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Assessment of the Drivers to Biodiversity Loss in Textile Fibre Production

A Case Study of Nudie Jeans' Supply Chain

Master's thesis in Industrial Ecology

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ABSTRACT

It is well known that textile fibre production has large impacts on the environment. However, the impact on biodiversity from this production remains largely understudied. With biodiversity being lost at alarming rates, it is becoming increasingly important to understand the negative impacts on biodiversity from human activities and how they can be reduced.

In this thesis, the impact on biodiversity from textile fibre production was analysed by using the clothing company Nudie Jeans' supply chain as a case study. Four different fibre production systems were analysed and compared: Turkish organic cotton, Indian organic cotton, conventional cotton and lyocell. The contribution to the five direct drivers of biodiversity loss as identified by IPBES – habitat change, pollution, climate change, overexploitation, and invasive species – were assessed. The contribution to these five drivers were used as indicators for the impact on biodiversity.

A model for assessing the impact on biodiversity was created, using the DPSIR framework. Within the framework, life cycle assessment (LCA), interviews and literature searches were used. The LCA was used to assess the contribution to the drivers climate change, land use and pollution. Invasive species was assessed qualitatively through literature. Overexploitation was found not to be relevant for the studied systems and was therefore excluded.

The results showed that production of conventional cotton had significantly larger contribution to climate change and pollution compared to the other fibres, which could indicate that it also has the largest impact on biodiversity. For the remaining fibres no clear indication of which fibre could have the largest impact on biodiversity was found.

The results suggest that actions to reduce impact on biodiversity loss primarily should be focused on land use, pollution and climate change. However, to establish more precise actions, more research is needed to determine how regional sensitivities affect the contribution to the drivers and the impact on biodiversity, as well as on how the drivers can be weighted.

Keywords: Biodiversity, drivers to biodiversity loss, textile fibres, cotton, lyocell, DPSIR, LCA

Contents

1 INTRODUCTION 1

1.1 Biodiversity definition 2

1.2 Nudie Jeans 2

1.3 Context 3

1.4 Aim 4

1.5 Research questions 4

1.6 Limitations 4

2 METHOD 5

2.1 Report structure 6

2.2 Literature search 7

2.3 Interviews 8

2.3.1 Interviewees 9

2.4 Life cycle assessment 10

2.4.1 Goal and scope 11

2.4.2 Life cycle inventory 15

3 DESCRIPTION OF FIBRE PRODUCTION SYSTEMS 21

3.1 Cotton 21

3.1.1 Turkish organic cotton (TOC) 22

3.1.2 Indian organic cotton (IOC 24

3.2 Tencel 25

4 PRESSURE AND STATE 27

4.1 Life cycle assessment 27

4.1.1 Life cycle impact assessment 27

4.1.2 Interpretation of LCIA 34

4.2 Qualitative assessment 36

4.2.1 Invasive species 36

5 IMPACT 38

6 RESPONSE 40

6.1 Response to driving forces (DF) 40

6.2 Response to pressure and state 40

6.3 Response to impact 42

7 DISCUSSION OF METHODOLOGY AND FUTURE RESEARCH 43
7.1 Discussion of DPSIR framework 43
7.2 Discussion of LCA methodology 44
7.3 Discussion of interview methodology 45
7.4 Future research 45

8 CONCLUSION 47

REFERENCES 48

APPENDIX A

APPENDIX B

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List of abbreviations

CC	Conventional cotton
DF	Driving force
DPSIR	Driving force-Pressure-State-Impact-Response
Eq.	Equivalents
f.u.	Functional unit
GM	Genetically modified
IOC	Indian organic cotton
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NJ	Nudie Jeans
RQ	Research question
TOC	Turkish organic cotton

1 Introduction

It is widely known that the production of textile fibres has large environmental impacts (Resta & Dotti, 2015; Sandin et al., 2019), but lesser known is the impact on biodiversity. A recent systematic literature review of how textile and apparel supply chains contribute to the United Nation's 17 Sustainable Development Goals (SDG), showed that the two SDG relating to biodiversity, "life on land" and "life below water", were almost completely ignored (Cai & Choi, 2020). The reason for not including impacts on biodiversity in environmental assessments is not that the aspect is considered less important, but rather that assessments of biodiversity are very complex. Since ecosystems and biodiversity differ substantially across regions and are interdependent on many different factors (Lammerant, 2019), it is difficult to create a standardised model that can make a general assessment on the impact on biodiversity.

There are many reasons why biodiversity assessments are important. Biodiversity is an essential aspect of functioning ecosystems. Ecosystems, and the services they provide, are in turn fundamental for human survival and well-being. Besides holding a lot of cultural values, the contributions from ecosystems help securing food and clean water, as well as producing medicines, materials and energy for people (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2019). Due to a wide range of factors, directly or indirectly linked to human activities, biodiversity is eroding at an alarming rate (IPBES, 2019; Khera & Kumar, 2010). This rate of change is unprecedented in human history and has, among other things, led to a quarter of all plant and animal species groups being threatened. Unless the drivers of biodiversity loss are addressed, the rate of species extinction is only predicted to accelerate, which would have devastating effects on ecosystems and human welfare (IPBES, 2019).

The most important and direct drivers to biodiversity loss have been identified. According to the Millennium Ecosystem Assessment (MEA, 2005) and IPBES (2019), these five direct drivers of biodiversity loss are:

- Habitat/land use change
- Pollution
- Climate change
- Invasive species
- Over exploitation

Habitat change is generally seen as the most important driver of biodiversity loss (MEA, 2005; Mittermeier et al., 2011) on land. For biodiversity loss of birds, insects and insectivorous mammals, intensive agriculture is believed to be the main activity, and pollution from the use of pesticides the primary driver causing this loss (Sánchez-Bayo & Wyckhuys, 2019). A crop that is commonly associated with large uses of pesticides is cotton. Despite "only" being cultivated on 2.4% of global arable land, cotton farming consumed 11% of the total pesticide amount the year 2000 (Kooistra et al., 2006).

Beside toxic pollution from pesticide use, cultivation of cotton is associated with a range of other environmental issues, including significant water and land use as well as eutrophication (Bevilacqua et al., 2014; Sandin et al., 2019). Organic cotton and other cellulosic fibres, such as lyocell, are sometimes presented as more sustainable alternatives to conventional cotton. Lyocell is a man-made fibre produced from wood pulp, perhaps most commonly known under the brand name Tencel. A study by Shen et al. (2010) comparing environmental impacts of different textile fibres showed that conventional cotton was the least preferred alternative due to high toxicity potential, eutrophication, water and land use. Lyocell was among the fibres with the lowest environmental impact in the study, suggesting that it is a more sustainable option over cotton. Organic cotton was however not included in the study.

Organic cotton is cultivated without the use of genetically modified seeds, synthetic pesticides and mineral fertilizers (Textile Exchange, 2014). These factors give reason to think that organic cotton would be preferred over conventional cotton in terms of pollution. However, these factors also generally make the yields for organic cotton lower, which may lead to more land-related pressures over time (Sandin et al., 2019). To determine the actual environmental performance of textile fibres one needs to make a holistic assessment considering a wide range of factors related to biodiversity that are often overlooked.

1.1 Biodiversity definition

Biodiversity, a contracted form of biological diversity, can be defined in several ways. When using the term “biodiversity” in this thesis, the definition made by the Secretariat of the Convention on Biological Diversity (CBD) is referred to, unless otherwise specified. The CBD (2005) defines biodiversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”.

1.2 Nudie Jeans

Loss of biodiversity is not only an environmental issue, but also a business issue. All businesses depend, and have an impact, on biodiversity and ecosystem services in some way. There is an increased recognition among businesses that this dependency and impact on biodiversity is a risk that needs to be accounted for, if only to guarantee that their impacts do not negatively affect their own business operations (International Union for Conservation of Nature, n.d.). The textile industry is no exception to this. For example, the non-profit membership organization Textile Exchange recently launched a tool for textile companies to understand their dependencies and impacts on biodiversity (Textile Exchange, n.d.).

Nudie Jeans (NJ) is a Swedish clothing company aiming to include biodiversity aspects into their sustainability. The brand’s main focus is jeans, meaning that cotton is the main raw material they use. However, other materials, such as Tencel, are used as well. Aiming to be a sustainable brand, NJ currently only uses organic or recycled cotton for their cotton products. The manufacturing of their materials and products have impacts throughout the supply chain, but according to NJ, the main environmental impacts of their products occur in the raw material production (Nudie Jeans, n.d.). Previous theses have analysed the environmental impact of NJ's jeans production through life cycle assessment (LCA). These LCAs included some aspects relevant to biodiversity loss, like climate change and land use (Saric & Nellström, 2019; Åslund Hedman, 2018), but no assessments were made on the impact on biodiversity at the endpoint level. Within these previous LCAs, comparisons between different fibres and regions of fibre production were not made either, leading to a knowledge gap not only in the biodiversity impacts of NJ's organic cotton, but also in the environmental performance of different fibres and suppliers.

The two main countries NJ source organic cotton from are Turkey and India (Nudie Jeans, 2020). Tencel is produced by a company called Lenzing, with a large production site in Austria. As shown in figure 1.1, the three abovementioned fibres production systems are analysed in this study, as well as conventional cotton. The conventional cotton is included as a reference fibre. Since it is not part of the supply chain, generic data and information from Indian conventional cotton production is used. More detailed information on the cotton and Tencel production systems is presented in chapter 3.

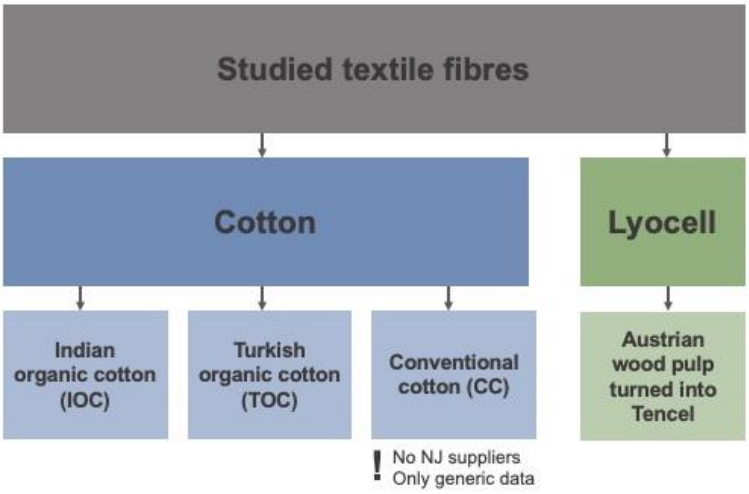

Figure 1.1 Textile fibres studied within the scope of this thesis.

1.3 Context

This thesis is made in collaboration with NJ and is part of a twin thesis project on NJ and biodiversity. Both studies explore, with the help of indicators, how biodiversity is affected in the NJ supply chain, but with different points of departure. This thesis has a narrower scope, analysing the biodiversity impacts from specific processes in the NJ supply chain by using indicators in an already existing framework. The partnering thesis, written by Nhu Anh Phan, has a broader approach in which she develops a framework of indicators that NJ can use in their future work with biodiversity assessments. From the two theses, the objective is to provide NJ with information on how their raw material processes affect biodiversity today as well as on how they can develop assessments of biodiversity in their supply chain in future work.

1.4 Aim

The aim of this thesis is to bring light on how textile fibre production affects biodiversity, mainly by analysing the contributions to the direct drivers of biodiversity loss. This will be done through a case study of the organic cotton NJ use in their products, with Tencel and conventional cotton as reference fibres. From the analysis of the impacts, recommendations for reducing the impact on biodiversity will be provided.

1.5 Research questions

To concretize the aim the following three research questions (RQ) were formulated:

RQ1: How does production of Indian organic cotton, Turkish organic cotton, Tencel and conventional cotton differ in terms of their contribution to the drivers of biodiversity loss?

RQ2: What are the potential impacts on biodiversity from the production of Indian organic cotton, Turkish organic cotton, Tencel and conventional cotton?

RQ3: What actions could be taken to reduce biodiversity loss in the production of Indian organic cotton, Turkish organic cotton, Tencel and conventional cotton?

1.6 Limitations

Effects on biodiversity can be seen throughout the textile supply chain, but in this project only the fibre production stage is included in the assessment. Since the materials are not evaluated throughout their entire lifecycles, no conclusions are drawn on the sustainability of the materials as a whole. Only four different fibres are evaluated, namely Indian organic cotton, Turkish organic cotton, Tencel and conventional cotton. The Tencel is assumed to be produced in Austria where a large production site is located (Lenzing Group, n.d.) and the conventional cotton is assumed to be of Indian origin since data is found from there

It is important to note that even though the two types of fibre studied here have similar qualities and uses, they are not completely exchangeable. Cotton can in some cases be replaced by Tencel, and vice versa, but not always. In this study no further consideration is taken to the different properties and uses of the fibres, but the reader should keep in mind that the two are not comparable in all end uses.

This thesis is based on a case study of NJ's supply chain, and the information from fibre producers is therefore limited to NJ suppliers. The aim is to make the findings relevant for different stakeholders interested in the biodiversity impacts of textile fibre production, but the scope will be limited to the NJ supply chain.

Further limitations related to the methodologies used is presented in chapter 2 below.

2 Method

Assessing impacts on biodiversity is complex. A combination of quantitative and qualitative methodology was chosen to compare the biodiversity impact of fibre production, thereby enabling analyses of variables that are not easily quantified.

When organizing and assessing complex environmental issues, like those relating to ecosystems, indicator frameworks are useful. DPSIR is one such indicator framework, which allows the user to model the issue in a context to see how different aspects interact with each other in the studied system (Bradley & Yee, 2015). In the DPSIR framework, the indicators are structured in a causal chain, starting with the driving forces, which are social and economic developments causing pressure on the environment. These pressures lead to changes in the state of the environment, which in turn generate impacts on humans and/or ecosystems. From these impacts, responses to improve the issue from the point of the driving force, pressure, state or impact might be taken (Niemeijer & de Groot, 2008). This chain is illustrated in figure 2.1 below.

This DPSIR framework was used to structure the issue of biodiversity loss, by using the drivers to biodiversity loss as indicators for the impact on biodiversity. In this thesis, the driving force to biodiversity loss is the fibre production, and more specifically agriculture and forestry, caused by social and economic motivational factors. This driving force could be considered the indirect driver of biodiversity loss. To avoid confusion about the driving forces in the DPSIR framework and the drivers to biodiversity loss, the driving forces in the DPSIR framework are from now on referred to as the DF. On the other hand, the term “driver” refers to the direct drivers to biodiversity loss (habitat change, pollution, climate change, overexploitation and invasive species), unless otherwise stated.

From the point of view of NJ’s production, the framework can be read as the fibre production (the DF) causing pressures on the environment from the release of polluting emissions, use of land and resources, and potential introduction of invasive species. These pressures can lead to changes in the state of the environment. The drivers to biodiversity loss (habitat change, climate change, pollution, invasive species and overexploitation) can be interpreted as different states of the environment in the framework. The contributions to these drivers/states in the fibre production systems are used as indicators for the impact on biodiversity. From the impact on biodiversity, responses to lower the impact departing from the driving forces, pressures, states and impacts are determined.

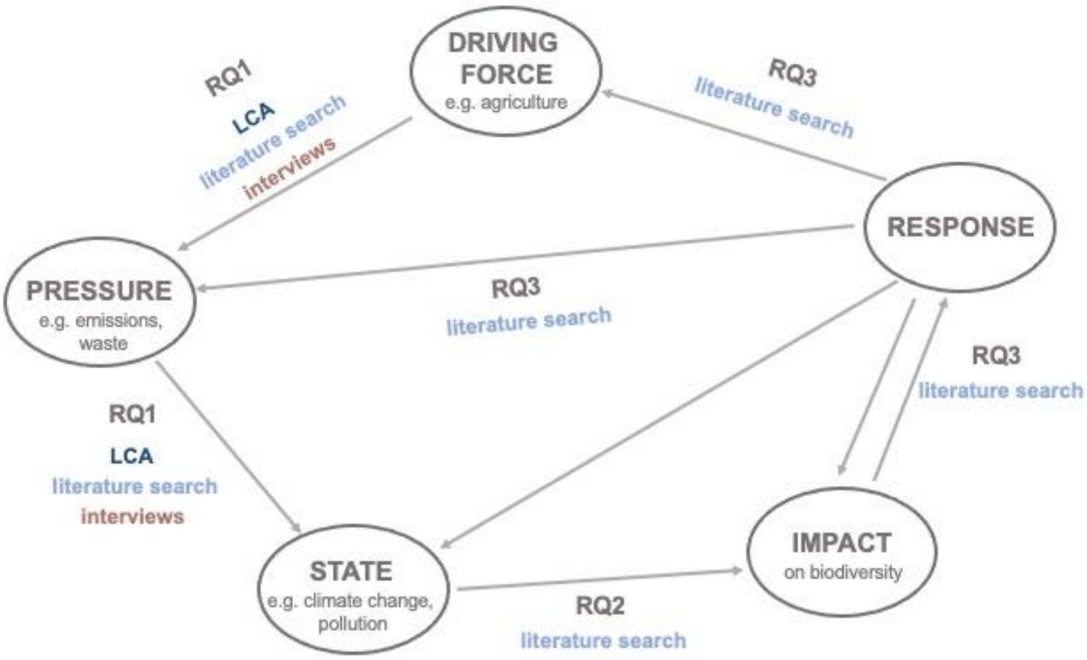

Figure 2.1 DPSIR framework for the thesis. The text beside the arrows state what research question is addressed and the method used to identify the coming step. The work started by identifying the pressures and ended by identifying the responses.

The focus of the report is identifying the contribution of fibre production to the pressures and states, which corresponds to RQ1. The objective of the thesis is further to assess the impacts caused by NJ's fibre production, and establish appropriate responses to minimize these. As shown in figure 2.1, the methods used for determining the pressures, states, impacts and responses were interviews, literature and life cycle assessment (LCA). These are described in more detail in section 2.2, 2.3 and 2.4 respectively.

The contribution to the direct drivers of biodiversity loss (pressure and state) are, as previously mentioned, the focus of this report. However, the focus on the drivers was not distributed equally, since some drivers proved to be more important than others. Overexploitation was in fact omitted from the results altogether, since contributions to that driver were not relevant for the studied systems. IPBES (n.d.-b) defines overexploitation as "harvesting species from the wild at rates faster than natural populations can recover", which "includes overfishing, and overgrazing". According to this definition, the fibre production systems studied in this thesis do not directly contribute to overexploitation since harvesting material from the wild is not part of either system.

2.1 Report structure

Figure 2.2 below shows the report structure of this thesis. To facilitate the reading of the report, the result and analysis section has been divided into four chapters (chapter

3-6). The results and analysis part start with a description of the case study, i.e., descriptions of the four different fibre production systems (see figure 1.1). Following these descriptions, the contributions to the drivers of biodiversity loss are identified, qualitatively and quantitatively. This part of the result and analysis represent the pressure and state in the framework (see figure 2.1). The contributions to all drivers are then assessed together to determine the impact on biodiversity loss in chapter 5. The final part of the result and analysis, and the DPSIR framework, is the assessment of appropriate responses in chapter 6. In the discussion, chapter 7, the DPSIR framework and methods used are evaluated.

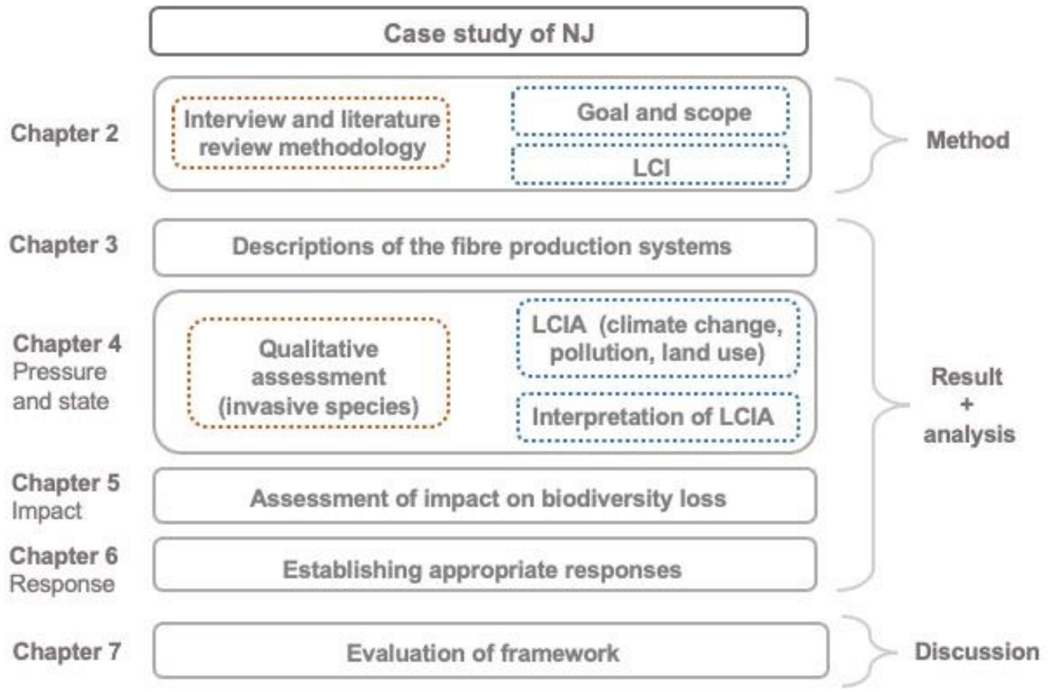

Figure 2.2 Overview of the report structure, showing the division of the strictly quantitative (blue dotted boxes) assessments and qualitative assessments (orange dotted boxes).

LCA consists of four defined phases: goal and scope (1), Life Cycle Inventory (LCI) (2), Life Cycle Impact Assessment (LCIA) (3) and interpretation (4). These are further described in section 2.4 below. To follow the structure of this report, the four LCA phases have been divided between the method and result. The division of the LCA phases is shown in figure 2.2, where the blue dotted boxes represent the LCA activities. The goal and scope and LCI are presented in the method, i.e. in chapter 2. The LCIA and the interpretation of LCIA are presented in the result (chapter 4).

2.2 Literature search

Literature was an important source of information throughout the study and was used for answering all the research questions. Literature was used for gathering information on the fibre production systems and their impacts on biodiversity, preparing for interviews, valuing answers from interviews, collecting data that was missing from the interviews, and comparing LCA results.

The literature search was exploratory and different approaches were taken to find valuable literature and information. These approaches included searches in databases, snowballing through references in relevant articles, internet searches for relevant reports, as well as suggestions from student colleagues and supervisors. This literature search generated valuable information from scientific articles, books, reports from organizations and governmental institutions, companies' sustainability reports and websites. The literature search for scientific articles was made in databases such as Scopus, Springer Link and Web of Science. Since the scope of the study was broad, many different search words were used. Examples of search words used in different versions, separately or in combination, are: "biodiversity", "drivers of biodiversity loss", "cotton", "conventional cotton", "organic cotton", "lyocell", "Tencel", "invasive species", "biological control", "tilling", "biodiversity hotspots", "LCA", "toxicity assessment", "DPSIR", "inventory data calculation".

An important source of information that continuously is referred to throughout this report is an LCA conducted by Textile Exchange in 2014. The LCA analyses the environmental impact from organic cotton production from different regions of production, including India and Turkey. Although the LCA does not include impacts on biodiversity, it provided reliable data for the organic cotton production which was used to complement and compare the data for the organic cotton production systems analysed in this thesis.

2.3 Interviews

To gather information and data on the fibre production, interviews were held with fibre suppliers. These interviews were mainly conducted to gather information to answer RQ1.

Before the interviews, questions were formulated and discussed together with supervisors. When demanded by the interviewees, questions were sent beforehand. Most questions aimed to gather specific data and were therefore formulated to yield objective data rather than subjective answers. Thus, most questions were close-ended. However, some questions aimed to gather descriptive data, on for example what the agricultural landscape looked like, and were therefore open-ended. For a list of the initial interview questions (i.e. not including follow up questions), see appendix A. When questions were not answered extensively follow-up questions were asked. Overall, the interview methodology was a combination of structured and semi-structured, leaning more towards structured.

Following the interviews, the results were analysed based on research questions. Only relevant information to answer the research questions was included in the thesis. Where the information given was unclear it was complemented by literature and/or by information provided by NJ environmental manager Eliina Brinkberg. When possible, the credibility of the information was analysed by comparing with data from literature.

All interviews were conducted as video call, using software such as Zoom and Teams. The interviews with the organic cotton suppliers were held together with Nhu Anh Phan who is writing the partnering thesis (see section 1.3). Although most of the information from the interviews used for this report was gathered from the interview questions found in appendix B, some of the information came from Phan's questions during the interviews. For more information on Phan's interview questions, see Phan (2021).

2.3.1 Interviewees

The suppliers were interviewed to get an overview of what the fibre production looked like, in terms of the agricultural landscape and management of the crops, but also for collecting input/output data of the systems for the LCA. The following suppliers and people working there were interviewed:

- Agrona, NJ's Turkish supplier of organic cotton. The person interviewed from Agrona was Onur Uçak, sales and marketing manager.

- Chetna Organic, NJ's Indian supplier of organic cotton. The persons interviewed from Chetna Organic were Srikar Yenuka, associate director, and Ashok Kumar, agronomist.

- Lenzing, NJ's supplier of Tencel. The persons interviewed were Dr. K. Christian Schuster, sustainability expert, and Jutta Schörghuber, business development manager.

All interviewees have approved the use of their names and positions for this thesis.

Even though all three companies interviewed are producers of textile fibre, their role in the supply chain and their relationship with the farmers/foresters producing raw material differ noticeably. The business structure and size of the companies vary as well. Chetna Organic is a cooperation, working directly, and closely, together with the farmers cultivating cotton sold through them. Agrona's relationship to their farmers is also direct. Lenzing on the other hand is a large corporation, producing different types of fibres from wood pulp. The actual raw material, wood, is not produced by Lenzing themselves, which means they have less insight into the actual raw material production (forestry) compared to Chetna and Agrona who work directly with the raw material production.

These factors affected the interview questions asked and answers given. For the interview questions with Chetna Organic and Agrona, more specific questions regarding the cultivation of the cotton were asked, which they to a large extent were able to answer as well. The questions for Lenzing were of a more general character since the interviewees were not able to answer any specific data questions due to confidentiality restrictions. The interview with Lenzing was therefore more of a discussion around forestry in Austria and clarification questions from statements made in their sustainability reports.

2.4 Life cycle assessment

LCA is a useful tool for assessing a product's potential impacts on the environment. Like the name suggests, an LCA studies a product throughout its life cycle – from the raw material to the disposal. Throughout the lifecycle, inputs and outputs are modelled and the impacts relating to them are quantified. This allows for a holistic assessment of the studied system and for a structured way of comparing environmental impacts of different products (Baumann & Tillman, 2004).

The LCA structure consists of four main phases, as illustrated in figure 2.3. The first phase is the goal and scope definition, where the fundamental methodological choices for the LCA are defined, including the functional unit (f.u.) that the environmental impacts are related to. The following step is the LCI, where the input/output data of the studied systems in relation to the f.u. are outlined. The third phase is the LCIA, where the LCI data is calculated to show the impacts on different environmental aspects. In the final interpretation phase the LCI and/or LCIA results are evaluated in relation to the goal and scope (Swedish Standards Institute, 2006). For more information on LCA methodology, see for example Baumann and Tillman (2004).

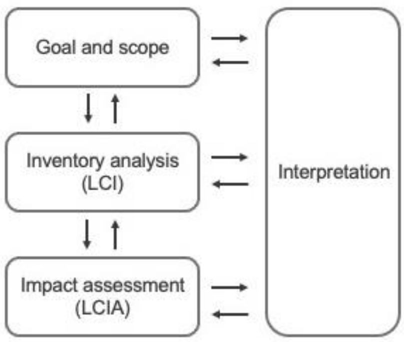

Figure 2.3 The four LCA stages. Figure adapted from (Swedish Standards Institute, 2006).

LCA was chosen as a method in this thesis since it is possible to assess several aspects of the drivers within it – climate change, land use and pollution. Although LCAs are simplified models of reality, they can provide useful insight into the environmental impacts of a product/system and where they occur. The strengths of LCA in this study, and of LCA in general, is the holistic approach including processes which are often otherwise overlooked (background processes) and that impacts are expressed quantitatively which facilitates comparison of the different fibres. Furthermore, LCAs are also becoming increasingly used by companies in their environmental assessments (Schatsky, 2011), which adds to the usefulness of the methodology in a framework created for company use.

The first two steps of the LCA, the 'goal and scope' and the LCI, describe methodological choices and are therefore presented below in this chapter. The following steps, the LCIA and LCIA interpretation, describe result and analysis and are therefore presented in chapter 4 of this report (see figure 2.2 for the report structure).

2.4.1 Goal and scope

When doing an LCA, the practitioner needs to make many important methodological choices along the way. The first choices, and perhaps the most important ones include definitions of the functional unit, system boundaries, allocation procedure, type of data and impact assessment (Baumann & Tillman, 2004), which are presented in the following subsections.

2.4.1.1 Goal

The goal of this LCA is to provide a basis for comparison for the different fibre production systems. Quantifying the impact on some components of the drivers makes the comparison of the fibres easier, as opposed to only studying the fibres qualitatively. Furthermore, an aim was also to clarify which processes contributed the most to the different impacts, the so called environmental hotspots, thus making it easier to identify where "responses" would be the most impactful.

2.4.1.2 Functional unit

The calculations in this LCA are based on the functional unit (f.u.) 1 metric tonne of staple fibres. For cotton this means 1 tonne of cotton lint, and for Tencel this means 1 tonne of cut filament fibres. This unit was chosen as it enables comparison between different types of fibres, while maintaining the focus on the fibre for the assessment. The following process step for the staple fibres is yarn spinning, which is not relevant to include in a study focusing on fibre production. The choice of f.u. is also relevant since previous LCAs studying textile fibres also have used this as the f.u. (Sandin et al., 2013; Shen et al., 2010), making comparisons of data with other studies easier.

2.4.1.3 Impact categories

The environmental impacts studied in this LCA are related to the drivers climate change, pollution and land use. This means that the following impact categories were studied:

- Climate change
- Habitat change
    - Land use
- Pollution:
    - Eutrophication
    - Acidification
    - Ecotoxicity
        - Freshwater aquatic ecotoxicity
        - Freshwater sediment ecotoxicity
        - Marine aquatic ecotoxicity
        - Marine sediment ecotoxicity
        - Terrestrial ecotoxicity

Different impact categories relating to ecotoxicity were included to get an overview on ecotoxicity impacts as a whole. The impact assessment was done using the CML 2001 method. This method shows midpoint indicator impacts, which was suitable for this thesis since the midpoint impacts represent the drivers to biodiversity loss studied.

Table 2.1 Applied impact categories in CML 2001. The impacts relating to climate change and pollution are calculated and presented in equivalents (Eq.). Land use is calculated and presented in area and year (a). The climate change and ecotoxicity impact categories are calculated based on a time frame of 100 years (100a).

Impact category	**Name of CML 2001 midpoint indicator**	**Unit**	**Description**
Climate change	Climate change (GWP 100a)	kg CO_2-Eq.	Change in global temperature caused by release of gases affecting Earth's greenhouse effect (Acero et al., 2016).
Land use	Land use (competition)	m^2a	Occupation of land due to agriculture, anthropogenic settlement and resource extraction (Acero et al., 2016).
Eutrophication	Eutrophication potential (generic)	kg PO_4-Eq.	Concentration of chemical nutrients in an ecosystem that causes abnormal productivity (e.g. algae growth in rivers). Includes both air and water emissions (Acero et al., 2016).
Acidification	Acidification potential (generic)	kg SO_2-Eq.	Reduced pH caused by acidifying effects of SO_2 and NO_X emissions (Acero et al., 2016).
Ecotoxicity	Freshwater aquatic ecotoxicity (FAETP 100a)	kg 1,4-DCB-Eq.	Toxic effects on the ecosystems caused by certain emissions (e.g. heavy metals). Impacts on ecosystems based on maximum tolerable concentrations in water (Acero et al., 2016).
	Freshwater sediment ecotoxicity (FSETP 100a)	kg 1,4-DCB-Eq.	
	Marine aquatic ecotoxicity (MAETP 100a)	kg 1,4-DCB-Eq.	
	Marine sediment ecotoxicity (MSETP 100a)	kg 1,4-DCB-Eq.	
	Terrestrial ecotoxicity (TAETP 100a)	kg 1,4-DCB-Eq.	

Note. The following abbreviations are used: GWP (global warming potential), a (years), FAETP (freshwater sediment ecotoxicity potential), FSETP (freshwater sediment ecotoxicity potential), MAETP (marine aquatic ecotoxicity potential), MSETP (marine sediment ecotoxicity potential), TAETP (terrestrial ecotoxicity potential), DCB (dichlorobenzene).

2.4.1.4 Type of LCA

This LCA is of the "accounting" type since the assessment is made of the current product systems and does not consider changes to them.

2.4.1.5 System boundaries

Since the fibre production stage is in focus for this thesis, this LCA only studies the fibres until they are ready to use – otherwise known as a cradle-to-gate LCA. This means that the use and end-of-life phases are not included in the modelling. Waste created in the fibre production, and its handling, is not included either.

Impacts created from construction of capital goods and the use of draft animals are not included in the LCA calculations, since these are believed to have a negligible impact on the systems as a whole. An exception was when existing Ecoinvent processes are used in which capital goods are already modelled as an input. This was not considered an issue for the comparison, since the impacts from the use of capital goods is negligible.

Geographical boundaries were set to the production countries of the specific fibres. That is, the organic cotton from India and Turkey has India and Turkey as the respective geographical boundary. Wood pulp for Tencel is sourced from different countries, but for the sake of this study, the wood and Tencel production are assumed to be placed in Austria where Lenzing has a large part of their production today. The geographical boundary for conventional cotton is assumed to be India, since Ecoinvent data from this region was used.

2.4.1.6 Data collection

The LCA was carried out using the OpenLCA software (version 1.10.3). Data for background processes was taken from the Ecoinvent database (version 3.7), which was the only database used.

In table 2.2 below, an overview of the sources used for the input/output data is shown. As presented in the table, inventory data for the conventional cotton production and sulfate pulp production for Tencel is taken from existing Ecoinvent processes, meaning no inventory data was collected for these processes in this study. Worth to note is that the production of wood is included in the sulfate pulp production here. Input data was collected through interviews for the organic cotton cultivation, but the output data (emissions) was calculated based on literature findings. As stated in table 2.2, the emissions from the cotton cultivation were calculated based on European parameters for agriculture, primarily collected from Nemecek and Kägi (2007). The inventory data for the ginning was based on interviews and data from the organic cotton LCA conducted by Textile Exchange (2014). No inventory data was provided for Tencel by the interviewees, which is why the data for Tencel production is based on literature findings and the Ecoinvent process for viscose production, which is similar to the Tencel production.

Table 2.2 Overview of data sources for LCA processes

Type of data	Data source	Notes
Conventional cotton		
Inputs to cotton cultivation	Ecoinvent	Data from specific region (Gujarat, India)
Outputs from cotton cultivation	Ecoinvent	Calculated by using LCI calculation tool
Inputs and outputs to/from ginning	Ecoinvent	Based on data from Bangladesh
Indian organic cotton (IOC)		
Inputs to cotton cultivation	Chetna Organic	Site specific data from India
Outputs from cotton cultivation	Different literature and Chetna Organic	Calculated mainly by using methods and data found in an Ecoinvent LCI document on agricultural production, by Nemecek and Kägi (2007) as well as other literature, including Brentrup et al. (2000), Lorimor and Powers (2004) and Province of Manitoba (2009). Not site or region specific data used, primarily calculated based on European conditions.
Inputs and outputs to/from ginning	Chetna Organic and Textile Exchange	Site specific (cotton lint / seed-cotton ratio) and literature based
Turkish organic cotton (TOC)		
Inputs to cotton cultivation	Agrona	Site specific data from the Aegean region in Turkey
Outputs from cotton cultivation	Different literature	Calculated mainly by using methods and data found in an Ecoinvent LCI document on agricultural production, by Nemecek and Kägi (2007) as well as other literature, including Brentrup et al. (2000), Lorimor and Powers (2004) and Province of Manitoba (2009). Not site or region specific data used, primarily calculated based on European conditions.
Inputs and outputs to/from ginning	Agrona and Textile Exchange	Site specific (cotton lint / seed-cotton ratio) and literature based
Tencel		
Inputs and outputs to/from sulfate pulp production	Ecoinvent	Based on European average data for sulfate pulp production from softwood found in Ecoinvent.
Inputs and outputs to/from Tencel production	Lenzing, literature and Ecoinvent	Calculated based on data from Lenzing (2014, 2019), literature and ratios used in the Ecoinvent viscose process. European data used.

2.4.1.7 Allocation

Seed cotton production is a multi-output process, with both cotton lint and cotton seeds as an output. In the case of the organic cotton, the cultivation of the land has outputs in the form of the inter- and border crop products. This means that allocation needs to be made, to share the environmental burden fairly between the different products. In this LCA, allocation of the seed cotton outputs is made based on economic value. The reason for doing the allocation based on economic value instead of mass is because cotton lint is a lightweight product, and doing the allocation based on mass would give an unfair environmental burden to the relatively heavy cotton seeds, which should be regarded as a by-product of the cotton production. The allocation method used in the Textile Exchange’s LCA (2014) is used for the allocation of the seed cotton in this LCA, where 84% of the burden is allocated to the cotton lint and 16% is allocated to the cotton seeds.

Similarly to the Textile Exchange LCA, no allocation was made to share the burden between the inter-/border-crops and cotton crops. Textile Exchange argued that the economic value of the intercrops is very small compared to the cotton crops. The same economic relationship is assumed to be true for the organic cotton production systems in this study. It should also be noted that although cotton is grown on the land only half of the year, the land use for the entire year is allocated to the cotton since this is the main reason for occupying the land and since the use of the land during the winter months is less profitable.

The allocation of the processes that are taken from Ecoinvent, i.e. the background processes for all systems and the foreground processes for Tencel and CC, are made according to Ecoinvent’s methodology and no adjustments have been made of these. Mass or economic allocation are usually used in multi-output processes, depending on the process. Different approaches to allocation of recycled and waste material can be used in Ecoinvent. In this case, the “cut-off” approach was used, which means that the production of a material always is allocated to the primary user (Ecoinvent, n.d.). For the multi-output processes used from Ecoinvent in this study – ginning of seed-cotton, pulpwood production and sulfate pulp production – economic allocation was applied.

2.4.2 Life cycle inventory

In this section the inventory data for the four fibre production systems are presented, including flowcharts of each system. The inventories are presented separately for each fibre. For more detailed descriptions of the production systems, see chapter 3. In this section, the methodology of collecting the input and output data is explained. In appendix B, the calculations made and specific datasets, including amounts used in the modelling of the processes, can be found. However, inventory data for processes used directly from Ecoinvent (including background processes) are not shown in appendix B as the Ecoinvent data is license restricted. For those processes, only the identifying name and code (UUID) for Ecoinvent is provided in appendix B.

2.4.2.1 Conventional cotton

All inventory data for the conventional cotton (CC) is taken from existing Ecoinvent processes. For the CC cultivation, the inventory data represents data from production in the Gujarat state in India (northern part of the west coast).

As shown in the flowchart in figure 2.4 below, the CC production starts with the preparation of the land, which includes ploughing and fertilizing the land. After that, the seeds are sown. This is done April-May. During the cotton cultivation, the crops and land are managed to support a large yield and good quality of the cotton. These practices for the CC include tilling, application of fertilizers, compost and mineral fertilizers (urea, ammonium phosphate), pest control with pesticides and irrigation. Irrigation is modelled as a mix of different types of irrigation (drip, sprinkler and surface irrigation).

The seed-cotton is harvested, at a yield of 1750 kg/hectare. After harvest, the seed-cotton is stored to dry, before being sent to ginning. However, the storage is not included in the LCA calculations, which is why that box is dotted in figure 2.4. This is most likely due to the storage having a negligible impact. Ginning is a mechanical process performed to separate the cotton lint (fibres) from the cotton seeds and other waste. The ginning consumes electricity. Fuel is also used throughout the cultivation, from the use of machinery and the irrigation pump. Transport of the seed-cotton, with fuel use, is assumed to take place from the cultivation area to the gin.

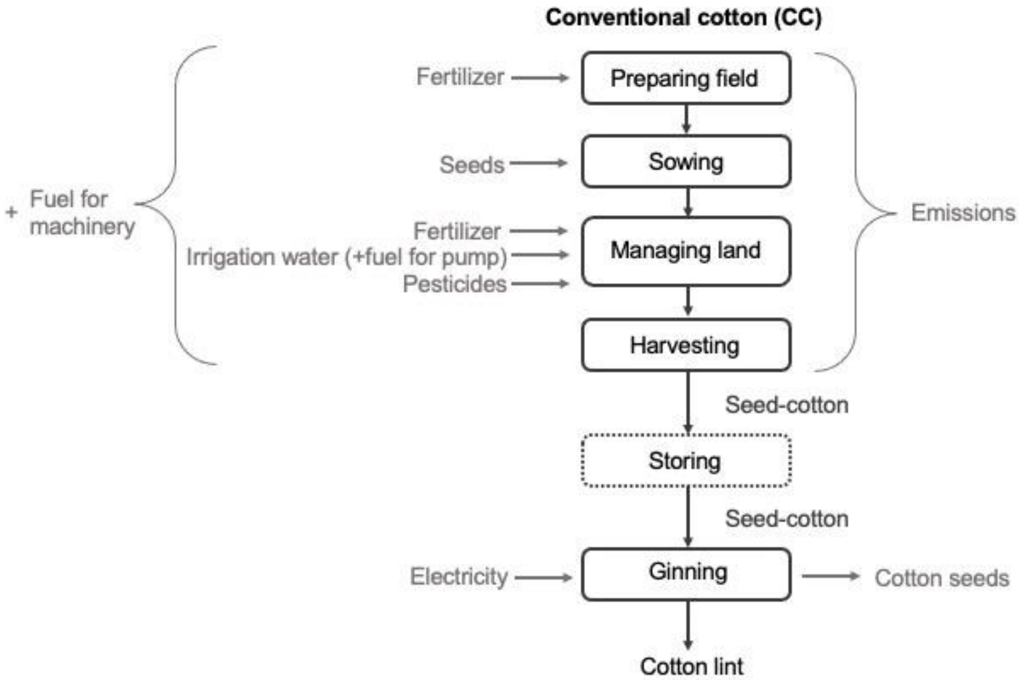

Figure 2.4 The main processes and inputs to the cultivation of conventional cotton (CC). Transport is assumed to take place between harvest and ginning. The process "storage" is dotted to show that the process is not included in the inventory modelling.

2.4.2.2 Indian organic cotton

The input inventory data for the production of Indian organic cotton (IOC) was primarily collected from Chetna Organic. Inventory data was complemented with data from Textile Exchange (2014) and from Ecoinvent processes. Output inventory data, i.e. emissions from the foreground processes, were primarily calculated for the use of fertilizer.

The main processes, and inputs and outputs, are shown in the flowchart in figure 2.5 below. The processes and inputs/outputs are roughly the same as for the CC production. The production starts with preparing the field, which includes ploughing and application of fertilizer, and followed by sowing with the cotton seeds. During the cotton cultivation, the practices differ from the ones used in CC production. No pesticide is applied on the IOC crops, but an organic pest spray including botanic extracts is used instead. However, due to lack of background data in the Ecoinvent database, this spray was omitted from the LCA modelling of the cultivation. This is not believed to be of major concern since botanical extracts can be assumed to have a negligible impact on the studied impact categories. According to Chetna, four different fertilizers are used (enriched manure, vermicompost, liquid manure and organic aminos). In the modelling of the process, fertilizers are assumed to only include compost and liquid cow manure, see appendix B for more info. A large difference to the CC cultivation is that no irrigation is used for the IOC production.

The seed-cotton is harvested, at a yield of 1850 kg/ha, and stored before being sent to ginning. The storage is, just like for the CC, excluded from the LCA modelling since it is assumed to have a negligible impact and since no data was given for this. The cotton lint is then transported to the gin, where the cotton lint is separated from the seeds. The transport distance of the seed-cotton to the gin is based on data from Textile Exchange (2014).

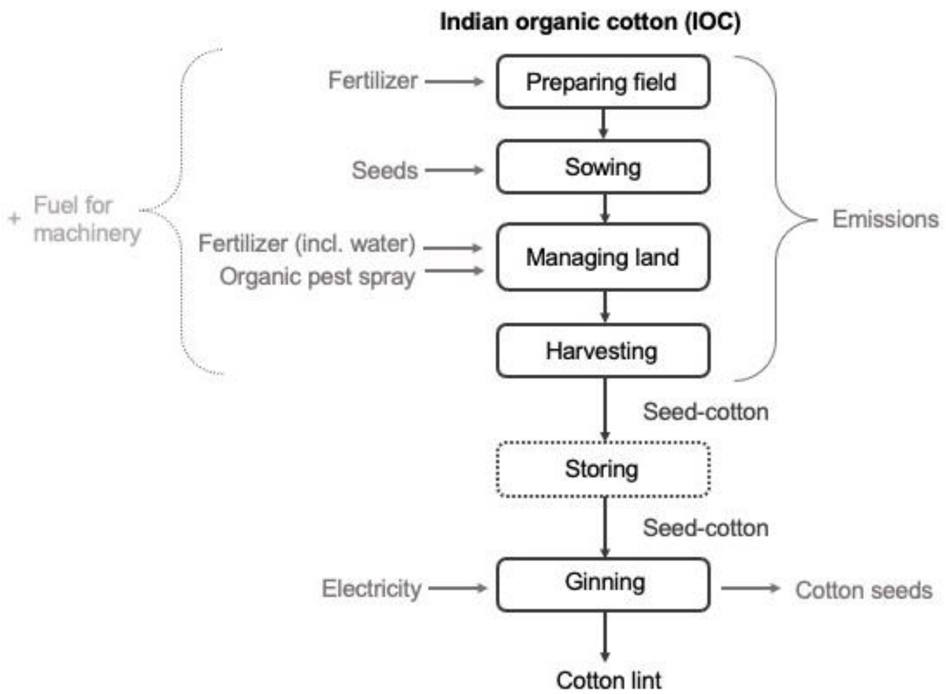

Figure 2.5 The main processes and inputs to the cultivation of Indian organic cotton (IOC). Transport is assumed to take place between harvest and ginning. The process "storage" is dotted to show that the process is not included in the inventory modelling.

According to the interviewed organic cotton producers (Chetna Organic in India and Agrona in Turkey), no fuel driven machinery is used during the cotton cultivation. In other literature, e.g. the LCA conducted by Textile Exchange (2014), fuel driven machinery is used in all studied regions of organic cotton except for Tanzania – this includes five different regions in India and one region in Turkey. Even though Chetna Organic's and Agrona's farmers do not use fuel driven machinery for their cotton cultivation, it is likely that other Indian and Turkish organic cotton farmers do, based on the information from Textile Exchange. So, organic cotton cultivation with machinery use would show the typical scenario for cotton farming in India and Turkey at least.

Data for the scenario with machinery use was collected from Textile Exchange (2014). In India 29.5 litres of diesel per hectare (an average over the five regions) is assumed.

2.4.2.3 Turkish organic cotton

The input inventory data to produce Turkish organic cotton (TOC) were primarily collected from Agrona. Just like for the IOC, inventory data was complemented with literature data from Textile Exchange (2014) and from Ecoinvent processes. Output inventory data, i.e. emissions from the foreground processes, were primarily calculated for the use of fertilizer.

The main processes, and inputs and outputs, are shown in the flowchart in figure 2.6 below. The processes and inputs/outputs are similar to the CC and IOC production. The production starts with preparing the field, which includes ploughing and application of fertilizer, and followed by sowing with the cotton seeds. During the cotton cultivation, the practices differ somewhat from the ones used for the CC and IOC production. No pesticide is applied on the TOC crops, but garlic is sometimes used. However, due to lack of background data in the Ecoinvent database, garlic was omitted from the LCA modelling of the cultivation. This is not believed to be of major concern since garlic can be assumed to have a negligible impact on the studied impact categories. According to Agrona, compost and manure are used as fertilizers. In the modelling of the process, the manure is assumed to be solid cow manure. Unlike the IOC, irrigation is used for the TOC cultivation during the summer months. However, the amount of irrigated water is much smaller than the amount used for the CC. The irrigation is assumed to be a mix of drip, sprinkler and surface irrigation, since the overall irrigation methodology is not specified by Agrona. The irrigation pump is assumed to be run on diesel.

The seed-cotton is harvested, 2160 kg/ha, and stored before being sent to ginning. The storage is, just like for the CC and IOC, excluded from the LCA modelling since it is assumed to have a negligible impact and since no data was given for this. The cotton lint is then transported to the gin, where the cotton lint is separated from the seeds. The transport distance of the seed-cotton to the gin is based on data from Textile Exchange (2014).

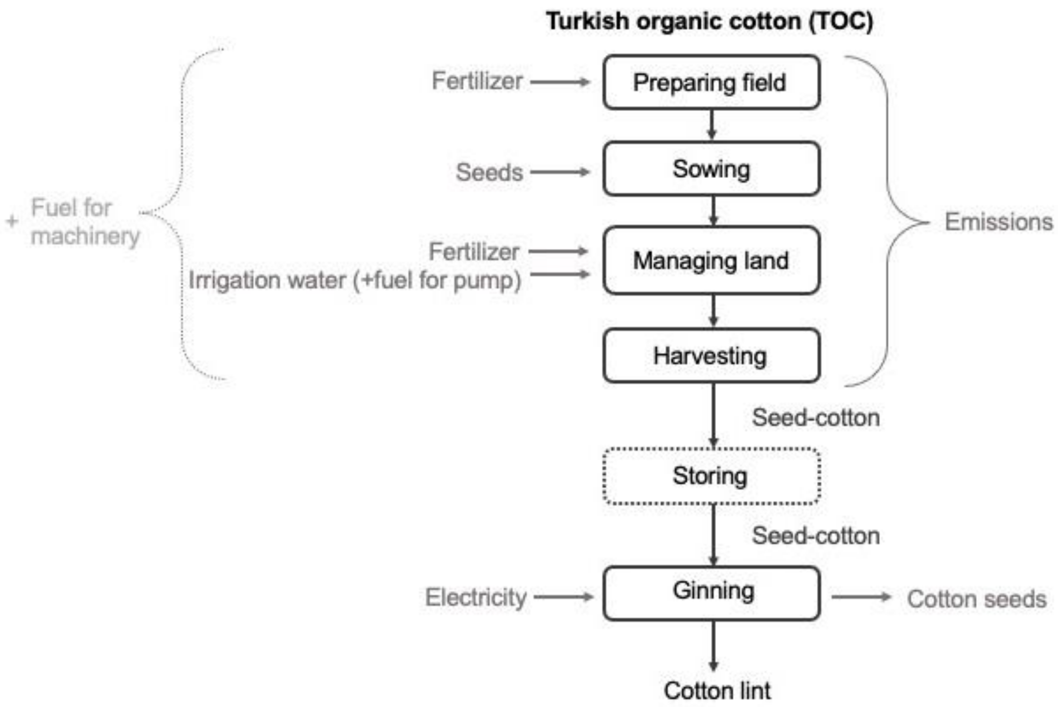

Figure 2.6 The main processes and inputs to the cultivation of Turkish organic cotton (TOC). Transport is assumed to take place between harvest and ginning. The process "storage" is dotted to show that the process is not included in the inventory modelling.

As explained in section 2.4.2.2, a scenario for machinery use was included for the TOC cultivation even though Agrona claim that no machinery is used. Based on data from Textile Exchange (2014), 60 litre diesel per hectare was assumed to be used for machinery in Turkey in this scenario.

2.4.2.4 Tencel

The input inventory data for the production of Tencel was primarily collected from the Ecoinvent. The wood production and sulfate pulp production processes were entirely taken from existing Ecoinvent processes. The inventory data for the lyocell process, i.e. when the pulp is spun into Tencel fibres (the process steps within the dotted box in figure 2.7), is based on the Ecoinvent process for viscose production, which is similar to the lyocell process. For example, data regarding energy and water use was calculated based on the ratios used for the viscose process, but the amount was corrected for by referring to literature and data from Lenzing's sustainability reports. For more details on how the lyocell production process was modelled, see appendix B.

The main processes, and inputs and outputs, are shown in the flowchart in figure 2.7 below. The production starts with the production of wood. In the Ecoinvent process for sulfate production they use a mix of pulpwood from pine and spruce, grown in Sweden, but more pine than spruce is used. There are many different inputs to the forestry operations, but the main ones include tree seedlings and machinery use. Emissions are only assumed to take place in the background processes and from the energy use, no direct emissions from the forestry are assumed in the Ecoinvent process. From the forestry production, pulpwood is one of many outputs. The inputs have been allocated based on economic value between the different outputs.

The wood is then transported to the production site for sulfate pulp. In the making of the pulp, many different chemicals are added. This also means that there is a mix of many chemicals and substances leaving the process as emissions and waste. Another important input to the sulfate pulp production is energy. Although not shown in the flowchart, the sulfate pulp production also has several outputs (pulp, bioenergy and biorefinery products) (Lenzing Group, 2019). In the Ecoinvent process, economic allocation is applied between the different outputs.

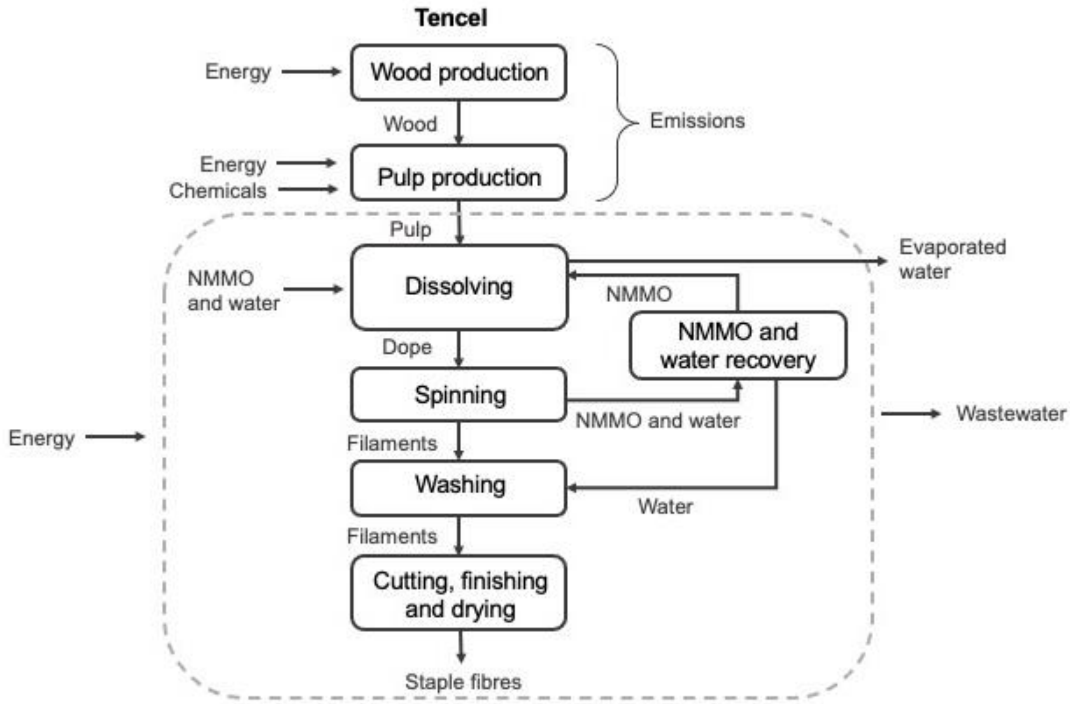

Figure 2.7 Flowchart over the main processes and inputs in Tencel production for Lenzing. The processes surrounded by the dotted line represent the so called lyocell process, i.e. when pulp is spun to fibres. Flowchart adapted from Shen et al. (2010).

The sulfate pulp then goes into spinning of the Tencel fibres. No transport is assumed to take place between the pulp production and lyocell spinning sites, as these are situated close to each other (Lenzing Group, 2019). The pulp is first dissolved into a homogenous slurry by mixing the pulp with water and NMMO (N-Methylmorpholine N-oxide, a solvent). Water is then removed from the slurry, resulting in a solution called dope. This dope is then spun into filaments, which are then washed, cut into staple fibres, finished and dried. Water and NMMO are recycled in the process – more than 99% of the NMMO used is recovered (Lenzing Group, 2019). Pulp, energy, NMMO and water are the only modelled inputs to lyocell process. The outputs include 1 tonne of staple fibre, wastewater and evaporated water. The energy mix is based on information from Lenzing's sustainability report (Lenzing Group, n.d.), and is assumed to be 87% renewable (biomass and waste), 6% natural gas, 6% coal and 1% oil.

3 Description of fibre production systems

In this chapter the fibre production systems are described in more detail, starting with a more general description of cotton production, then going into the specific NJ organic cotton production systems, and finally describing Tencel production. The descriptions of the organic cotton systems are mostly based on interviews with suppliers, whereas the Tencel and conventional cotton systems predominantly are based on literature findings. The descriptions in this chapter lay the foundations for the analysis of the contribution to pressure/state and impact in chapter 4 and 5 of this report.

3.1 Cotton

NJ's material use is 94% cotton, mainly virgin organic cotton but also reused/recycled cotton (Nudie Jeans, 2020). Although NJ mostly source organic cotton for their products, organic cotton is globally a very small share of the total cotton production at 0.9% (Textile Exchange, 2020).

The main differences between CC and organic cotton production are summarized in table 3.2. In the cultivation of CC, genetically modified (GM) seeds can be used, but this is not allowed for the organic cotton (Gardetti & Muthu, 2019). Nearly three quarter of all cotton is currently grown with GM seeds (Better Cotton Initiative, 2018). However, not all CC is grown with GM seeds. In Turkey for example, no cotton is grown with GM seeds (Ü. Evcim, personal communication, 22 February, 2021). Another major difference between the CC and organic production is that the organic production involves other crops in the fields, so called border- and inter-crops. Border- and intercrops are beneficial for the farmers in more ways than to simply provide food and other income sources. These border- and intercrops are also grown because they can help in pest management by increase the diversity of natural enemies to pests, work as traps for insects to keep them away from the cotton crops and contribute to supressing weed by shading the soil or releasing growth inhibiting substances (cereals). Intercrops are also beneficial in many other ways, by for example lowering need for fertilizers by fixing nitrogen and reducing erosion (Riar et al., 2020). For the CC, intercrops are typically not used, and pests are manged with synthetic pesticides instead (Gardetti & Muthu, 2019).

Table 3.2 Main differences between conventional and organic farming practices, based on information from Gardetti and Muthu (2019).

Conventional cotton	**Organic cotton**
Synthetic fertilizers are used	Only organic fertilizers are used
Synthetic pesticides are used	No synthetic pesticides are used. Organic pesticides or biological control is used
Mono crop culture	Crop rotation and border-/inter-crops
GM seeds	Non-GM seeds

Yield is an important parameter when assessing environmental impacts, since smaller yields require more land to produce the same amount of material. Cotton yields differ a lot from region to region and from year to year. For example, the LCA on organic cotton conducted by Textile Exchange (2014) reported seed-cotton yields ranging from 650 kg/ha in Tanzania to 6000 kg/ha in China. Yields also differ between CC and organic cotton. For the season 2018/19 the yield is reported to be around 780 kg cotton lint/ha for CC (International Cotton Advisory Committee, 2020) and around 570 kg cotton lint/ha for organic cotton (Textile Exchange, 2020). However, organic cotton production does not always have lower yields than CC. In certain regions, the organic cotton production is on average larger than the CC, for example in Peru (Textile Exchange, 2019).

As shown in table 3.1 the seed-cotton yields for the three cotton production systems differ somewhat. As mentioned, CC typically have higher yields than organic cotton, but this is not the case here. The reason for larger seed-cotton yields for the studied organic cotton systems could be explained by a range of different factors, including different harvesting years, and differences in environmental and soil conditions between the production regions.

Table 3.1 Seed-cotton yields given for each cotton production system.

	Indian organic cotton (IOC)	Turkish organic cotton (TOC)	Conventional cotton (CC)
Yield [kg/ha]	1850	2160	1750

The CC in this study is assumed to be produced in the Gujarat region in India, since Ecoinvent data was found for that region. The average cotton yield for that region is 590 kg/ha (CEIC Data, n.d.), being around 1730 kg seed-cotton/ha. This suggests that the yield used in the Ecoinvent process, 1750 kg seed-cotton/ha is representative for the area. However, between 2001 and 2012 the yields ranged from 122 kg cotton lint/ha to 689 kg cotton lint/ha (CEIC Data, n.d.), so large differences from year to year can sometimes be seen. Yearly variations in yield is estimated to mostly be attributed to environmental conditions, but management of the crops also has an influence (Gardetti & Muthu, 2019). As shown in table 3.1, the yield for TOC is considerably larger than the two other production systems. This could be explained by the favourable cultivation conditions in Turkey, which has resulted in Turkey being one of the countries with largest yields per hectare (Gardetti & Muthu, 2019).

3.1.1 Turkish organic cotton (TOC)

The majority of all of NJ's organic cotton, 85%, is sourced from Turkey (Nudie Jeans, 2020). Agrona is one of NJ main suppliers in Turkey. Agrona is a company retrieving organic cotton from farmers in the Aegean region in the western part of Turkey. NJ primarily source cotton from the Izmir and Aydin provinces of the Aegean region (E. Brinkberg, personal communication, 3 February, 2021), which are situated on the coastline to the Aegean Sea. In figure 3.1 below, the abovementioned region and provinces are marked out. Important to note about the Turkish west coast is that it is part of one of the global biodiversity hotspots, called the Mediterranean basin. The meaning of a biodiversity hotspot is that it holds a an exceptionally large concentration of endemic species and at the same time is experiencing an exceptional decrease in habitat for these species (Myers et al., 2000).

Figure 3.1 *Map of Turkey showing the Aegean region, where Agrona source it's organic cotton from. NJ mainly source cotton from Izmir and Aydin, shown in darker grey.*

Border- and intercrops are applied in the cultivation of TOC. As illustrated in figure 3.2, roughly 70% of the farmland is cotton crops and the remaining 30% is border- and inter crops in the form of e.g. vetch, wheat and barley.

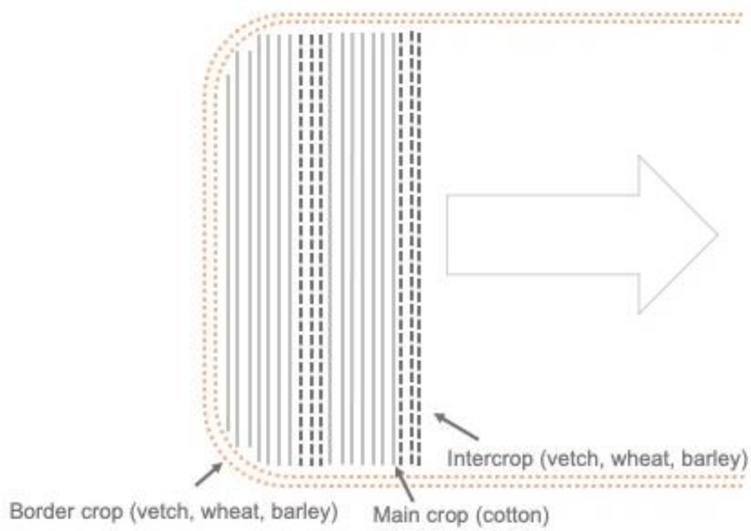

Figure 3.2 *Schematic overview of the farmland at Agrona. Cotton is the main crop and is shown as straight light grey lines. The intercrops are shown in dark grey dashed lines. The border-crops are shown in the orange dotted lines. Roughly 70% is cotton and 30% are intercrops and border crops.*

The TOC is irrigated during the summer months when Turkey is very dry. To control and reduce the amount of water being irrigated, dripping water irrigation systems have recently been installed in some places. The other, more commonly used, irrigation techniques are not specified. Apart from the drip irrigation system, efforts are also made to convert to renewable energy sources. For the electricity use in ginning, the aim is to have 100% renewable energy by 2025.

Soil tillage and biotechnical control measures are used as pest management. The biotechnical control measures include use of garlic (repels insects in the land) and the release of insects in the fields which act as natural enemies to the pests. Uçak from Agrona also claim that new insects have been seen in the area over the last decades, which he attributes to climate change.

3.1.2 Indian organic cotton (IOC

The second largest sourcing country for NJ is India, where they source from Chetna Organic (Nudie Jeans, 2020). Chetna Organic is a Fairtrade organic cotton cooperative working with smallholder farmers to make their farming more sustainable and profitable (Chetna Organic, n.d.). Their farmers cultivate cotton in the Telangana, Maharashtra, Odisha and Andra Pradesh districts in India, as illustrated in figure 3.3. NJ mainly source cotton from farmers in Telangana district located in central India (E. Brinkberg, personal communication, 3 February, 2021). A biodiversity hotspot exist in India as well, on the southern part of the west coast (the western Ghats) (Myers et al., 2000). However, Chetna Organic's operation is not within this area. This therefore marks an important difference to the TOC production.

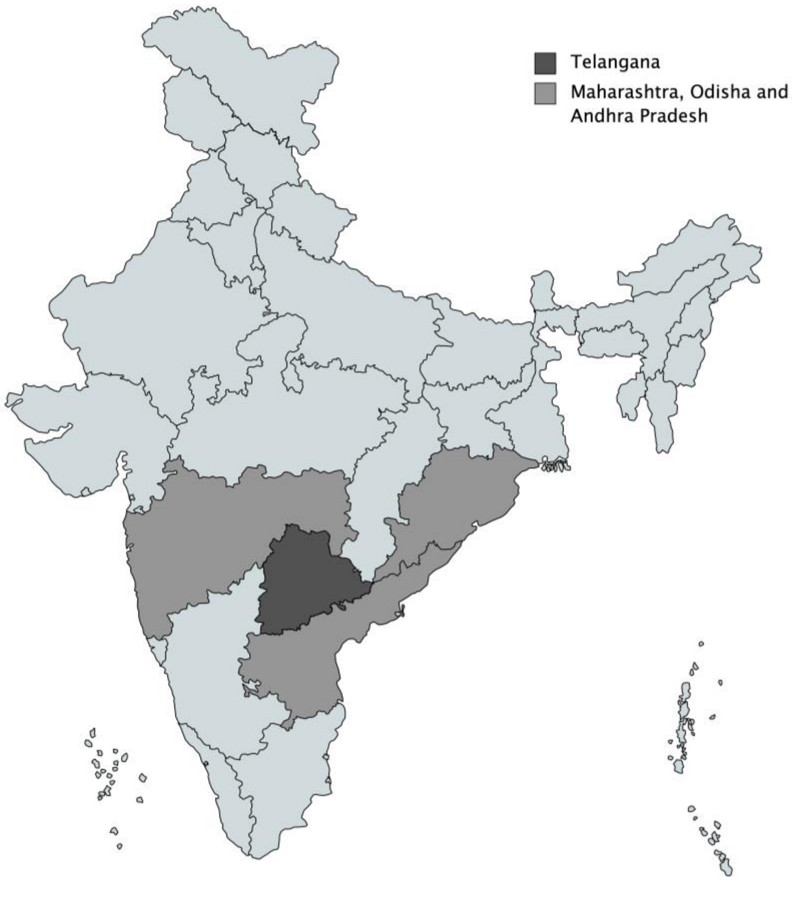

Figure 3.3 *Map of India showing the four regions Chetna Organics source cotton from, Telangana, Maharashtra, Andhra Pradesh and Odisha. NJ mainly source cotton produced in Telangana, showed in darker grey*

Figure 3.4 shows which border- and intercrops that are cultivated with the cotton for the IOC. Around 80% of the agricultural land is cotton crops, and the remaining share are lentil intercrops and maize or sorghum border crops.

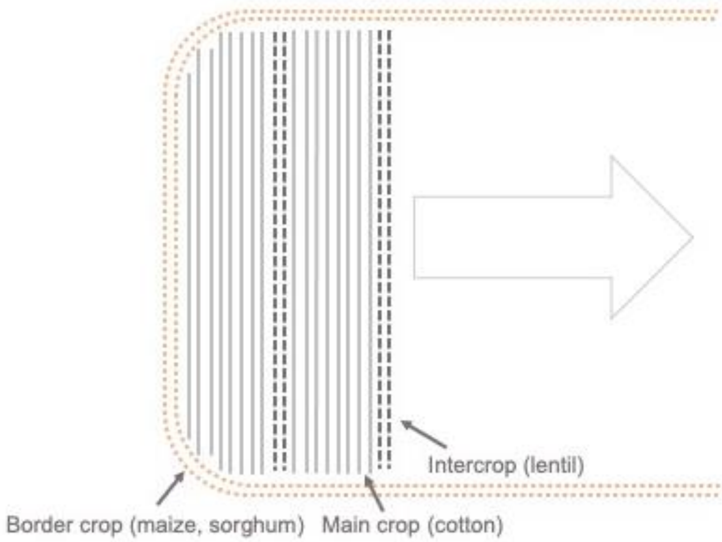

Figure 3.4 *Schematic overview of the farmland at Chetna. Cotton is the main crop and is shown as straight light grey lines. The intercrops are shown in dark grey dashed lines. The border-crops are shown in the orange dotted lines. Roughly 80% is cotton and 20% are intercrops and border crops.*

The main form of pest management in the IOC cultivation is tillage of the soil, but some organic prophylactic sprays are also used for keeping pests away. In the management of the land the farmers use wood bullocks and draft animals.

Chetna Organic is involved with a cotton seed exchange program, where seeds between different farmers and regions are exchanged. This is believed to create more genetic diversity and in turn result in more resistant cotton crops. Exchanging seeds between farmers is typically not done for the TOC according to Uçak, so this also marks an important difference between the organic cotton production systems. Another aspect that differs the IOC from the TOC is that Chetna Organic actively test the quality of their soils, by analysing soil samples. This gives them indications where soil improvement practices need to be focused. Exactly what parameters that are analysed is not declared.

3.2 Tencel

Tencel accounts for 0.62% of NJ's total material use. Although making up a very small share of their production today, NJ use of Tencel has increased a great deal in recent years, from 30 kg in 2018 to 2 308 kg in 2019 (Nudie Jeans, 2020). Tencel is, as previously mentioned, a lyocell fibre produced by the company Lenzing.

One of Lenzing's main production sites, both for the sulfate pulp and the Tencel fibre, is located in Austria. For simplicity, the Tencel studied in this thesis is assumed to be produced in Austria. For this production site, they mainly source pulpwood from Austria too (Lenzing Group, n.d.). It should be noted that no biodiversity hotspots are found in Austria.

At the Austrian site, beech is the main raw material for the pulp (Lenzing Group, n.d.). However, note that in the Ecoinvent modelling of the pulp production, pine and spruce were used as the raw materials. Efforts have been made to regenerate the Austrian forests to include more deciduous species, like beech. Today that means that around 10% of the Austrian forests are covered by beech (Schwarzbauer & Wittmann, 2018). The wood used for pulp production primarily comes from small trees removed in the thinning process and from parts of larger trees that are not suitable for high grade products like construction (Lenzing Group, n.d.).

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The majority of the Austrian forests that Lenzing source pulpwood from are PEFC certified (Lenzing Group, n.d.). PEFC is a certification to show that the forestry is controlled and “managed in line with challenging environmental, social and economic requirements” (Programme for the Endorsement of Forest Certification, n.d.). What this management entails can differ between regions depending on legal requirements. For more information on forestry management in Austria, see for example Schwarzbauer and Wittmann (2018) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management (2008).

4 Pressure and state

In this chapter the contribution to the five drivers of biodiversity loss for the four different fibre production systems are assessed. This is firstly done quantitatively in an LCA for the drivers climate change, pollution, and habitat change. Following the LCA is a qualitative assessment of the driver invasive species.

4.1 Life cycle assessment

In this chapter the results from the LCIA and the interpretation of them are presented.

4.1.1 Life cycle impact assessment

In this section the impact from the four fibre production systems are presented. An overview of the results can be seen in figure 4.1 below. The figure shows that CC has the largest impacts overall. In the following sub sections the impact results are explained in more detail.

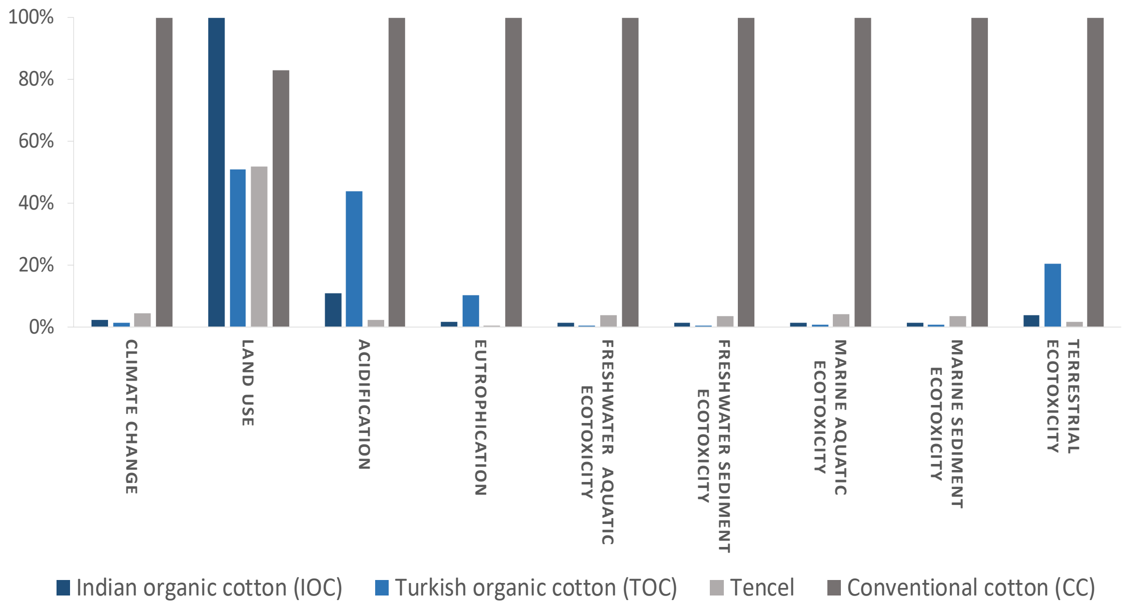

Figure 4.1 Overview of the impact from the four fibre production systems, showing the relative relation between the fibres' impact results, where the fibre system with the highest impact is set to 100%.

As explained in section 2.4.2.2, a scenario for machinery use is included for the organic cotton production. This scenario only had a significant impact on climate change and ecotoxicity, and is therefore only presented in relation to those impact categories.

4.1.1.1 Climate change

Figure 4.2 below shows that among NJ's organic cotton suppliers, the IOC supplier has a larger impact on climate change compared to the TOC supplier. IOC has roughly 60% higher impact than TOC in this category. Figure 4.3 shows the relative contributions for each fibre production system. As shown in that figure, the majority of the contribution to climate change impacts for both the TOC (77% of total impact) and IOC (86% of total impacts) come from electricity use in the ginning process. Since the main contributor is the same activity for both systems, the difference in total climate change impact is mainly influenced by differences in energy mix between the different countries, where the IOC system to a larger degree uses coal.

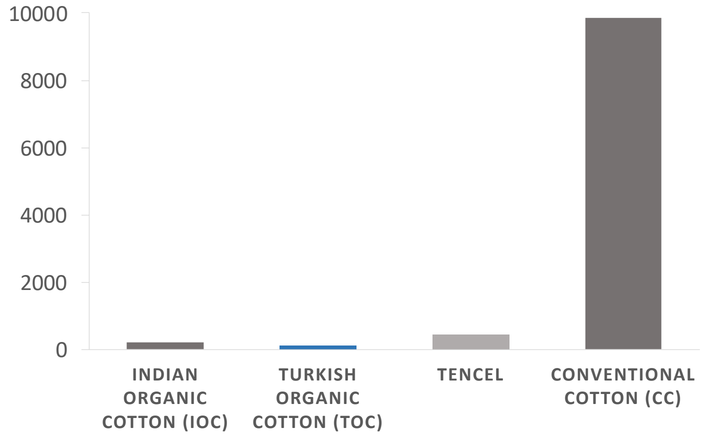

Figure 4.2 Climate change impact in kg CO_2-Eq. per f.u.

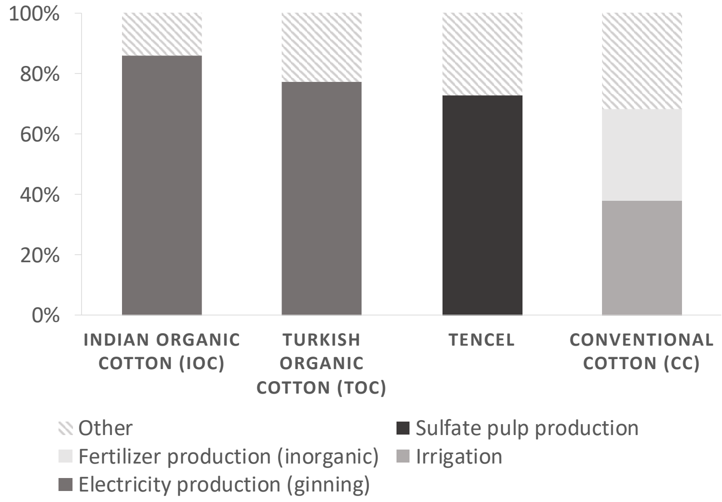

Figure 4.3 Relative contributions to climate change impact for each fibre production system, shown in percent of the total impact per system.

When comparing with CC, the climate change impact from the organic cotton systems are very small in comparison (see figure 4.2). As shown in figure 4.3, the main reasons for the significantly higher impact for CC is its extensive use of irrigation (38% of total impacts) and production of synthetic fertilizers (14% of total impacts). Irrigation is a large contributor to climate change in this system since the water pump consumes a lot of energy (electricity from coal and diesel). IOC is not irrigated at all, but the TOC is. However, the impact from the TOC irrigation is much smaller than for the conventional cotton since a significantly smaller amount of water is irrigated in that system (0.05% of the amount of water used for CC). Production of synthetic fertilizers is also energy consuming. Neither of the two organic cotton production systems use synthetic fertilizers, which is another reason for much lower impact from those systems compared to CC.

For Tencel the impact on climate change is higher than from the organic cotton systems (around double the impact of IOC), but significantly smaller than from CC production. The majority of the contribution (73%) come from the sulfate pulp production, where the production of input materials seems to be the main contributors as well as energy used in the process. Another important contributor (11%) is the production of the solvent used in the Tencel process.

Climate change impact is largely affected by use of fossil fuel. In the scenario where diesel fuelled machinery is used, the impact on climate change is almost doubled and tripled for IOC and TOC respectively, as shown in figure 4.4. The impact also become quite even between the two production systems when machinery use is included. This is because more diesel fuelled machinery is assumed to be used for the TOC than for the IOC (see section 2.4.2.2).

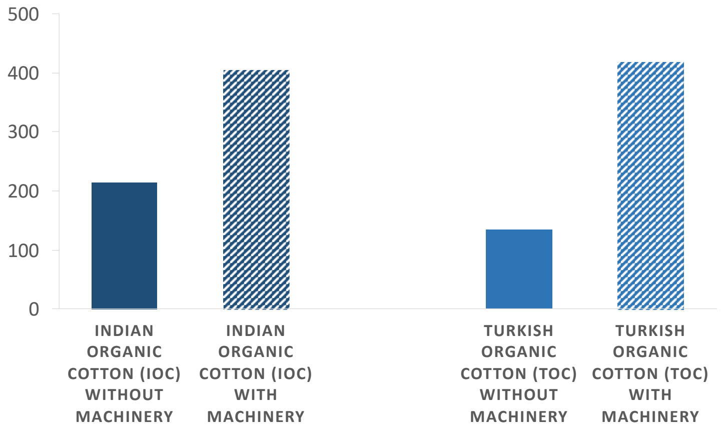

Figure 4.4 *Climate change impact in kg CO_2-Eq. per f.u. for the organic cotton production, comparing production with and without diesel fuelled machinery.*

4.1.1.2 Land use

As shown in figure 4.5 below, IOC has the largest land use per f.u. and TOC and Tencel have the smallest. However, it is important to note that the land use is not the same for cotton and Tencel, as cotton is grown on agricultural land and Tencel raw material is grown on forestry land. The land use in this case shows the land area occupied to produce the fibres, which almost exclusively is the land for the cultivation/growing of cotton or forest.

The differences in land use for the cotton fibres has to do with yield and cotton lint to seed cotton ratio. IOC has a larger yield than CC, but a lower cotton lint to seed cotton ratio, which results in larger land use for the IOC. The land use for Tencel depends on what type of wood that is used and how the forestry land use is allocated to the different forestry outputs. For example, the wood used in the sulfate pulp production process (modelled by Ecoinvent) contains both pulpwood from pine and spruce, and the pine has roughly 27% larger land occupation per m^3 pulpwood compared to spruce. More pine than spruce is used for the sulfate pulp production, leading to a larger land use compared to a scenario with 100% spruce pulpwood.

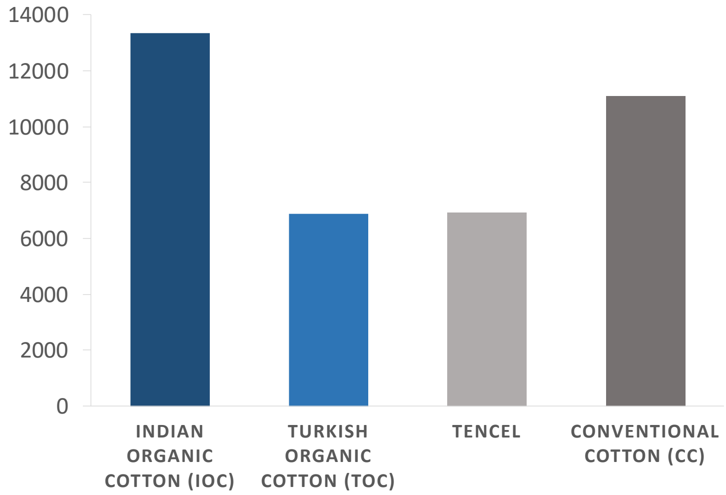

Figure 4.5 Land use (competition) in m^2a per f.u. Note that there is a mix of agricultural (cotton) and forestry (Tencel) land use.

4.1.1.3 Acidification

As shown in figure 4.6 below, IOC clearly has the lower impact on acidification of the cotton production systems. The impact on acidification from TOC is more than four times the impact from IOC. From the IOC, the main impacts (94% of total impact) occur in the cotton cultivation. Figure 4.7 shows the relative contributions for each fibre production system. As shown in that figure, it is primarily fertilizer use that is responsible for IOC’s acidification impact (94% of total impact). The same situation is true for the TOC, where fertilizer use constitutes 99% of the total contribution to the acidification potential.

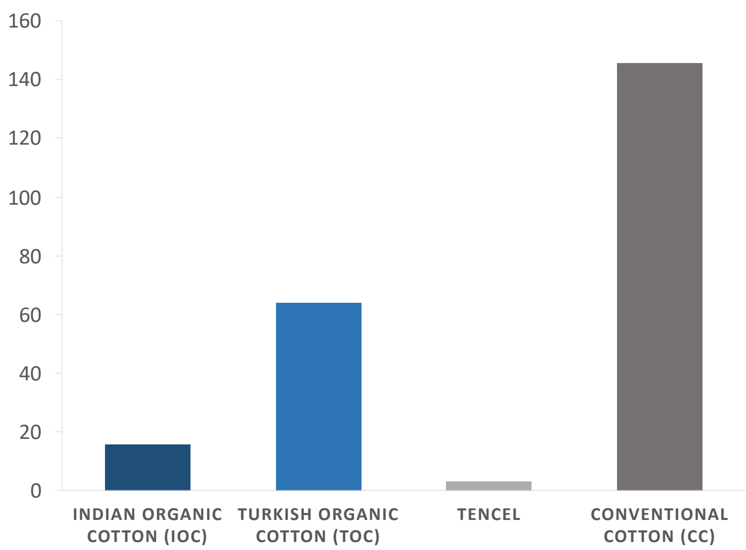

Figure 4.6 Acidification impact in kg SO_2-Eq. per f.u.

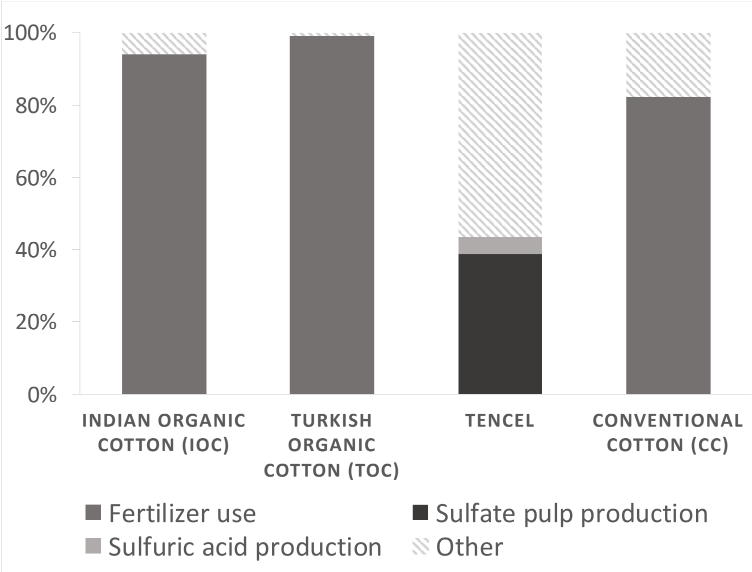

Figure 4.7 Relative contributions to acidification impacts for each fibre production system, shown in percent of the total impact per system.

The acidification potential differs significantly between the fibres. CC has the largest contribution of the four production systems and Tencel has the lowest. For CC, the main contributor to acidification impact is fertilizer use (82% of total impact), just like for the organic cotton. Other important contributors for CC are emissions from energy production. For Tencel, the acidification impact is very small compared to the other systems, with sulfate pulp production seeming to contribute the most, and the nitrogen oxide emissions from the pulp production to be the main issue (30% of total impact). The production of sulfuric acid also has a significant contribution for the acidification impact from Tencel.

4.1.1.4 Eutrophication

As shown in figure 4.8 below, IOC clearly has the lower eutrophication potential of the cotton production systems. TOC's impact on eutrophication is more than six times higher than for the IOC. For the TOC, nitrate and ammonia emissions from fertilizer use are the main contributors (99% of total impact) to the acidification impact, as shown in figure 4.9. For the IOC, fertilizers use is also identified as the main contributor (91% of total impact).

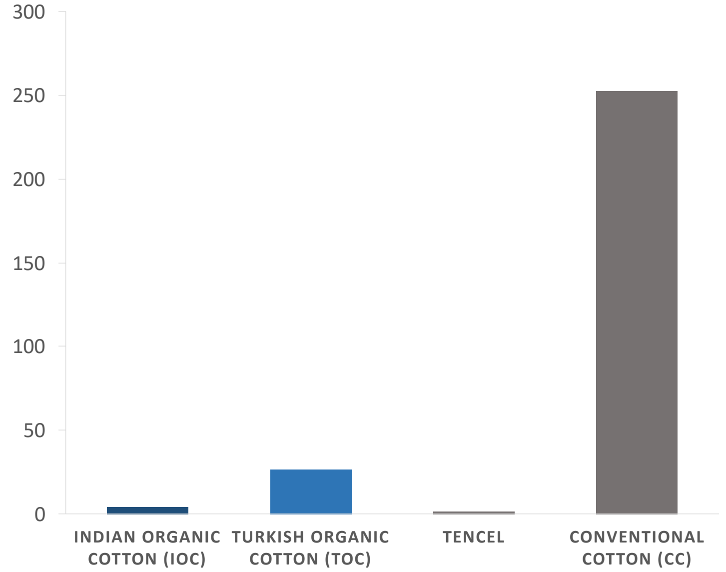

Figure 4.8 Eutrophication impact in kg PO_4-Eq. per f.u.

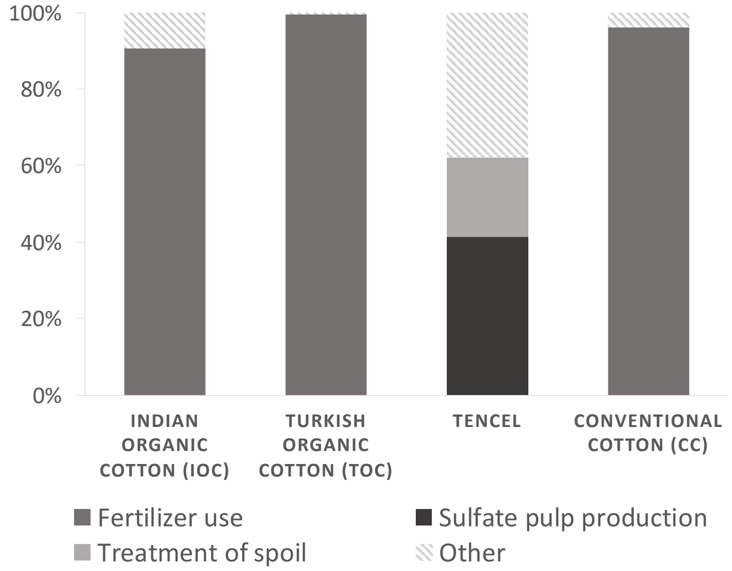

Figure 4.9 Relative contributions to eutrophication impact for each fibre production system, shown in percent of the total impact per system.

Compared to CC, both the IOC and TOC production has low eutrophication impact. The main cause of the high impact from the CC is also fertilizer use (96% of total impact). The eutrophication impact from Tencel is very small compared to the other fibres. Emissions from the sulfate production and treatment of spoil are the main contributors to eutrophication for Tencel.

4.1.1.5 Ecotoxicity

As shown in figure 4.10 below, CC has the highest toxicity impacts for all ecotoxicity impacts. From figure 4.10 and 4.11, a repeating pattern can be seen for the freshwater and marine ecotoxicity impacts, where TOC has the lowest impact, IOC has around twice the impact of TOC, Tencel has around triple the impacts of IOC and CC has a much higher impact than the other three. However, this pattern is broken for terrestrial ecotoxicity impact, where Tencel has the lowest impact and TOC has five times as large impact as IOC.

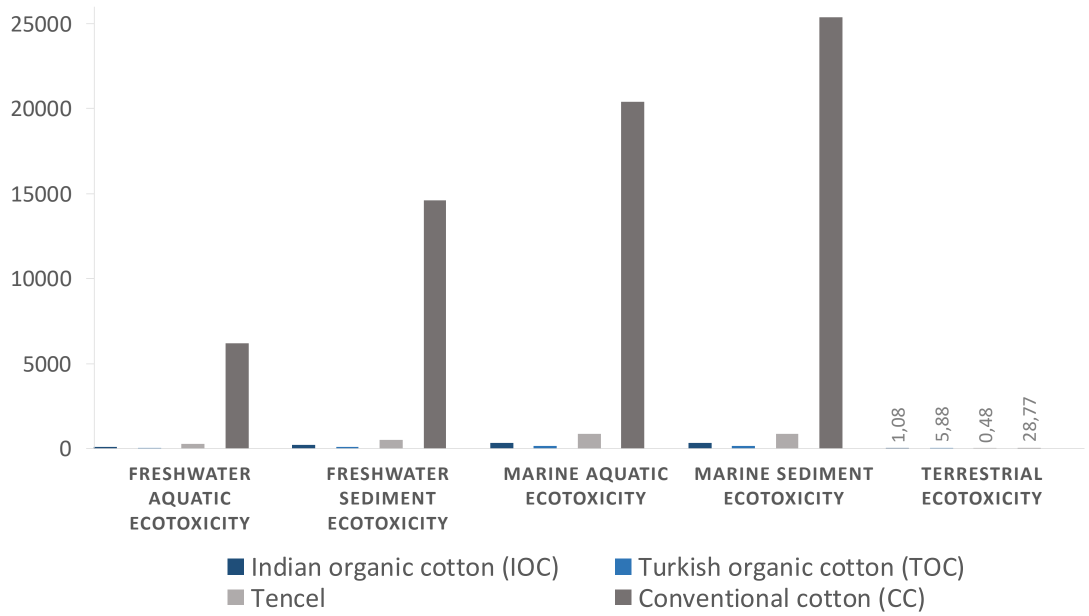

Figure 4.10 Ecotoxicity impacts for conventional cotton, organic cotton (Indian and Turkish) and Tencel measured in kg 1.4-DCB Eq.

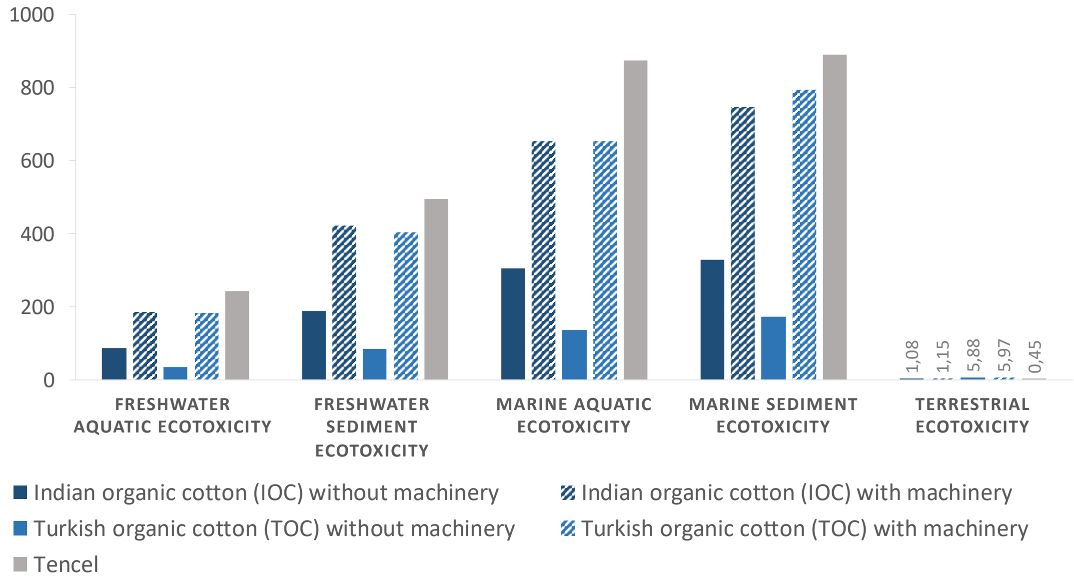

Figure 4.11 Ecotoxicity impacts for organic cotton (Indian and Turkish) and Tencel measured in kg 1.4-DCB Eq.

For the IOC and TOC production, freshwater and marine ecotoxicity impacts mainly come from energy production for the ginning process, more specifically related to emissions from the treatment of spoil from hard coal mining. For impact on terrestrial ecotoxicity, the main contributor is mercury emissions from the cotton cultivation. Mercury comes from the use of fertilizer, where mercury and other metals are present in small quantities. The main reasons for differences in ecotoxicity impacts between IOC and TOC are differences in the yield and cotton-to-seed ratio (for freshwater and marine ecotoxicity) and different amounts of fertilizers used (terrestrial ecotoxicity).

Irrigation is the main activity responsible for aquatic and marine ecotoxicity for the CC production, more specifically background processes relating to treatment of copper waste. Waste processes from coal energy are also significant contributors for the CC production. For terrestrial ecotoxicity impact, metal emissions from the fertilizer use in the CC cultivation are the main contributors, especially chromium.

For freshwater and marine ecotoxicity impacts from Tencel production, background processes relating to waste from energy production are the main contributors. For terrestrial ecotoxicity, the main activity responsible for the impact is the sulfate pulp production (92%). The largest contributors within that process are background processes related to palm oil production, which is used in the power sawing in the forestry operations.

The freshwater and marine ecotoxicity impacts are clearly linked to energy consuming activities. In the scenario where diesel fuelled machinery is used for IOC and TOC production, significant changes in the impacts occur. As shown in figure 4.11, the impacts become quite even between the two production systems when this diesel use is added. That they become even is because more diesel fuelled machinery is assumed to be used for the TOC than for the IOC (see section 2.4.2.2).

4.1.2 Interpretation of LCIA

The most significant take away from this LCA is that CC has a considerably larger impact throughout all studied impact categories except for land use. No clear trend in the ranking of the remaining three fibres is seen. Simplified, the results show that large energy use gives a larger impact for climate change and freshwater and marine ecotoxicity, while large fertilizer use gives larger impacts for eutrophication, acidification and terrestrial ecotoxicity. Also, important to keep in mind when evaluating the results is that all impacts are related to the final output, 1 tonne of staple fibres. Since this f.u. is based on weight, this suggests that systems with larger yields will have lower environmental impacts. However, this also depends on other factors, regarding inputs and outputs. The yield is nonetheless important. As mentioned in chapter 3, the yield is typically higher for CC than organic cotton, but not in this study. Ideally a sensitivity analysis should have been performed on different yields for the CC to compare with CC grown in regions with larger yields.

The calculation of field emissions that were made for IOC and TOC (see appendix B), considered type of fertilizer and amount, but did not consider other aspects of soil type, cultivation climate and land management. The calculations made were based on European agriculture, so the result would most likely differ when calculating based on specific parameters for the regions in Turkey and India. However, due to time and data constrains more specific calculations were not made in this study. One aspect of the organic cotton production systems, that likely would have had a large impact on emission rate if included, is that the cotton crops are mixed with intercrops. For example, in the LCA of organic cotton performed by Textile Exchange (2014), it is assumed that the erosion rate is 90% lower than for CC cultivation thanks to intercropping and other soil protection measures used by organic farmers. This suggests that the field emissions from IOC and TOC might be lower than what was calculated. However, it is difficult to definitively say if the net field emissions for IOC and TOC would be lower or not, since other parameters, like soil type, climate, water content in the soil etc., might increase the emissions from what was calculated based on the average European conditions. So, calculations including more regionally specific parameters for Turkey and India should ideally be done to make a fair comparison between the systems. Although, since the TOC system uses significantly higher amounts of fertilizer compared to the IOC one, it is still reasonable to believe that the field emissions, and therefore the acidification and eutrophication potential, would be larger for the TOC than the IOC at least.

CC was the only production system that was completely modelled using existing Ecoinvent processes. Efforts were made to model the organic cotton systems in a similar way to the CC one to provide a good foundation for comparison. However, it is possible that differences in the modelling might have influenced the results either in a favourable or a less favourable way for the organic cotton. This is more likely to have affected the impact on acidification, eutrophication and terrestrial ecotoxicity, since fertilizer use is the main contributor to these impacts and methods for calculating emissions from fertilizer use in this study possibly differs from the ones used for the Ecoinvent modelling. For the climate change impact, different modelling of the cotton systems seems like a smaller issue, since the main contributors to that impact for CC (mineral fertilizer production and irrigation) are not even used for the IOC and in very small quantities for the TOC (irrigation). Land use is not influenced by advanced calculations, so the modelling of the different systems should therefore not be very different. Regarding marine and freshwater ecotoxicity, the effect of potential differences in the modelling is not believed to have significant impact on the results, since it is the background processes that are responsible for the largest contributions. Differences in calculation methods of the direct field emissions for the cotton production systems should therefore not have a significant impact on marine and freshwater ecotoxicity.

One surprising result from the ecotoxicity assessment, is that pesticide use from the CC cultivation did not seem to have a major impact. This could have to do with the fact that toxicity assessments in LCA tools are not yet very advanced and do not include all chemicals. If the pesticide use has a larger toxicity impact than what was shown in the impact assessment here, it would still not change the ranking between the cotton fibres, since the CC is considered the worst in this category despite this uncertainty. The Tencel production, or the sulfur pulp production more specifically, is also a quite chemical heavy process. Whether the chemicals used in that process are assessed adequately or not also remains unclear. It is possible that Tencel production could have a higher ecotoxicity potential if other impact assessment methods were used. However, this is not further investigated, but remain as a potential source of error.

When comparing the LCA results in this study with those from other studies, some differences can be seen. These differences could indicate potential sources of error within this study that should be further investigated in future research. One of these important differences is regarding the climate change impact of CC production, which in this study differs significantly from other LCA findings. According to Sandin et al. (2019) climate change impact for CC usually range from 0.5 to 4 tonnes CO_2 equivalents per tonne fibre, which is much lower than the 9.8 tonne CO_2 equivalents per tonne fibre found in this study. This could indicate that the Ecoinvent process for CC production is not representative for CC cultivation in general, and that the impact should be much lower that what is stated in this study. Another important difference in the climate change impact results between this study and the LCA conducted by Textile Exchange (2014) is that direct field emissions were seen as the most important contributor in Textile Exchange's LCA while ginning was seen as the most important contributor in this study. This is likely due to different methods of calculating field emissions. As mentioned in section 2.4.1.6., the field emissions in this study were calculated based on European conditions, which might have influenced this effect. More specific calculations on the field emissions based on the conditions in India and Turkey should ideally be made to make a fair assessment on the effect of the field emissions.

4.2 Qualitative assessment

In this chapter the contribution to the driver invasive species is assessed qualitatively. As explained in chapter 2, overexploitation is not included in the qualitative assessment since it is not relevant for these types of production systems.

4.2.1 Invasive species

IPBES (n.d.-a) defines invasive species as "species whose introduction and/or spread by human action outside their natural distribution threatens biological diversity, food security, and human health and well-being". That species are invasive means that they "expand into and modify ecosystems to which it has been introduced". With this definition, one practice from the TOC farming could potentially contribute to this driver. This practice is the release of natural enemy insects into the farmland to combat pests, which is otherwise known as a form of biological control. This biological control method could contribute to invasive species in the area if the insects released are in fact invasive.

Biological control is an important component of integrated pest management (IPM), which is a pest management method that aims at minimizing the disruption to agro-ecosystems by encouraging natural pest control mechanisms (European Commission, n.d.). The aim of biological control is thus to take advantage of predation, parasitism, pathogenicity and competition that naturally occur between organisms, which can minimize the need for potentially harmful pesticides. Different organisms can be used for the biological control, including insects, nematodes and fungi (Swedish University of Agricultural Sciences, 2021). The interviewee from the TOC supplier (Agrona) did not specify which type of insect that was used or which type of pest it was supposed to target. Assessing whether this practice contributes to this driver of biodiversity loss or not is therefore very difficult to do.

In general, biological control is considered to be a successful method against pests (Myers & Cory, 2017). It is also considered to have positive effects for ecosystem services in the area, as biological control is linked to lower pesticide use, increased agricultural production, improved soil moisture conditions and reduced competition with native organisms (Myers & Cory, 2017; Van Driesche et al., 2010). However, it is estimated that around 1-2% of the released organisms have caused harm to species that were not targeted, i.e. not pests. Although it is rare, a few organisms used in biological control have also ended up being invasive (Myers & Cory, 2017). Choosing the biological control agents with care is therefore fundamental. This is of even greater importance in Turkey since the cotton is cultivated in a biodiversity hotspot.

With these risks in mind, one must also consider the risks of the alternatives. Using toxic agents to combat the pests, as done in the CC cultivation, can also harm surrounding ecosystems. Ideally, a risk assessment of the biological control species used in the TOC farming should be performed and compared with the risks of the alternatives, including the biodiversity hotspot perspective.

Another important aspect brought up by Agrona during the interview, is that over the last decades new types of insects are seen by the farmers in the area. This, Uçak from Agrona thought, is related to the climate change. If new types of insects in the area are treated with biological control, perhaps non-native species are required, which could imply higher risks for invasive species being introduced. Impacts of biological control on invasive species might thus be higher in the future.

From the definition of invasive species, release of insects as a biological control is the only relevant example found. For the pulpwood production, no risks of invasive species are known. For the CC, GM seeds are often used. However, although these seeds are alien to the natural ecosystem they are not considered invasive in this context, since these seeds are designed to not be able to spread and since the probability of gene transfer and contamination is relatively low (Rostoks et al., 2019).

5 Impact

When analysing the results from pressure/state, i.e. the contributions to the drivers of biodiversity loss, several points stand out. One important result is that no examples of contribution to overexploitation are found and only one example of potential contribution to invasive species is found. This implies that these drivers are the least important to take into consideration for the studied system. Regarding the potential contribution to invasive species from the TOC cultivation, it does not seem likely that the insects used would even be invasive. The potential contribution to invasive species is therefore assumed to be negligible in all systems today. However, it should be noted that invasive species is a very large problem that affects biodiversity. Even though the potential contribution to invasive species is low for the studied systems today, it does not mean that the contribution will be low in the future. With changes in climate, new insects might be introduced into the production regions (Sandra et al., 2021), which perhaps could require more high-risk species to be used in the biological control.

The impact on biodiversity loss should primarily be analysed based on the contributions to climate change, pollution and land use for the studied fibre production systems. Habitat change is generally seen as the most important driver to biodiversity loss on land (MEA, 2005; Mittermeier et al., 2011). This would suggest that land use is the most important driver to consider. The LCA results showed that IOC had the largest land use (due to lower yields than TOC) and TOC and Tencel had the lowest land use. However, in the LCA, land use was assessed as occupied land and it can be discussed whether land occupation is in fact the most important factor to look at when assessing the impact on biodiversity. Occupying land will have different impacts on biodiversity depending on where the occupation is done. Agricultural and forestry land occupation in a biodiversity rich area will have larger impacts on biodiversity than land occupation in a less biodiversity dense area (Sandin et al., 2019). The regional impacts of land use were not considered within the LCA. So, although the results showed that TOC had the lowest land use of the four fibres, the land use impact for TOC might in fact be the largest since it is the only fibre produced in a biodiversity hotspot. Further studies are required to assess the regional land use impact of the fibres, how these can be compared across different landscapes, and to what extent land use impacts are affected by production within a biodiversity hotspot.

Regarding the two remaining drivers, climate change and pollution, it is clear that CC has the largest contributions. Using these contributions as indicators for the impact on biodiversity, CC would have the largest impact on biodiversity. When analysing the contributions of the other fibres, no clear indication of which fibre has the highest or lowest impact on biodiversity is found. Tencel has quite large contributions to climate change and freshwater and marine ecotoxicity, but very low contribution to eutrophication, acidification and terrestrial ecotoxicity. IOC production requires large land use, but has otherwise among the lower contributions to the climate change and pollution impacts. TOC has low contributions to climate change, land use and freshwater and marine ecotoxicity, but among the larger contributions to eutrophication, acidification and terrestrial ecotoxicity. Further assessments need to be done on how the drivers, and aspects within drivers (pollution), can be weighted in order to determine the impact on biodiversity. Just like for land use, more information on how regional ecosystems are impacted by pollution is required to make an assessment on the impact on biodiversity. Lower pollution in an area with more sensitive ecosystem might have a more severe impact on biodiversity compared to higher pollution levels in an area with less sensitive ecosystem (Sandin et al., 2019).

6 Response

In this chapter appropriate actions, or responses, to reduce the impact on biodiversity are discussed. As shown in the DPSIR framework in figure 2.1, responses can be directed to different points in the causal chain, addressing the indirect drivers in the "driving forces", the emissions and land use in "pressure" and "state", or the translation of these into the "impact" on biodiversity. In this chapter, the responses are structured based on the different stages in the DPSIR framework. Undoubtedly, many actions can be taken to reduce the potential impact on biodiversity. In this chapter, some of these actions are discussed based on the previous findings. Important to also note is that the responses considered here are quite general. To formulate more specific and precise actions require more research into the local "states" and impacts on biodiversity, as mentioned in chapter 4 and 5.

6.1 Response to driving forces (DF)

Although the direct drivers of biodiversity loss are in focus for this thesis, the indirect drivers are important to consider when analysing ways to reduce impact on biodiversity since they are the root cause of these direct drivers. According to IPBES, the indirect drivers of biodiversity loss are related to societal values and behaviours, leading to human activities such as production and consumption (2019). In this case, reducing the need for producing and consuming clothes would therefore be a way to address the indirect drivers.

Many different measures could be taken to reduce the production and consumption of clothes in general, including government policies or shifting of societal norms. Regarding the production and consumption of NJ clothes, which is the case in this study, NJ is the actor with the most power to reduce these. NJ have in fact already included several aspects of circularity in their business model to address over-consumption and production. These circular measures include repair and reuse programs to prolong the life of their jeans, designing for recycling and using recycled fibres in their clothes (Nudie Jeans, 2020). Moving forward, these programs could be further developed to reduce the virgin fibre production, by for example expanding their repair and reuse concept to more stores and to include more product categories.

6.2 Response to pressure and state

The pressure and state correspond to the direct drivers of biodiversity loss studied in this thesis. Since these occur in the production of the fibres, the responses to these stages are formulated towards the fibre producers. Habitat change, climate change and pollution were identified as the most important drivers in the studied systems, and therefore the responses are focused on these.

Before discussing the specific actions that could be taken to reduce pressure and state, one general response regarding CC should be stated. The LCA results showed that

CC by far had the largest contribution to the drivers overall, which suggests that converting the cultivation to organic methods would lower the contributions to the direct drivers. However, as discussed in section 4.1.2, the uncertainties regarding the results for the CC should be analysed further before establishing this as a fact. What seems to cause the main contributions to the direct drivers for CC are irrigation and use of synthetic fertilizers, so reducing the use of these would have the largest impact on the contribution to the drivers.

Land use change is considered the most critical driver of biodiversity loss on land. Actions to reduce the use of land are therefore important to consider. Except for regional sensitivities to land occupation, yield is one of the main factors affecting land use. To increase the yield would reduce the land occupation requirements for the fibres. Yield is affected by many aspects in the cultivation, both those that can be controlled, like land management, and those that cannot be controlled, like climate. Up to a certain point there is a link between yield and amount of fertilizers applied (Ruixiu et al., 2017). However, as shown in the LCA, there is also a link between fertilizer use and pollution. So, careful considerations of the measures to increase yield should be done, to avoid trade-offs with other drivers.

One measure that potentially could increase yield and also reduce the contribution to the other drivers is by minimizing tilling of the soil. Tilling, which is applied in all cotton production systems, can have significant effects on GHG emissions of the soil and overall soil quality (Mangalassery et al., 2014; Shakoor et al., 2021). An interesting find from a recent meta-analysis on tillage (Shakoor et al., 2021) is that crop yield is significantly improved with no-till management under certain conditions, e.g. coarse textured soils. This indicate that under the right agricultural conditions, where yield would increase, no-tillage could lead to a reduction in climate impact per ton fibre. Cotton can be grown on both clayey and sandy loam types of soil (World Wildlife Foundation, 2010). Where the soil texture is sandier and coarser, no-tilling could be a good alternative for cotton management.

Previous LCAs of NJ’s supply chain show that the main climate impact of their jeans occurs in the fabric and jeans manufacturing as well as the use phase (Saric & Nellström, 2019; Åslund Hedman, 2018). The climate impact from the cotton cultivation is small in comparison. Although it is important to minimize impacts in all areas of the supply chain, NJ’s actions to reduce climate change should primarily not be focused on the cotton cultivation, but rather the fabric and jeans manufacturing. With that said, agriculture, forestry and other land uses cause around a quarter of all anthropogenic GHG emissions (Smith et al., 2014). Since cotton is a major agricultural crop, covering around 2.4 % of all arable land, measures to reduce climate impact for cotton cultivation are still important. The importance of climate change as a driver of biodiversity loss is also predicted increase (Arneth et al., 2020), which suggests that all climate change impacts are important.

In cotton production energy is mainly consumed in the ginning, transportation, machinery use during cotton cultivation and irrigation. The climate impact from the energy use could be reduced in several ways, for example by optimising the energy use, switching to renewable energy sources with lower carbon footprint, switching irrigation technique or optimising the fertilizer use. Since the use of fossil energy sources is a large contributor to climate change impact and also causes pollution (marine and freshwater ecotoxicity), this suggests that transition to more renewable energy sources could be one of the most effective measures. However, it is important to remember that there is sometimes a trade-off between climate change and biodiversity, and measures aimed at reducing climate change impacts might have negative effects on biodiversity. Hydropower is one example of a renewable energy source with significant impacts on local ecosystems (Wu et al., 2019). Further analysis on appropriate renewable energy alternatives in the respective regions, that avoid increased stress on biodiversity, is thus necessary.

Tencel production is more complex than cotton cultivation in terms of processes and inputs into the system. Assessing appropriate responses is therefore also more complex. For Tencel, the main contributions to the drivers are from energy use. Since Lenzing still uses fossil energy sources to a certain degree at their Austrian site, their focus should primarily be on reducing this amount.

6.3 Response to impact

Responses at the point of impact are important to consider. Different stakeholders working together with measures to reduce local biodiversity impacts could have even greater effects on biodiversity than reducing the contribution to pressure/state, since the main problems in the area would be addressed directly and perhaps not only those relating to the fibre production. However, since the impact on biodiversity was difficult to assess in this thesis, no specific responses can be formulated at the point of impact in the DPSIR framework.

7 Discussion of methodology and future research

In this chapter the methodology is discussed and suggestions for future research are presented. The results are only discussed in relation to the methodology here since chapter 4 to 6 have included both presentation and analysis of the results.

7.1 Discussion of DPSIR framework

The DPSIR framework, with the drivers to biodiversity loss used as indicators for the impact on biodiversity, has both advantages and disadvantages. Positive aspects of the framework include the cause-effect linkages of environmental issues, the communicative strength and the integration of stakeholders (Gari et al., 2015). These are important aspects in the assessment of biodiversity impacts, which make the DPSIR framework useful here. The framework has also been criticised. One of the main criticisms of the framework is that it simplifies the complex causal relationships that occur in the real world (Gari et al., 2015). The way the DPSIR framework is used in this thesis, with the drivers of biodiversity loss as indicators for the impact on biodiversity, is a further simplification of the causal relationships. This is probably the main drawback of the model used for this thesis, that it is too simplified. From the drivers it is not easy to assess what the impact on biodiversity is.

Some form of simplification is necessary to make an assessment on biodiversity. The drivers to biodiversity loss are very broad concepts, making it perhaps too simplified to work with. One way to make the indicators in the framework less simplified would therefore be to break down the drivers to biodiversity loss into more concrete aspects.

As the results showed, the contribution and relevance of the five drivers was not equal. The drivers to biodiversity loss used for this study represented the main drivers globally across different sectors. However, for assessments on biodiversity impact from the drivers to biodiversity loss to be as useful as possible, more specific drivers related to textile fibre production should ideally be used.

In the model that was used for this thesis several states (drivers) were used to determine the impact, which complicated the use of the framework. To use this model, some method for valuing the states (drivers) is necessary to determine the impact. As shown in the result, the fibre production usually has low contributions to some drivers but large contribution to another driver. Further investigation into whether the states/drivers can be weighted to each other is necessary in order to determine the usefulness of the model.

The model used for assessing biodiversity impacts in this thesis is not perfect. Several uncertainties on the applicability of the model exist. With that said, it is important to remember that assessing biodiversity with a method that is not perfect is better than not attempting to do it at all. Sandin et al. (2013) also highlight this, that given the acute need for biodiversity assessments, using a method that is an “acceptable ‘better than nothing’ option” is preferred over omitting biodiversity impacts in environmental assessments altogether.

Since the regional aspect of environmental stressors is important when assessing impacts on biodiversity, perhaps departing from the regional biodiversity impact would be more useful. The framework created could then be used, but in the reversed direction, as illustrated in figure 7.1. The impact on, or expected threat to, biodiversity in the region would be identified first, by doing local assessments. Based on this, the drivers (states) to that impact would be analysed. By establishing the main drivers to biodiversity loss in the region, the pressures contributing to those drivers could then be identified. By having knowledge on what types of emissions and other pressures that are causing threats to biodiversity, NJ and other stakeholders (driving forces) can more easily identify which of their operations that have the largest impacts on biodiversity and make informed decisions on where to focus their mitigation procedures (response). This “reversed” approach to the framework could possibly lead to more concrete and effective measures to reduce negative impacts on biodiversity, since the responses would be formulated from the main threats to biodiversity in the region.

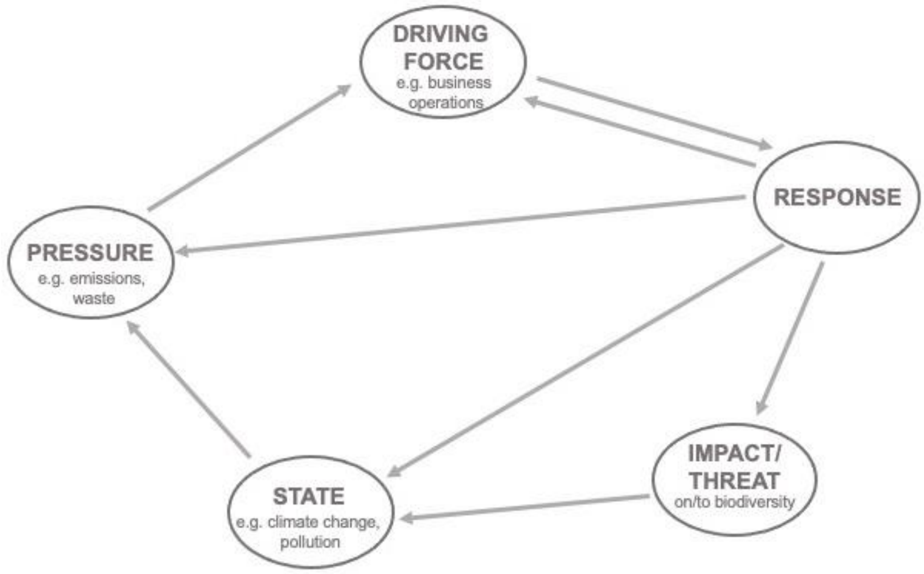

Figure 7.1 “Reversed” approach of DPSIR framework.

In the following sections, 7.2-7.3, the methodologies used within the DPSIR framework are further discussed.

7.2 Discussion of LCA methodology

LCA was chosen as one of the methods to use within the framework since it could be used for assessing three of the drivers, and also present the results quantitatively. Quantifying environmental impacts is useful since it facilitates comparisons. The main strength of LCA is it’s holistic perspective, including background activities that otherwise might be ignored. The LCA also shows what processes that have the largest contributions to the environmental impact, which is useful to know when analysing how to improve the environmental performance (response).

An important limitation in LCA is the lack of data and information available to make qualified estimations for certain aspects of environmental impacts. Even though LCA is the most commonly used method for environmental impact assessment of agricultural products (van der Werf et al., 2020), there are several limitations associated with LCA assessment for this type of product. Toxicity and land use impacts are two impact categories with lack of data. That these impact categories lack data Sandin et al. (2019) argue is largely owing to the difficulty in collecting inventory data and translating this data to quantifiable environmental impacts. Regarding toxicity impacts in LCA, calculated based on Ecoinvent and data from other databases, they are mostly related to energy processes (Roos, 2017). This is also what the ecotoxicity results showed in the LCA performed in this thesis. Regarding the large uncertainties concerning toxicity assessments in LCA methodology, the validity of the ecotoxicity impacts from the LCA in this thesis should be questioned and further studied.

Another limitation of the LCA methodology is that it is quite complex. When doing LCAs many important methodological choices are made along the way. As a relatively new LCA practitioner, these choices have sometimes been difficult to make. To calculate the outputs/emissions from the land use for the organic cotton cultivation was quite complex. Many factors influence the emissions, and it was not possible to account for all of them in the calculation of the emissions. The complexity of calculating emissions and making methodological choices is an important limitation to LCA, which should be considered when determining if it is a good method to use in a framework for NJ. Future work should consider if better alternatives to LCA exist for assessing climate change, pollution and land use in the framework.

7.3 Discussion of interview methodology

The data provided by the suppliers in the interviews is assumed to be correct. The accuracy of this data has however not been verified, for time and logistic reasons. Due to communication barriers, or other unknown factors, there might therefore be errors in the data and information provided and used for this thesis.

The interviews were carried as video calls. Ideally, this study would have included visits to the areas of production. This would likely have reduced uncertainties in the data, for example regarding machinery use in the organic cotton cultivation, and would have allowed for a better understanding of the local conditions that was not possible to assess over video call. By visiting the production sites, more precise questions and follow up question are also likely to have been formulated, which could have resulted in more precise and extensive answers from the interviewees.

7.4 Future research

As previously discussed, more research is needed to fully answer the research questions set out for this thesis. Without integrating the local sensitivities to the fibre production activities for example, it is very difficult to determine the contribution to the drivers, and in turn the impact on biodiversity and relevant responses. Further research on how the regional differences influence the contribution to the drivers is thus needed.

Further analysis of the LCA data and results are also needed to fully answer the research questions. As discussed in section 4.1.2., uncertainties regarding the reliability of the inventory data, calculated emissions and toxicity assessments exist, which should be further investigated to ensure reliable results. For example, in future studies emissions from the organic cotton production should ideally be calculated with more regionally specific parameters and include the effect of different land use practices (like intercropping). The conventional cotton production process should also be analysed in more detail and compared with other processes for conventional cotton cultivation to establish what is representative for that type of production.

Finally, to answer RQ2 more research is needed to establish if and how the drivers can be weighted to each other. The results showed that the no fibre production system consistently had the highest or lowest contribution across the drivers, which makes conclusions on the impact on biodiversity impossible to draw. It is likely that larger contribution to one driver leads to lower contribution to another driver. For example, large fertilizer use could cause a larger contribution to pollution but also lead to lower land use thanks to higher yields. If and how the drivers can be weighted is therefore essential to investigate if using the model created for this thesis.

8 Conclusion

From the study no clear conclusions can be drawn on which fibre has the highest or lowest contribution to the drivers of biodiversity loss and consequently the impact on biodiversity. The results show that production of conventional cotton have significantly larger contribution to climate change and pollution compared to the other fibres, which could indicate that it also has the largest impact on biodiversity. For the remaining fibres, Indian organic cotton, Turkish organic cotton and Tencel, no indication of which fibre has the largest impact on biodiversity can be seen, since neither system consistently has the largest or smallest contribution to the drivers.

From the analysis of the contribution to the drivers, overexploitation and invasive species seem to be the least important drivers to consider for textile fibre production, at least in Nudie Jeans' supply chain. Overexploitation is not considered relevant for cotton and Tencel production at all, and only one example of potential contribution to invasive species was found, for the Turkish organic cotton. This suggests that actions to reduce impact on biodiversity loss primarily should be focused on land use, pollution and climate change. These actions could include using renewable energy sources, reducing tillage and optimizing fertilizer use.

In order to assess the biodiversity impact from the different fibres and formulate more precise responses to reduce this impact, more research is needed on the regional sensitivities to the drivers and aspects within them. Furthermore, for assessing the impact from the model created, more knowledge on how the drivers can be weighted in relation to one another and improved methods for toxicity assessments are necessary.

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Appendix A

Interview questions prepared for interviews with Chetna Organic and Agrona (not including follow up questions):

- What does the agricultural landscape look like?
    - How large are the cotton fields?
    - Is it a cotton monocrop?
    - Is there any inter-cropping? If yes, what type of plants?
    - Do you have any cover crops in between cotton plantation?
    - Are there any natural or semi-natural habitats (forest, trees, bushes etc.) for animals in the landscape?

- Is the cotton only rain-fed or is there an irrigation system in place?
    - If irrigated, what quantities of water are used?

- What (natural) fertilizers are used? I read this on the website, does this mean
    - How are they applied?
    - What quantities are used?
    - Are there any measures taken to reduce fertilizer leakage?

- How are weeds and pests managed?
    - Is there any soil tillage? If yes, how often and how deep in the soil?

- Are machines used in the cultivation and harvesting?
    - If yes, how much energy do these require? And what type of fuel?

- What is the cotton yield at harvest?
    - How much of that yield is lint cotton (fibers)?
    - How often is cotton harvested?
    - When harvesting, is debris left on the ground or removed?

- Is the cotton perennial or annual?
    - How often are new plants sown?

- Is the farming certified according to any standard?

Interview questions prepared for interview with Lenzing (not including follow up questions):

Tencel production:

- Are data on the energy, water and chemical quantities used something you are willing to share?
- How much of the incoming water is recirculated?

- When the fiber leaves the Lenzing site, it is stable fiber ready for yarn spinning?

Other questions on LCA:

- I have read in the sustainability reports that you do LCAs, but I couldn't find them published anywhere. Do you know if they are published or are they only for the internal use?
- Are there any general findings from the LCAs that you know and that you can share?
- Is the forestry product used mainly branches and small trees from thinning out the forest? So, is it correct to say that when looking at the economic value of the forest, the wood used for the Tencel production has a quite "low" value?
- In the sustainability reports you write that in the pulp production around 40% of the wood become pulp and the remaining 60% become bioenergy and biorefinery products. Based on economic allocation of the wood, what would this division between pulp, bioenergy and biorefinery products be?

Questions about Austrian forestry:

- Do you know how biodiversity is accounted for and assessed in Austrian forestry?
- Do you know if any chemicals are used in the Austrian forestry operations?
- From your sustainability reports I understood it as Austrian forests were PEFC certified and not FSC certified, is that correct?

Appendix B

Inventory data for Indian organic cotton (from Chetna Organic)

Inventory data given by Chetna Organic

Input data given	Amount given	Modelled as in OpenLCA	Amount modelled in OpenLCA
Cotton seeds	450 grams/acre	Organic cotton seeds	450 grams/acre
Fertilizers			
Enriched manure	5 tonne/ha	Manure, liquid, cattle	2.7 kg/kg seed-cotton
Vermicompost or enriched manure	1 tonne/ha	Compost	0.54 kg/kg seed-cotton
Liquid manure	0.75 L + 150 L water per acre	Manure, liquid, cattle Water	0.000949 kg liquid manure/kg seed-cotton 150 L water/acre
Organic aminos	0.75 L + 150 L water per acre	Manure, liquid, cattle Water	0.0013068 kg/kg seed-cotton 150 L water/acre
Pest management			
Prophylactic spray	0.75 L + 150 L water per acre (6 sprayings)	Water (the prophylactic component was not included since no fitting replacement was found in OpenLCA)	(150 * 6 =) 900 L water/acre
Assumed additional inputs			
Diesel for machinery use	-	Diesel, burned in agricultural machinery	0.62 MJ/kg seed-cotton

Seed-cotton cultivation process modelled in OpenLCA for Indian organic cotton. Inputs and outputs are based on 1000 kg of seed-cotton.

	Amount	Unit	Notes	Background data (provider)
Input				
Cotton seeds, organic	0.6	kg	Amount based on data from Chetna Organic (see table above)	India, from ginning (UUID: 46cc1907-5ea3-3a02-9ef0-0d0daa459b0f)
Manure, liquid, cattle	2702	kg	Amount based on data from Chetna Organic (see table above)	Global, recycled content (UUID: 8540aacb-3c81-3e0f-a487-30533900f5c5)
Compost	540	kg	Amount based on data from Chetna Organic (see table above)	Global, biowaste (UUID: 60e92884-7929-

				3154-9323-430e52e95394)
Water, in air	6103	m^3	Calculated based on data from Textile Exchange (2014)	-
Water, river	1.6	m^3	Amount based on data from Chetna Organic (see table above)	-
Carbon dioxide, in air	1500	kg	Based on data from Ecoinvent process for conventional cotton (UUID: bf7a0455-5cf9-3ee1-82a9-fd5bdcb7c4e2)	-
Occupation, annual crop, non-irrigated	5396	m^2*a	Amount based on data from Chetna Organic (see table above)	-
Diesel, burned in agricultural machinery[1]	623	MJ	Based on data from Textile Exchange (2014)	Global (UUID: 8a428767-9f57-317e-b918-40187509d68a)
Output				
Seed-cotton	1000	Kg	Reference output flow	-
Cadmium, to soil	$7.0E^{-5}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Cadmium (ion), to water	$5.4E^{-6}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Chromium, to soil	$-2.4E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Chromium (ion), to water	$4.4E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Copper, to soil	$-2.8E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Copper (ion), to water	$1.8E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Lead, to soil	$1.0E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Lead, to water	$3.4E^{-5}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Mercury, to soil	$6.3E^{-5}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Mercury, to water	$5.7E^{-7}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Methane, to air	$4.8E^{-2}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Nickel, to soil	-1004	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-

Ammonia, to air	3.1	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Nitrate, to water	1.3	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Nitrogen oxides, to air	0.1	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Phosphorus, to water	0.1	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Water, to air	3113	m^3	Calculated based on data from Textile Exchange (2014)	-
Water, to groundwater	2381	m^3	Calculated based on data from Textile Exchange (2014)	-
Water, to surface water	610	m^3	Calculated based on data from Textile Exchange (2014)	-
Zinc, to soil	$2.8E^{-2}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Zinc (ion), to water	$9.5E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-

1. Only included in the scenario with machinery use.
2. Calculation based on model found in the section “emissions of heavy metals to agricultural soil, surface water and ground water” in Nemecek and Kägi (2007). The calculation model is based on European conditions.
3. Calculation based on emission models found in (Brentrup et al., 2000) with European conditions. Additional data regarding fertilizer characteristics was added from Lorimor and Powers (2004) and Province of Manitoba (2009)

Cotton lint production (ginning) process in OpenLCA for Indian organic cotton. Inputs are based on the functional unit, 1000 kg of staple fibre (cotton lint).

	Amount		**Notes**	**Background data (provider)**
Input				
Seed-cotton	2470	kg	Calculated based on cotton lint / seed-cotton ratio, provided by Chetna	Seed-cotton cultivation calculated in previous process
Electricity	478	MJ	Calculated based on data from Textile Exchange (2014)	Indian electricity mix (UUID: 17eb941a-df8c-3ef5-9f2f-26ee41b1be47)
Transport	222	t*km	Calculated based on data from Textile Exchange (2014)	Global lorry transport (UUID: 5791df6e-7057-3796-9668-b1348e739c82)
Output				
Cotton lint	1000	kg	Functional unit / reference flow	-

Inventory data for Turkish organic cotton (from Agrona)

Inventory data given by Agrona

Input data given	Amount given	Modelled as in OpenLCA	Amount modelled in OpenLCA
Cotton seeds	3 kg/acre	Cotton seeds, organic	3 kg/acre
Irrigation water	6 tonnes/ha/year	Irrigation	6 tonnes/ha
Fertilizers			
Manure and compost	170 kg N/ha/year	Manure, solid, cattle Compost	4.37 kg manure/kg seed-cotton[1] 2.62 kg compost/kg seed-cotton[1]
Pest management			
Garlic and insects	No amount or detail given	Not included in LCA, no appropriate alternatives in Ecoinvent were found	-
Assumed additional inputs			
Diesel for machinery use	-	Diesel, burned in agricultural machinery	1.088250121 MJ/kg seed-cotton

1. Assumed that 50% of N amount is manure and 50% of N is compost. N content of compost is assumed to be 1.5% and 0.9% in manure, based on data from Textile Exchange (2014).

Seed-cotton cultivation process modelled in OpenLCA for Turkish organic cotton. Inputs and outputs are based on 1000 kg of seed-cotton.

	Amount	Unit	Notes	Background data (provider)
Input				
Cotton seeds, organic	3.4	kg	Amount based on data from Agrona (see table above)	Global, from ginning (UUID: f791ee46-d1a3-32cd-b031-144a690bf54b)
Manure, solid, cattle	4368	kg	Amount based on data from Agrona (see table above)	Global (UUID: b79a6a4f-3524-3473-8e8a-99b181f7d606)
Compost	2621	kg	Amount based on data from Agrona (see table above)	Global (UUID: 88f58667-ee11-31cc-8564-dace7807f429)
Irrigation	6.9	m^3	Amount based on data from Agrona (see table above)	Global mix of irrigation (UUID: 35c9f11b-0fed-3c1b-86cf-87ced0c2db0f)

Water, in air	6103	m^3	Calculated based on data from Textile Exchange (2014)	-
Carbon dioxide, in air	1500	kg	Based on data from Ecoinvent process for conventional cotton (UUID: bf7a0455-5cf9-3ee1-82a9-fd5bdcb7c4e2)	-
Occupation, annual crop, non-irrigated	3238	m^2*a	Amount based on data from Agrona	-
Diesel, burned in agricultural machinery[1]	1088	MJ	Based on data from Textile Exchange (2014)	Global (UUID: 8a428767-9f57-317e-b918-40187509d68a)

Output

Seed-cotton	1000	Kg	Reference output flow	-
Cadmium, to soil	$3.1E^{-4}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Cadmium (ion), to water	$1.3E^{-5}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Chromium, to soil	-6.3^{-3}	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Chromium (ion), to water	$7.2E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Copper, to soil	$2.1E^{-2}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Copper (ion), to water	$1.6E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Lead, to soil	$3.3E^{-3}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Lead, to water	$9.5E^{-5}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Mercury, to soil	$3.7E^{-4}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Mercury, to water	$5.7E^{-7}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Methane, to air	0.2	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Nickel, to soil	$6.8\ E^{-4}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Ammonia, to air	15.6	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Nitrate, to water	62.5	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-

Nitrogen oxides, to air	1	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Phosphorus, to water	0.1	Kg	Calculated based on calculations found in Brentrup et al. (2000) [3]	-
Water, to air	230	m^3	Calculated based on data from Textile Exchange (2014)	-
Water, to groundwater	176	m^3	Calculated based on data from Textile Exchange (2014)	-
Water, to surface water	45	m^3	Calculated based on data from Textile Exchange (2014)	-
Zinc, to soil	0.1	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-
Zinc (ion), to water	$1.2E^{-2}$	Kg	Calculated based on calculations found in Nemecek and Kägi (2007) [2]	-

1. Only included in the scenario with machinery use.
2. Calculation based on model found in the section "emissions of heavy metals to agricultural soil, surface water and ground water" in Nemecek and Kägi (2007). The calculation model is based on European conditions.
3. Calculation based on emission models found in (Brentrup et al., 2000) with European conditions. Additional data regarding fertilizer characteristics was added from Lorimor and Powers (2004) and Province of Manitoba (2009)

Cotton lint production (ginning) process in OpenLCA for Turkish organic cotton. Inputs are based on the functional unit, 1000 kg of staple fibre (cotton lint).

	Amount		**Notes**	**Background data (provider)**
Input				
Seed-cotton	2470	kg	Calculated based on cotton lint / seed-cotton ratio, provided by Agroma	Seed-cotton cultivation calculated in previous process
Electricity	478	MJ	Calculated based on data from Textile Exchange (2014)	Middle East electricity mix (UUID: c7470139-43a2-3745-94d3-edcec6946008
Transport	222	t*km	Calculated based on data from Textile Exchange (2014)	Global lorry transport (UUID: 5791df6e-7057-3796-9668-b1348e739c82)
Output				
Cotton lint	1000	kg	Functional unit / reference flow	-

Inventory data for conventional cotton production

Seed-cotton cultivation. This inventory data is entirely based on the Ecoinvent process "seed-cotton production, conventional" with UUID: bf7a0455-5cf9-3ee1-82a9-fd5bdcb7c4e2 in version 3 of the database. A full list of the inventory data is not included since full access to the data requires a license.

Inventory data for Tencel production

	Amount	Unit	Notes	Background data (provider)
Input				
Sulfate pulp, bleached	1000	kg	Assumed that no water or NMMO is part of the final product and that no losses take place in the spinning	European data, pulp produced from softwood, Elemental Chlorine Free (ECF) and Totally Chlorine Free (TCF) pulp (UUID: 3445bed0-b96e-39f8-b776-bc56e9eb38c7)
Solvent, organic	20	kg	Data based on article by Perepelkin (2007) of specific NMMO consumption. Note that the amount used is higher, since >99% is recycled. No specific data for NMMO was found in Ecoinvent, why this generic solvent was used.	Global data (UUID: 78c5a956-0b45-3bcc-8358-1e055ddc7775)
Water, river	66.6	m^3	Calculated based on amount used in the viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14). Assumed to be 47,6% of water used in viscose production based on data from Shen et al. (2010).	Natural flow, no provider
Heat, district or industrial, other than natural gas (waste)	1718.6	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Austrian data, municipal waste incineration (UUID: 17d904c5-eab9-3999-8c21-771a6ede671e)
Heat, district or industrial, other than natural gas (biomass)	1312.9	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	European data, energy from sulfate production (UUID: b955a50d-ed30-3fe3-aeda-44557d9ffdbc)
Heat, district or industrial, other than natural gas (oil)	27.5	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Austrian data, oil (UUID: be7047d6-d8b5-3c70-954e-acbb218534e4)
Heat, district or industrial, other than natural gas (coal)	224.4	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Austrian data, hard coal (UUID: ac3237a8-b1dd-37ae-aacd-4e6260c0e717)

Electricity, medium voltage (oil)	4.0	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Europe without Switzerland, petroleum refinery operation (UUID: b7ccb7db-06fe-3e8c-8284-56565b493ea9)
Electricity, low voltage (biomass)	405.7	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Swiss data, biomethane (UUID: 848f02f0-f787-372b-b22d-524312c87e1e)
Electricity, low voltage (natural gas)	244.1	MJ	Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14), and energy consumption/type based on data from Lenzing and Shen et al. (2010)[1].	Swiss data, natural gas burned in solid oxide fuel cell (UUID: 95006c94-230d-3684-98d3-a3a2bb01097d)

Output

Tencel fibre	1000	kg	Functional unit / reference flow	
Wastewater	0.05	m^3	Calculated based on water input/output ratio from Ecoinvent viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14) and adding solvent input as wastewater. It is assumed that the entire (specific) consumption of NMMO goes to wastewater.	European market (without Switzerland) (UUID: 77c39554-0d59-3671-a0ee-3074a76b23cc)
Water (emission to air)	13.6	m^3	Calculated based on water input/output ratio from Ecoinvent viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14)	Natural flow, no provider
Water (emission to water)	53.9	m^3	Calculated based on water input/output ratio from Ecoinvent viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14)	Natural flow, no provider

1. Heat/electricity ratio based on viscose process (UUID: 23f0cabc-ea80-36bb-a481-5275143dbd14). Energy use is assumed to be 7.15% lower for Tencel production compared to the viscose process, based on data from Shen et al. (2010). The division of energy sources (Lenzing Group, 2014) is 87.3% renewable, 0.8% oil, 6.2% natural gas and 5.7% coal. Based on Lenzing's 2019 sustainability report, it is assumed that 50% of the renewable energy comes from waste and 50% from biomass.

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