within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Tilted Tor Dry Royal Embo. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly values allocated to the specific fabric *Organic Donner Indigofera* and the specific jean *Tilted Tor Dry Royal Embo*, thus not the entire water usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Source of water	Happens with water after use	Total yearly value (L)	Liters /Pair	Reference of values	Modeled with
Cotton Cultivation	Irrigation	Ground water	Leaks out to nearest water body	12500 L/ha	44,33	Textile Exchange (2014)	Ecoinvent 3: Irrigation {GLO}| market for | Alloc Def, S
Fabric Manufacturing	Dyeing	Municipal grid	Municipal wastewater treatment plant	156780	64,38	Bossa (2018)	Ecoinvent 3: Tap water {GLO}| market for | Alloc Def, S
							Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
	Sizing	Municipal grid		4321,90	1,77	Bossa (2018)	Ecoinvent 3: Tap water {GLO}| market for | Alloc Def, S
							Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
	Other	Municipal grid		88842	36,48	Bossa (2018)	Ecoinvent 3: Tap water {GLO}| market for | Alloc Def, S
							Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S

Table 17: Inventory data for the transports between and within the processes: cotton cultivation, fabric manufacturing, production of jeans and transport to warehouse in Sweden for the product system Tilted Tor Dry Royal Embo.

Phase of transportation and Transportation destinations		Means of transportation	Distance (km)	Tkm /year	Tkm /Pair	Reference of value
From	To					
Cotton Cultivation *Unknown, Turkey*	**Ginning Process** *Unknown, Turkey*	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}|market for| Alloc Def, S	30	142,5/ha	0,51	**Distance and load:** Textile Exchange (2014). **Dataset:** Ecoinvent 3
Cotton Cultivation *Akasya, Turkey*	**Fabric manufacturing** *Adana, Turkey*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	800	4730,28	0,66	**Location, Distance and load:** Bossa (2018) and Google Maps. **Datasets:** Ecoinvent 3
Fabric manufacturing *Celal Bayar Caddesi, Turkey*	**Storage** *Unknown, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	3116	16284,22	2,28	**Location, Distance and Load:** Idea Mode: Bobo (2018) and Google maps **Dataset:** Ecoinvent 3
Storage *Unknown, Italy*	**Cutting & Sewing** *Sant' Omero, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	200	250,29	0,040	**Location, Distance and Load:** Idea Mode: Bobo (2018) **Dataset:** Ecoinvent 3
Cutting & Sewing *Sant' Omero, Italy*	**Finishing** *Acqualagana, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	201	371,45	0,033	**Location, Distance and Load:** Idea Mode: Bobo (2018) and Google maps **Dataset:** Ecoinvent 3
Finishing *Acqualagana, Italy*	**Storage: Facility** *Borås, Sweden*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	2287	4226,38	1,37	**Location, Distance and Load:** Idea Mode: GG Productions (2018), Korallen (2018) and Google maps **Dataset:** Ecoinvent 3

Appendix 4: Inventory data – Grim Tim Conjunctions

Table 18: Inventory data for the materials used in the processes: cotton cultivation, fabric manufacturing and jeans production, for the specific product system of Grim Tim Conjunctions. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly value allocated to the specific fabric *RR 7216 Sioux Preshrunk* and the specific jean *Grim Tim Conjunctions*, thus not the entire production at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Material (In- and outputs)	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Cotton cultivation	Field preparation (Inputs)	Arable land occupation	1 ha	0,0019 ha	Textile Exchange (2014)	Occupation, arable, organic Transformation, from arable, organic Transformation, to arable, organic Carbon Dioxide, in air Energy, gross calorific value, in biomass
		Ploughing	1 ha	0,0019 ha	Textile Exchange (2014	Ecoinvent 3: Tillage, ploughing {GLO}| market for | Alloc Def, S
		Cotton seeds	2 kg/ha	0,0037 kg	Textile Exchange (2014)	Ecoinvent 3: Cotton seed, for sowing {GLO}| market for | Alloc Def, S
	Cultivation (Inputs)	Manure	11531,95 kg/ha	21,38 kg	Textile Exchange (2014)	Agri-footprint: Manure, from cows, at farm/RER Economic
		Rock phosphate	313,6 kg/ha	0,58 kg	Textile Exchange (2014)	Agri-footprint: Lime fertilizer, at plant/RER Economic
	Waste (Outputs)	Waste	124,3 kg/ha	0,23 kg	Textile Exchange (2014)	Ecoinvent 3: Biowaste {RoW}| treatment of, composting | Alloc Def, S
	Products (Outputs)	Seed	598,9 kg/ha	1,11 kg	Textile Exchange (2014)	Allocated 16 % of the environmental burden based on economic value
		Cotton Lint	406,8 kg/ha	0,75 kg	Textile Exchange (2014)	Allocated 84 % of the environmental burden based on economic value
Fabric Manufacturing	Spinning and warping	Organic cotton	802568,42 kg	0,75 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Cotton fibers from above made process "Cotton Lint – India"
		Elastane	15560 kg	0,015 kg	Italian Fabric Producer (2018) & Denim Authority (2018)	Ecoinvent 3: Viscose fibre {GLO}| market for | Alloc Def, S
	Dyeing and Sizing	Pre-reduced indigo	5181227,4 $ (51146,67 kg)	4,87 $ (0,048 kg)	Italian Fabric Producer (2018)	USA Input Output Database: Synthetic dye and pigment manufacturing
		Caustic Soda	12786,67 kg	0,012 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Sodium hydroxide, without water, in 50% solution state {GLO}|market for| Alloc Def, S
		Sodium Hydrosulphite	6393,33 kg	0,0060kg	Italian Fabric Producer (2018)	Ecoinvent 3: Sodium hydrosulfide {GLO}|market for| Alloc Def, S
		PVA	10229,33 kg	0,0096 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Potassium permanganate {GLO}|market for| Alloc Def, S
		Potato Starch	25573,33 kg	0,024 kg	Italian Fabric Producer (2018)	Ecoinvent 3: Potato starch {GLO}|market for| Alloc Def, S
	Waste (Outputs)	Spill Cotton fibers	40128,42 kg	0,038 kg	Italian Fabric Producer (2018) & Bobo (2018)	Ecoinvent 3: Waste textile, soiled {GLO}| market for | Alloc Def, S
		Spill Mixed packaging	49247,4 kg	0,046 kg	Italian Fabric Producer (2018) & Bobo (2018)	Ecoinvent 3: Waste packaging paper {GLO}|market for| Alloc Def, S
	Products (Outputs)	Finished fabric: RR 7216 Sioux Preshrunk	778000 kg	0,67 kg	Italian Fabric Producer (2018) & Bobo (2018)	Allocated 100 % of the environmental burden of the above processes

Life cycle phase	Process	Material (In- and outputs)	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Production of jeans	Cutting and sewing (Inputs)	Denim Fabric RR 7216 Sioux Preshrunk	7482,72 kg	0,67 kg	Idea Mode: Bobo (2018)	Denim fabric from above made process "RR 7216 Sioux Preshrunk"
		Zipper Metal, nickel free	100,60 kg	0,009 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Brass, Nickel free {GLO}|market for| Alloc Def, S
		Button Organic copper, nickel free	134,14 kg	0,012 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Copper, nickel free {GLO}|market for| Alloc Def, S
	Laundry (Inputs)	Pumice Stone	6083 kg	0,67 kg	Everest (2018)	Ecoinvent 3: Pumice {GLO}| market for| Alloc Def, S
		Pigment Bruno 2GL	96 $ (0,6 kg)	0,011 $ (6,58E-05 kg)	Everest (2018)	USA Input Output Database: Synthetic dye and pigment manufacturing
		Pigment Arancino 7GL	9,6 $ (0,06kg)	0,0011 $ (6,58E-06 kg)	Everest (2018)	USA Input Output Database: Synthetic dye and pigment manufacturing
		Salt	456 kg	0,050 kg	Everest (2018)	Ecoinvent: Sodium chloride, powder {GLO}| market for | Alloc Def, S
	Finishing (Inputs)	Waist tag Cotton	15,4 kg	0,005 kg	Idea Mode: GG Productions (2018)	Ecoinvent 3: Textile, woven cotton {GLO}| market for | Alloc Def, S
		Booklet Paper	27,72 kg	0,009 kg	Idea Mode: GG Productions (2018)	Ecoinvent 3: Paper, woodfree, uncoated {RER}| market for | Alloc Def, S
	Packaging (Inputs)	Cardboard	593,92 kg	0,053 kg	Idea Mode: GG Productions (2018)	Ecoinvent 3: Corrugated board box {GLO}|market for corrugated board box| Alloc Def, S
	Waste (Outputs)	Spill Fabric	1111,26 kg	0,10 kg	Idea Mode: Bobo (2018)	Ecoinvent 3: Municipal solid waste {RoW}| market for | Alloc Def, S
		Spill Mud made above ally of pumice	1915,2 kg	0,21 kg	Everest (2018)	Ecoinvent 3: Refinery Sludge {Europe without Switzerland} |market for refinery sludge| Alloc Def, S
	Products (Outputs)	Finished jeans Grim Tim Conjunctions	11178 kg	0,60 kg	Idea Mode: GG Productions (2018)	Allocated 100 % of the environmental burden of the above processes

Table 19: Energy use within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Grim Tim Conjunctions. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly value allocated to the specific fabric *RR 7216 Sioux Preshrunk* and the specific jean *Grim Tim Conjunctions*, thus not the entire energy usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Source of energy	Total yearly value	Value per pair	Reference of value	Modeled with/Dataset used
Cotton Cultivation	Irrigation	Electricity	145,22 MJ/ha2	0,27 MJ/pair	Textile Exchange (2014)	Ecoinvent 3: Electricity, low voltage {IN} |market for| Alloc Def, S
	Harvesting	Diesel	1 ha	0,0035 ha	Textile Exchange (2014)	Ecoinvent 3: Combine harvesting {GLO}| market for| Alloc Def, S
	Ginning	Electricity	231,88 MJ/ha	0,43 MJ/pair	Textile Exchange (2014)	Ecoinvent 3: Electricity, low voltage {IN} |market for| Alloc Def, S
Fabric Manufacturing	Dyeing & sizing and finishing	Natural gas	66235,28 m^3	0,062 m^3	Italian Fabric Producer and Idea Mode: Bobo (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
	Heating	Natural gas	459399,03 m^3	0,43 m^3	Italian Fabric Producer and Idea Mode: Bobo (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
	Other processes	Electricity	4445025,2 kWh	4,18 kWh	Italian Fabric Producer and Idea Mode: Bobo (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
		Diesel	1077,87 kg	0,0010 kg	Italian Fabric Producer and Idea Mode: Bobo (2018)	Ecoinvent 3: Diesel {GLO}|market group for| Alloc Def, S
Production of jeans	Cutting & Sewing	Electricity	4617,13 kWh	0,41 kWh	Idea Mode: Bobo (2018)	Ecoinvent 3: Electricity, low voltage {IT} |market for| Alloc Def, S
	Laundry	Electricity	6840 kWh	0,75 kWh	Everest (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
	Finishing	Electricity	330,89 kWh	0,11 kWh	Idea Mode: GG Productions (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
	Heating	Natural gas	137222,29 MJ	12,28 MJ	Idea Mode: Bobo & GG Productions (2018), Everest (2018) and Italian Fabric Producer (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
		Natural gas	174283,2 MJ	19,10 MJ	Everest (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
		Natural Gas	882,08 MJ	0,079 MJ	Idea Mode: GG Productions (2018)	Ecoinvent 3: Heat, central or small-scale, natural gas {GLO}| market group for| Alloc Def, S
	Other	Electricity	1915,2 kWh	0,21 kWh	Everest (2018)	Ecoinvent 3: Electricity, low voltage {IT}| market for | Alloc Def, S
Storage at Korallen	Total	Green electricity	150,95 kWh	0,014 kWh	Kamgarn (2018)	Ecoinvent 3: Electricity, low voltage {SE}| market for| Alloc Def, S
	Heating	District heating	884,71 kWh	0,080 kWh	Kamgarn (2018)	Ecoinvent 3: Heat, for reuse in municipal waste incineration only {SE}| market for | Alloc Def, S

Table 20: Water use data within the processes: cotton cultivation, fabric manufacturing and production of jeans for the specific product system of Grim Tim Conjunctions. Note that the total yearly value column for the fabric manufacturing and jeans production processes only represent the total yearly values allocated to the specific fabric *7216 Sioux Preshrunk* and the specific jean *Grim Tim Conjunctions* thus not the entire water usage at the facilities. In the cotton cultivation process 1 hectare is used as the reference for "total yearly value".

Life cycle phase	Process	Source of water	Happens with water after use	Total yearly value	Value per pair	Reference of values	Modeled with/Dataset used
Cotton Cultivation	Irrigation	Ground water	Leaks out to nearest water body	137000 L/ha	253,95 L	Textile Exchange (2014)	Ecoinvent 3: Irrigation {IN}|market for| Alloc Def, S
Fabric Manufacturing	Total	Ground water	Treated in an on-site treatment facility	55425964,8 L/year	52,08 L	Italian Fabric Producer (2018)	Water, well, in ground, IT Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S
Production of jeans	Laundry	Ground water	On site biochemical wastewater treatment	494760 m3	54,22 m3	Everest (2018)	Water, well, in ground, IT Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S

Table 21: Inventory data for the transports between and within the processes: cotton cultivation, fabric manufacturing, production of jeans and transport to warehouse in Sweden for the product system Grim Tim Conjunctions.

Phase of transportation and Transportation destinations **From**	**To**	**Means of transportation**	**Distance (km)**	**Tkm /year**	**Tkm /Pair**	**Reference of value**
Cotton Cultivation *Unknown, India*	**Ginning Process** Unknown, India	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}|market for| Alloc Def, S	90	101,7/ha	0,19	**Distance and Load:** Textile Exchange (2014). **Dataset:** Ecoinvent 3
Cotton Cultivation *Hyderabad, India*	**Fabric manufacturing: Harbor** *Genoa, Italy*	Transport, freight, sea, transoceanic ship {GLO}|market for| Alloc Def, S	8630	6926165,47	6,51	**Location, Distance and Load:** Italian Fabric Producer (2018) and Google Maps. **Datasets:** Ecoinvent 3
Fabric manufacturing: Harbor *Genoa, Italy*	**Fabric manufacturing: Facility** *Robecchetto con Induno, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	179	143659,75	0,13	**Location, Distance and Load:** Denim Authority (2018), Italian Fabric Producer (2018) and Google maps **Dataset:** Ecoinvent 3
Warping *Unknown, Italy*	**Dyeing & Sizing** *Unknown, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	3	2334	0,0022	**Distance and Load:** Italian Fabric Producer (2018), Denim Authority (2018) **Dataset:** Ecoinvent 3
Fabric manufacturing: Facility *Robecchetto con Induno, Italy*	**Storage** *Unknown, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	575	447350	0,42	**Location, Distance and Load:** Italian Fabric Producer (2018), Idea Mode: Bobo (2018) and Google maps **Dataset:** Ecoinvent 3
Storage *Unknown, Italy*	**Cutting & Sewing** *Sant' Omero, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	200	1341,36	0,033	**Location, Distance and Load:** Italian Fabric Producer (2018), Idea Mode: Bobo (2018) **Dataset:** Ecoinvent 3
Cutting & Sewing *Sant' Omero, Italy*	**Laundry** *Piombino Dese, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	460	2097,7	0,23	**Location, Distance and Load:** Idea Mode: Bobo (2018), Everest (2018) and Google maps **Dataset:** Ecoinvent 3
Laundry *Piombino Dese, Italy*	**Finishing** *Acqualagana, Italy*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	337	1536,72	0,17	**Location, Distance and Load:** Idea Mode: Bobo & GG Productions (2018), Everest (2018) and Google maps **Dataset:** Ecoinvent 3
Finishing *Acqualagana, Italy*	**Storage: Facility** *Borås, Sweden*	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	2287	15338,45	1,37	**Location, Distance and Load:** Idea Mode: GG Productions (2018), Kamgarn (2018) and Google maps **Dataset:** Ecoinvent 3

Appendix 5. Inventory data – Distribution and Use

Table 22: Inventory data for the materials used in the use process for the product systems of Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions. The data is only gathered for one (average) pair of jeans, expressed in relation to the functional unit.

Life cycle phase	Process	Material (In- and outputs)	Value per pair	Reference of value	Modeled with/Dataset used
Use	Residential washing	Washing detergents	240 ml	Authors' assumptions	Ecoinvent 3: Soap {GLO}| market for | Alloc Def, S

Table 23: Inventory data for the energy use within the use process for the product systems of Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunction. The data is only gathered for one (average) pair of jeans, expressed in relation to the functional unit.

Life cycle phase	Process	Source of energy	Value per FU	Reference of value	Modeled with/Dataset used
Use	Residential washing	Electricity	3,68 kWh	The Swedish Energy Agency (2014)	Ecoinvent 3: Electricity, low voltage {SE} |market for| Alloc Def, S

Table 24: Inventory data for the water use within the use process for the product systems of Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunction. The data is only gathered for one (average) pair of jeans, expressed in relation to the functional unit.

Life cycle phase	Process	Source of water	Happens with water after use	Value per FU	Reference of values	Modeled with/Dataset used
Use	Residential laundry	Tap water	Municipality's wastewater treatment facility	280 L	VIA (2018) and Göteborg Energi (n.d.)	Ecoinvent 3: Tap water {GLO}|market for| Alloc Def, S
						Ecoinvent 3: Wastewater, average {Europe without Switzerland}| market for wastewater, average | Alloc Def, S

Table 25: Inventory data for the transports within the processes: distribution and use for the product systems of Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions. The data is only gathered for one (average) pair of jeans, expressed in relation to the functional unit.

Phase of transportation and Transportation destinations From	 To	Means of transportation	Distance (km)	tkm/Pair	Reference of value
Storage Facility *Borås, Sweden*	**Store** 80 cities, Sweden	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}|market for| Alloc Def, S	253,5	0,16	**Distance, Location and Load:** Nudie Jeans **Dataset:** Ecoinvent 3
Store *Gothenburg, Sweden*	**Home** *Gothenburg, Sweden*	Transport, passenger car {RER}| market for | Alloc Def, S	3,83	Not included as tkm – included as km	**Distance and Load:** City of Gothenburg (2017), Granello et al. (2015) **Dataset:** Ecoinvent 3
		Transport, regular bus {GLO}| market for | Alloc Def, S	2,38	Not included as tkm – included as person km	**Distance and Load:** Gothenburg City (2017), Granello et al. (2015) **Dataset:** Ecoinvent 3

Table 26: Inventory data for the incineration process included in the end-of-life phase of the three styles of jeans, Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions.

Process	Amount	Unit	Modeled with/Dataset used
Incineration of cotton textile	1	kg	EU-27: Waste incineration of textile fraction in municipal solid waste (MSW)
Transportation of waste to incineration	0.03	tkm	Ecoinvent 3: Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}| market for | Alloc Def, S
Heat credit	- 5,29	MJ	Ecoinvent 3: Heat, central or small-scale, other than natural gas {SE}| heat and power co-generation, biogas, gas engine| Alloc Def, S
Electricity credit	- 1,78	MJ	Ecoinvent 3: Electricity, low voltage {SE}| market for | Alloc Def, S

Table 27: Inventory data for the recycling process included in the waste management sensitivity analysis scenario of the three styles of jeans, Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions.

Process	Amount	Unit	Modeled with/Dataset used
Recycling of cotton textile	1	kg	"Recycling of textiles"
Transportation of textile to recycling facility in Germany	0,854	tkm	Ecoinvent 3: Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {GLO}| market for | Alloc Def, S
Generation of municipal solid waste	0,1	kg	Ecoinvent 3: Municipal solid waste {RoW}| market for | Alloc Def, S
Production of rock wool	- 0,72	kg	ELCD: Rock wool, fleece, production mix, at plant, density between 30 to 180 kg/m3 RER S
Heat credit	- 2,5	MJ	Ecoinvent 3: Heat, central or small-scale, other than natural gas {SE}| heat and power co-generation, biogas, gas engine| Alloc Def, S

Table 28: Inventory data for the second-had selling process included in the waste management sensitivity analysis scenario of the three styles of jeans, Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions.

Process	Amount	Unit	Modeled with/Dataset used
Second-hand selling of jeans (Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions)	1	kg	"Second-hand "
Transportation of jeans from household to store by car	3,825	km	Ecoinvent 3: Transport, passenger car, EURO3 {RER}| market for | Alloc Def, S
Transportation of jeans from household to store by bus	2,38	personkm	Ecoinvent 3: Transport, regular bus {GLO}| market for | Alloc Def, S
Avoided production of each style of jean (Lean Dean Lost Legend, Tilted Tor Dry Royal Embo and Grim Tim Conjunctions) respectively	1	kg	Ecoinvent 3: Municipal solid waste {RoW}| market for | Alloc Def, S

Appendix 6. Results

Lean Dean Lost Legend

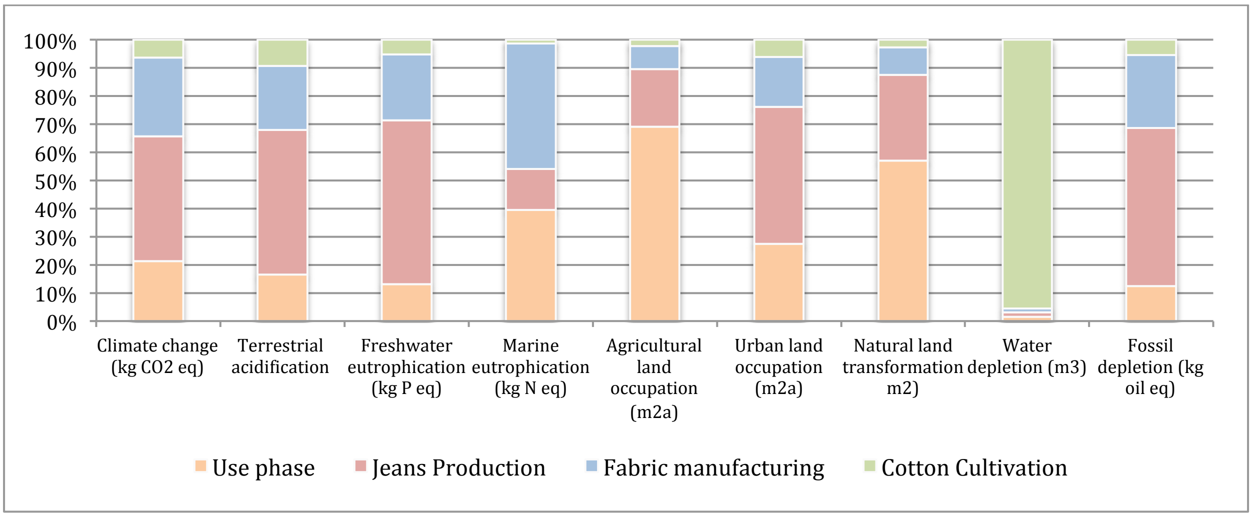

Figure 39: Characterized results of all impact categories for one pair (0.72 kg) of Lean Dean Lost Legend showing the contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration).

Table 29: Specific results for the product system Lean Dean Lost Legend, within all impact categories, presented in unit per FU.

	Cotton Cultivation	Fabric Manufacturing	Jeans Production	Use Phase	Total
Climate change (kg CO_2-eq)	1,16	4,53	7,41	3,53	16,63
	7,0	27,2	44,6	21,2	100 %
Terrestrial acidification (kg SO_2-eq)	0,009	0,017	0,042	0,013	0,080
	9,3 %	22,7 %	51,5 %	16,4 %	100 %
Freshwater eutrophication (Kg P-eq)	0,00037	0,0016	0,0041	0,00092	0,0070
	5,3 %	23,4 %	58,2 %	13,1 %	100 %
Marine eutrophication (Kg N-eq)	0,00042	0,014	0,0045	0,012	0,031
	1,4 %	44,6 %	14,5 %	39,6 %	100 %
Agricultural and occupation (m^2a)	0,060	0,21	0,53	1,80	2,61
	2,3 %	8,2 %	20,5 %	69,0 %	100 %
Urban land occupation (m^2a)	0,016	0,041	0,12	0,067	0,24
	6,6 %	17,1 %	48,8 %	27,6 %	100 %
Natural land transformation (m^2)	0,00026	0,00081	0,0026	0,0049	0,0086
	3,1 %	9,4 %	30,5 %	57,1 %	100 %
Water depletion (m^3)	7,29	0,11	0,11	0,12	7,63
	95,5 %	1,4 %	1,5 %	1,6 %	100 %
Fossil depletion (Kg oil-eq)	0,33	1,40	3,14	0,69	5,55
	6,0 %	25,2 %	56,5 %	12,3 %	100 %

Tilted Tor Dry Royal Embo

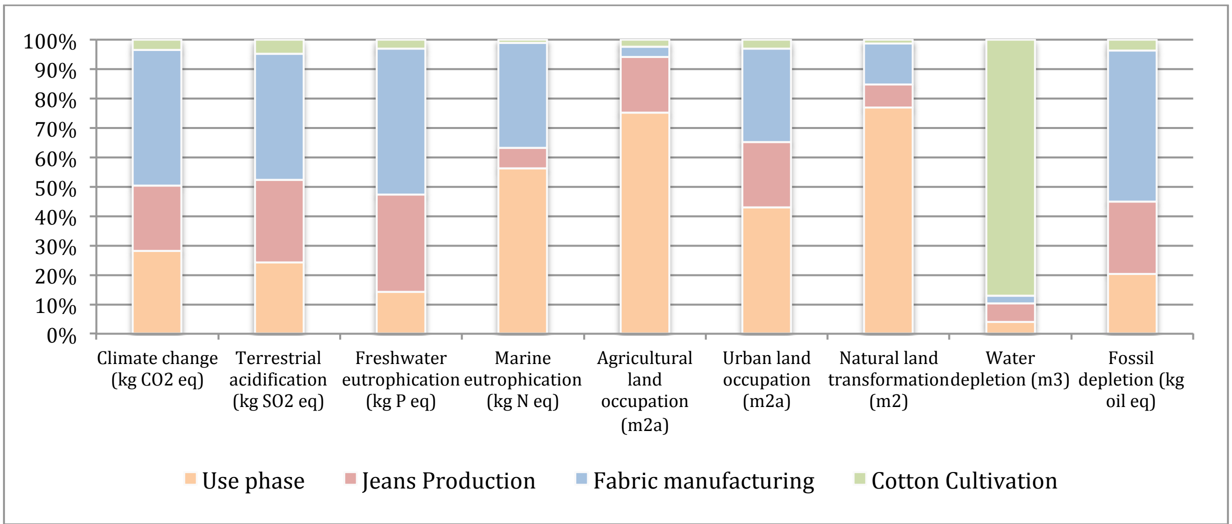

Figure 40: Characterized results of all impact categories for one pair (0.63 kg) of Tilted Tor Dry Royal Embo showing the contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration).

Table 30: Specific results for the product system Tilted Tor Dry Royal Embo, within all impact categories, presented in unit per FU.

	Cotton Cultivation	Fabric manufacturing	Jeans Production	Use	Total
Climate change (kg CO_2-eq)	0,51	5,70	2,75	3,53	12,47
	4,1 %	45,5 %	22,0 %	28,3 %	100 %
Terrestrial acidification (kg SO_2-eq)	0,0030	0,023	0,015	0,013	0,054
	5,6 %	41,9 %	28,1 %	24,3 %	100 %
Freshwater eutrophication (Kg P-eq)	0,00021	0,0032	0,0022	0,00092	0,0065
	3,2 %	49,4 %	33,2 %	14,2 %	100 %
Marine eutrophication (Kg N-eq)	0,00023	0,0077	0,0016	0,012	0,022
	1,1 %	35,6 %	7,2 %	56,2 %	100 %
Agricultural land occupation (m2a)	0,057	0,083	0,45	1,80	2,39
	2,4 %	3,5 %	18,9 %	75,2 %	100 %
Urban land occupation (m2a)	0,0093	0,044	0,034	0,069	0,15
	6,0 %	28,3 %	22,3 %	43,3 %	100 %
Natural land transformation (m^2)	0,00012	0,00084	0,00050	0,0049	0,0064
	1,9 %	13,3 %	7,9 %	77,0 %	100 %
Water depletion (m^3)	2,59	0,076	0,19	0,12	2,97
	87,1 %	2,6 %	6,3 %	4,1 %	100 %
Fossil depletion (Kg oil-eq)	0,15	1,69	0,83	0,69	3,35
	4,5 %	50,4 %	24,6 %	20,4 %	100 %

Grim Tim Conjunctions

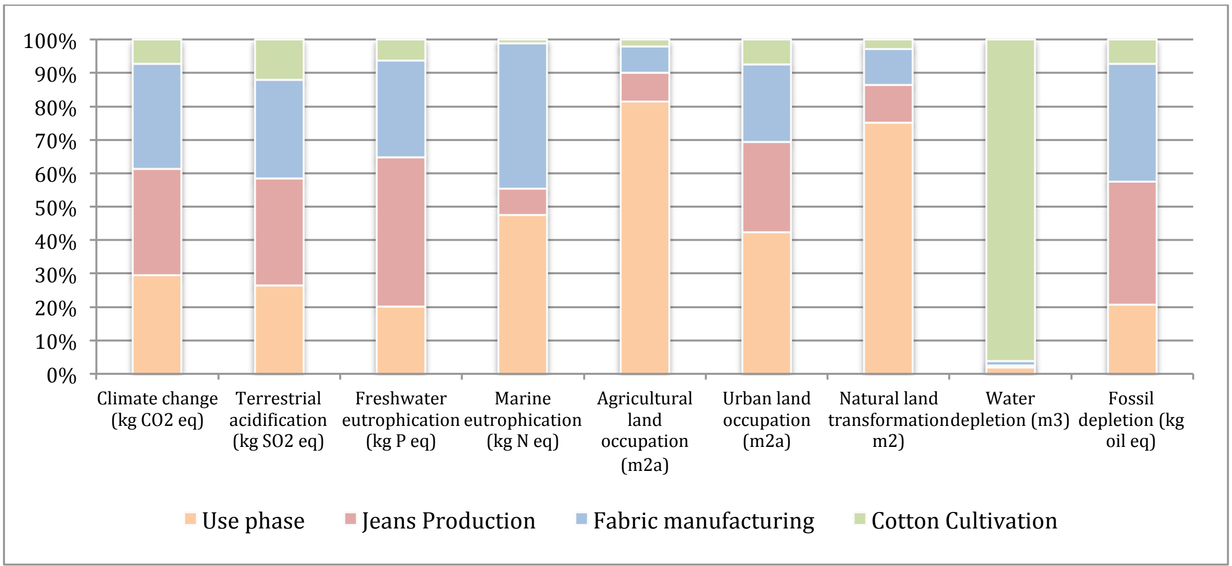

Figure 41: Characterized results of all impact categories for one pair (0.6 kg) of Grim Tim Conjunctions showing the contribution of the four life cycle phases: cotton cultivation, fabric manufacturing, jeans production and use (including incineration).

Table 31: Specific results for the product system Grim Tim Conjunctions, within all impact categories, presented in unit per FU.

	Cotton Cultivation	Fabric manufacturing	Jeans Production	Use	Total
Climate change (kg CO_2-eq)	0,94	3,69	3,80	3,53	11,96
	7,8 %	30,9 %	31,8 %	29,5 %	100 %
Terrestrial acidification (kg SO_2-eq)	0,0073	0,014	0,016	013	0,050
	14,4 %	26,9 %	32,0 %	26,6 %	100 %
Freshwater eutrophication (Kg P-eq)	0,00030	0,0013	0,0020	0,00094	0,0046
	6,5 %	28,8 %	44,5 %	20,2 %	100 %
Marine eutrophication (Kg N-eq)	0,00034	0,011	0,0020	0,012	0,026
	1,3 %	43,3 %	7,7 %	47,6 %	100 %
Agricultural land occupation (m2a)	0,049	0,17	0,19	1,81	2,22
	2,2 %	7,8 %	8,5 %	81,5 %	100 %
Urban land occupation (m2a)	0,013	0,035	0,043	0,067	0,16
	8,2 %	22,3 %	27,2 %	42,3 %	100 %
Natural land transformation (m^2)	0,00021	0,00066	0,00074	0,0049	0,0065
	3,3 %	10,2 %	11,3 %	75,2 %	100 %
Water depletion (m^3)	5,90	0,067	0,028	0,12	6,13
	96,2 %	1,4 %	0,5 %	2,0 %	100 %
Fossil depletion (Kg oil-eq)	0,27	1,14	1,22	0,69	3,32
	8,1 %	34,4 %	36,7 %	20,8 %	100 %

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