Methodological Issues in the LCA Procedure for the Textile Sector

A case study concerning fabric for a sofa

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Preface

This work was done as a part of my doctoral studies. The overall purpose of the studies is to give suggestions for solving some of the methodological issues within the LCA method when used in the field of textiles.

The studies are being carried out at the Environmental Systems Analysis Department at Chalmers University of Technology in Gothenburg, Sweden and are being financed mainly by Stiftelsen Svensk Textilforskning and CPM, Centre for Environmental Assessment of Product and Material Systems. I would like to thank CPM and Stiftelsen Svensk Textilforskning for funding, Adjunct Prof. Bengt Steen for serving as my supervisor and Maria Walenius Henriksson at IFP Research AB for her critical review.

Disclaimer

This LCA study is not to be used for commercial applications. Its purpose is to identify methodological issues in a realistic context. In specific cases, both impact data and the ranking of alternatives may vary.

Confidentiality

On the request of Stiftelsen Svensk Textilforskning, most tables in the inventory part of the report are in appendix 6 and confidential.

Abbreviations

AE	Alcohol Ethoxylate
AOX	Adsorbable Organic Halogens
BOD	Biological Oxygen Demand
CFC	ChloroFluoroCarbons
CMC	CarboxyMethyl Cellulose
COD	Chemical Oxygen Demand
DALY	Disability adjusted life years
DAS-1	Triazinylaminostilbene-type of fluorescent whitening agent
DS	Dissolved Solids
EDIP	Environmental Development of Industrial Products (a combined characterization and weighting method)
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EPS	Environmental Priority Strategies in Product Design
EPS 2000d	EPS 2000 default impact assessment method (a combined characterization and weighting method)
GE	Genetically engineered (=GMO)
GMO	Genetically Modified Organisms (=GE)
HC	Hydrocarbons
LAS	Linear Alkylbenzene Sulphonate
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non Methane Volatile Organic Compounds
PA	Polyamide (in this case study: Polyamide 66)
PAH	PolyAromaticHydrocarbons
PDF	Potentially Damaged Fraction
PSR	Product Specific Rules (in this context for EPDs)
Seed cotton	Raw cotton, cotton including fibers, seed and waste
SS	Suspended Solids
TAED	Tetra Acetyle EthyleneDiamine
TOC	Total Organic Compounds
TS	Total Solids
VOC	Volatile Organic Compounds

*It is assumed that the reader knows the basics of chemistry, and so the basic chemical abbreviations are not explained here.

Summary

Because the Swedish textile industry is broadening its environmental concern towards the entire textile chain, more knowledge about the LCA methodology is needed. In order to explore the methodological issues specifically for the textile sector, an LCA case study was made.

The goal of this case study was to identify, map and discuss LCA related methodological issues in the textile sector. This was done through an LCA study, with the goal of ranking three fabrics types for a sofa.

The LCA included three fiber types: conventional cotton, Trevira CS (a flame retardant polyester) and wool/polyamide. The entire life cycle, from raw material extraction to incineration of the fabric was studied. Production was assumed to take place as far as possible in Sweden, and representatives (production or environment managers) for Swedish plants were interviewed. Data for two German plants were also collected. Literature data were used, both to fill in data gaps and to compare with the data from the interviews.

Two main types of methodological issues are recognized in the case study:

- Problems in following the LCA methodology, as defined by ISO 14040 (1997) to ISO 14043 (2000). These are referred to as methodological issues regarding the *procedure*.

- Methodological issues in the LCA methodology influencing the ability of the LCA model as defined by ISO 14040 (1997) to 14043 (2000) to fulfill the expectations or answer the questions raised in a specific problem situation. These types are referred to as methodological issues regarding the *model*.

The main LCA method development needs for the textile sector are
- to improve the resolution of inventory data, especially for cotton cultivation including land and irrigation water use, but also for land use in sheep farming or for the production of chemicals and
- to develop impact assessment methods with higher resolution for the agriculture activities especially for cotton cultivation including assessment of land and irrigation water use, but also for land use in sheep farming.

The following methodological issues were only approximately dealt with in the sensitivity analysis, thus uncertainty remains to what extent they are important issues:

- The need to obtain better inventory data and to perform impact assessment of health effects in the work environment. When more of the production than in this case takes place in the developing world, this issue may be particularly important.
- The need to collect inventory data for and to assess the effects of chemicals discharged to water. Moreover, if most of the fabric production takes place in countries without wastewater-treatment and where more environmentally impacting chemicals are used, the effects of chemicals emitted to water become more important.
- The need to collect inventory data for and to assess the use of GE cotton.

The LCA weighting methods used in the study gave less impact scores to the polyester type of fabric than to the natural fibers in the study. None of the costs of the environmental impacts from the three textile types as determined by the EPS 2000d method is high compared to the value of the fabrics as determined by their price. Table 1 shows the main environmentally impacting steps for each fiber type.

Table 1: The main environmentally impacting steps for each fiber type
According to the EPS 2000 default impact assessment method (EPS 2000d)

Cotton	Cotton cultivation, wet treatment of the fabric (the processes includes dyeing)
Trevira CS	Polyester fiber production
Wool/polyamide	Sheep farming, ring spinning , nylon fiber production, wool scouring

The significant issues found in the case study are:

- the production phase, especially
    - irrigation water type in the cotton growing activity,
    - yield (for example regarding cotton cultivation),
    - air emissions of methane and ammonia from sheep or sheep manure,

and if unsustainable use of irrigation water does not overrule the results:

- fossil energy extraction and use,
- type of electricity used, e.g nuclear power and
- system expansion/allocation choice. The system expansion/allocation choice in sheep farming, where oddments were assumed to replace first class wool had most influence. Fuel replacement in the incinerator and recycling of packaging material had less influence.

Less significant issues are:

- use phase,
- production of drinking water,
- freighter and truck transports,
- business trips,
- waste management of used fabrics or fiber waste and
- type of heating value used (gross or net calorific).

Issues not/not (fully) inventoried or assessed are:

- the effects of chemicals discharged to water,
- inclusion of a wastewater-treatment plant. With the weighting methods used it is not critical but maybe it might be if the chemicals emitted to water had been followed after the wastewater-treatment plant,
- eutrophying discharges to water (with the weighting methods used they are not important, but the agricultural steps were not sufficiently studied),
- land use,
- human health impacts from the working environment,
- the effects of the use of GE cotton,
- the effects of lubricants,
- production of packaging materials,
- production of chemicals and
- risks with e.g. mining or nuclear power.

1 Introduction

In recent decades, companies in the Swedish textile industry have worked on solving their emission problems from their own production sites. Lately the companies have also started to broaden their environmental care to the entire textile chain. Therefore they have identified a need for Life Cycle Assessment (LCA) knowledge and development. LCA is, as noted in LCA standard, ISO 14040 (1997): “still at an early stage of development”. The standard also says: “Considerable work remains to be done and practical experience gained in order to further develop the level of LCA practice.”

It is therefore important to find and characterize remaining methodological issues in the LCA methodology, in this case for the textile sector. Studying a specific sector also makes it possible to estimate how important the different methodological issues are for it.

A few LCAs for the textile sector were carried out in the 1990s and later; some of them reported in a literature review by Dahllöf (2003). The methodological issues found in these reports were discussed in the review, but by doing a case study, more methodological issues could be identified and systemized. The present report shows such a case study, where the methodological issues were identified, discussed and mapped.

1.1 Definition of LCA

In this study, LCA is defined as an environmental assessment method following the procedure in ISO 14040 (1997) to ISO 14043 (2000). The idea underpinning the LCA method is to assess the environmental impact of a product, process or service during its entire life cycle. The text in the standard was interpreted in the broad sense, for example when it is stated in ISO 14040 (1997) that “LCA typically does not address the economic or social aspects of a product”, I have interpreted it as meaning that it should, in principle, be possible to include such aspects.

1.1 Help for the reader

The requirements (recognized by the word “shall”) in the standards were followed, but not always the recommendations. This report is written according to what the ISO 14040 (1997)-14043 (2000) standards say about reporting.

The methodological issues were numbered and methodological issues of the same type have the same number. The iterative process was carried out in accordance with ISO 14041 (1998), which states in clause 5.1.2: “LCA is an iterative technique. Therefore the scope of the study may need to be modified while the study is being conducted as additional information is collected”. The discussion about the methodological issues is found in chapters 8 and 9. Some important methodological issues (“limitations”) are already mentioned in the introduction in ISO 14040 (1997) and here discussed in relation to the methodological issues found in this study, see chapter 8.5.

It is important to point out that the case study was an LCA with the emphasis on identifying methodological issues. For many activities, it should be possible to obtain better data by investing in data acquisition.

In the introduction to ISO 14040 (1997) it is stated that: “in all cases, the principles and framework established in this International Standard should be followed”. This could be interpreted as meaning that all subsequent sections with requirements are only recommendations, since the word “*should*” (and not shall) is used in the quotation above (methodological issue 1). I presume that this “should” actually means “shall” or “must”.

2 Goal and scope

The requirements for the goal and scope definition are described in ISO 14041 (1998). The description in clause 8 in the standard regarding how to report on an LCI study was followed with additions from clause 5: “Definition of goal and scope” and clause 5.1 in ISO 14040 (1997):”Goal of the study”. These clauses are not 100% consistent, which may create confusion for the practitioner (methodological issue 1). The mandatory items for a third-party report given in clause 8 are mainly used as headings below. The first sentences in clause 8 in ISO 14041 (1998) are not clear: “The results of an LCI study shall be fairly, completely and accurately reported to the intended audience as described by the relevant parts of clause 6 of ISO 14040 (1997). If a third-party report is required, it shall cover all items marked with an asterisk. All additional items should be considered”. If the reader wants to follow this sentence, it is logical for him to look in clause 6 in ISO 14040 (1997) for the asterisks and not in clause 8 in ISO 14041 (1998), and to use the headings clause 6 for the report. I think the authors of the standard mean the headings under clause 8: why would the headings be there otherwise (methodological issue 1)? It is also confusing that the headings do not have asterisks, while the subheadings do.

2.1 Goal of the study

According to clause 8 in ISO 14041 (1998), the goal of the study shall cover:

i) reasons for carrying out the study,
ii) its intended applications,
iii) the target audiences.

This is in accordance with ISO 14040 (1997) which states: ”The goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated”.

The goal of this case study was to identify, map and discuss LCA methodological issues in the textile sector.

This was done by carrying out an LCA study with the goal of ranking three fabric types for a sofa.

i) The main reason for carrying out the study was that the LCA methodology is not fully developed and different sectors have different method development needs. This work was being done on the basis of interest from the textile industry in Sweden.

ii) The study could be used for further development regarding methodological issues in the efforts to establish Product Specific Rules (PSRs) for Certified Environmental Declarations (EPDs) in the textile sector (the Swedish Environmental Management Council 2000) and for the modification work of the ISO 14040 (1997) - ISO 14043 (2000) standards.

iii) It is intended to be used by purchasers, designers, etc., in the textile industry as well as for researchers and others working with the ISO 14040 (1997) - ISO 14043 (2000) standards.

2.2 Scope of the study

The following shall be covered in the scope according to clause 8 in ISO 14041 (1998)*:

1) Function:
    - i) statement of performance characteristics
    - ii) any omission of additional functions in comparisons
2) Functional unit:
    - i) consistency with goal and scope
    - ii) definition
    - iii) result of performance measurement
3) System boundaries:
    - i) omissions of life cycle stages, processes or data needs
4) Data categories
    - i) quantification of energy inputs and outputs
    - ii) assumptions about electricity production
    - iii) combustion heat
6) Criteria for initial inclusion of inputs and outputs
    - i) descriptions of criteria and assumption
    - ii) effect of selection on results
    - iii) inclusion of mass, energy and environmental criteria (comparisons)
7) Data quality requirements

* It is not stated that these *headings* shall be included in the report, but since this is a study intended to identify the methodological issues, it is convenient to use these items as headings.

2.2.1 Function

The function was to provide a surface covering for a sofa.

2.2.1.1 Statement of performance characteristics

The fabrics were assumed to not to be worn out before they were disposed of, a realistic scenario for Swedish conditions. Therefore the abrasion resistance was not taken into consideration in the study, while the effect of different lifetimes of the fabrics is discussed in chapter 4.3.7.

2.2.1.2 Omission of additional functions in the comparisons

This study focused on surface covering of the sofa and not on other aspects such as aesthetics and comfort issues or more quantifiable aspects. If they were to be considered, it could be difficult to define a functional unit (methodological issue 2).

2.2.2 Functional unit

2.2.2.1 Consistency with goal and scope

Considered

2.2.2.2 Definition

The functional unit was: surface covering of a 3-seat sofa for private use during 10 years.

The reference flow was: average mass of fabrics consumed (the demand for a reference flow is mentioned in clause 5.3.2 in ISO 14041 (1998) but is not mentioned in clause 8 in the standard, probably because it is not a demand for the report.

2.2.2.3 Result of performance measurement

A performance measurement was not made, since the fabrics were assumed to be disposed before they were worn out.

2.2.3 The product system to be studied

This heading is not found in ISO 14041 (1998), but is mentioned in clause 5.1.2 of ISO 14040 (1997). The ISO 14040 (1997) standard includes more items in the scope than ISO 14041 (1998), which may create confusion for the LCA practitioner (methodological issue 1).

The three fiber types in the LCA study were conventional cotton, wool (worsted) with 15 % polyamide (nylon) 66 (wool/PA) and Trevira CS (a flame retardant polyester).

What was considered to be the most probable production and use chains were followed and are called “base case” in the report. As seen below, the base case was determined from a Swedish point of view.

The color of the fabric was red. Six laundry washings for the cotton and Trevira CS fabrics or dry-cleaning for the wool/PA fabrics were assumed in order to see the relative environmental importance of the cleaning step. It was assumed that the fabric could be readily removed from the sofa. Incineration at disposal of the fabric used was assumed in the base case (the most probable life cycle chains). Heat recovery and emissions from the incineration were taken into account, but possible oil saving or replacement of other waste in the incinerator was only tested in the sensitivity analysis.

2.2.4 System boundaries

In clause 5.3.3: “Initial system boundaries” in ISO 14041 (1998), it is stated that: “Decisions shall be made regarding which unit processes shall be modeled by the study and the level of detail to which these unit processes shall be studied. Resources need not be expended on the quantification of such inputs and outputs that will not significantly change the overall conclusions of the study. Decisions shall also be made regarding which releases to the environment shall be evaluated and the level of detail of this evaluation”. Decisions regarding releases are found in chapter 2.2.7: “Data categories”, and not under “system boundaries”, which is in accordance with clause 8 in ISO 14041 (1998) but contradicts clause 5.3.3 (methodological issue 1).

Activities were included that were considered to have the most environmentally impacting effects in the life cycles. How to choose system boundaries is a methodological issue (methodological issue 3). Forsberg (2003) has created a checklist for boundary setting and a way of describing system boundaries.

The specific system boundary headings below are not mentioned in the ISO 14041 (1998) standard, but they are often used, e.g. in the SPINE format (a format to enhance uniform reporting of data in LCA studies (Pålsson 1999)) which includes nature, time, geographical boundaries and others.

2.2.4.1 Spatial system boundaries

Cotton:	*production of cotton fibers: Texas, USA *yarn production, weaving, wet treatment including dyeing of the fabric, upholstering, use and incineration: Sweden
Trevira CS:	*production of Trevira CS polymer fibers: Germany *production of Trevira CS filament yarn and dyeing of the fibers: Denmark *weaving, finishing, upholstering, use and incineration: Sweden
Wool/PA	*production of raw wool: New Zealand *wool scouring, spinning of wool yarn: Germany *PA production: Europe *weaving, wet treatment including dyeing of the fabric, upholstering, use and incineration: Sweden

In practice there were some data gaps, and data were taken in those cases from other areas, see chapter 3.1.5 (methodological issues 11 and 15).

In the impact assessment, chapter 4, the characterization and weighting was mainly done on a global or regional basis, and not site-specifically. Characterization of site-specific impacts has been very little developed (methodological issue 23). In addition, some methods have one affected area as a default while, in the textile chains, production takes place in several parts of the world, making these default weighting methods not perfectly suitable (methodological issue 26).

2.2.4.2 Nature system boundaries

Mineral resources and water were traced back to their reserves in nature and emissions were followed to air, water or soil.

Below are the exceptions found, when the processes were not traced back to the nature reserves or water, or followed to air, water or ground.

- A wastewater-treatment plant was included, but the decomposition of each individual chemical was not studied (methodological issues 16 and 23). One attempt, however, to characterize impacts from chemicals on human beings was made by Hertwich et al (2001) in their model, CalTox. Another model for characterization of chemicals in water is USES-LCA. Beck et al (2000) tested this model for textile chemicals.

- The production of the process chemicals and some packaging materials were not within the system boundaries, see chapter 2.2.4.3.

2.2.4.3 Process system boundaries

The process boundaries were at product specific level for specific plants. Thus the allocation had already been done by the plant staff.

The process chart of the base cases, figure 1, is structured to a foreground and background system. The foreground system includes the textile specific activities, while the background system includes the activities that could quantitatively affect/be affected *by* one or more activities in the foreground system or *between* the activities in the foreground system.

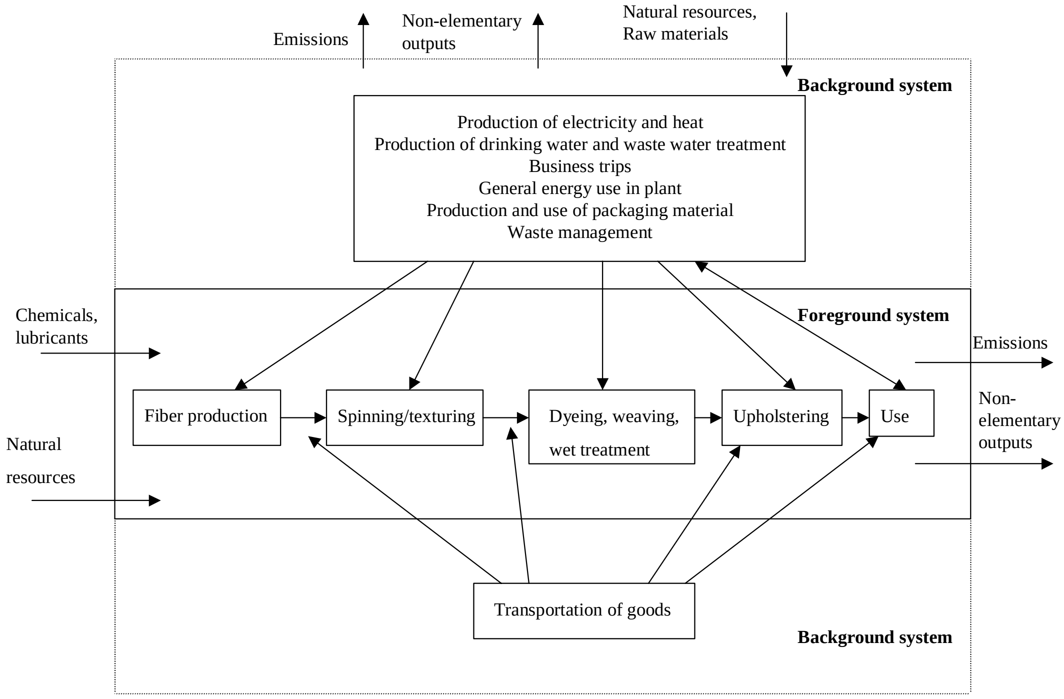


Figure 1: Foreground and background systems

- Data for the production of the machinery were excluded.

- Data for the production and transport of energywere to stock were included. Transports to the combustion site were not included. As it belongs to the background system it is not normally known (methodological issue 11).
- The fate of packaging, fiber and fabric waste from production were not within the studied system in the base cases but were tested in the sensitivity analysis.
- LCI data for the production of chemicals or lubricants were not included. The criterion was that the environmental impact from their production was assumed to be insignificant for the cases, and the assumption was partly tested in the sensitivity analysis. However, if the chemical or lubricant is toxic or persistent, I have decided that the LCI data for their production should be included if the amount is higher than 1% of the total use of materials except water. The dyeing agents are persistent, but the amount is 0,6% of the total amount of materials in the cotton life cycle The same principle is valid for the fluorine polymer emulsion used in the cotton case: 0,5% of the materials used is fluoric polymer emulsion, which is only partly degradable (methodological issue 3 and 11).
- LCI data for the production of some packaging material were not included due to the same reasons as for the exclusion of the production of the chemicals or lubricants, see chapter 3.2 for data for each specific activity.
- For some activities general energy use and travel at work was not reported (methodological issue 11 and 4) and sometimes it could not be clarified from the reports *if* general energy use was included (methodological issue 19).

2.2.4.4 Temporal system boundaries

The goal was that data should be sufficiently recent in order to rank the three different fabrics for a sofa. However, how does a practitioner, who does not know details about the processes, *know* that no essential change has occurred in the process after the reporting date? It is often not realistic to check all activities when an LCA is done (methodological issue 4).

Data were collected by interviews from 1999 to 2002, but data from reports ranged from 1993 to 1998. Most reports were from 1997.

2.2.4.5 Omissions of life cycle stages, processes or data needs

These are given under each type of boundary above.

2.2.5 Allocation procedures

This heading is not mandatory under the “scope of the study” according to clause 8 in ISO 14041 (1998), but according to clause 5.1.2: Scope of the study, in ISO 14040 (1997) it is (methodological issue 1). I have chosen to place the information about allocation procedures in chapter 3.1.7, in accordance with clause 8 in ISO 14041 (1998).

2.2.6 Types of impact and methodology of impact assessment, and subsequent interpretation to be used

This heading is not mentioned in clause 8 in ISO 14041 (1998), but according to clause 5.1.2: Scope of the study, in ISO 14040 (1997) it should be considered and clearly described here (methodological issue 1).

The impacts that are calculated are the ones that threaten one or more of four safeguard subjects (Steen 1999A): human health, resources, ecosystem production capacity and biodiversity. The fifth safeguard subject: cultural and recreational values, was not assessed, owing to shortage of data (methodological issue 27). The characterization methods used are found in chapter 4.1 and the combined characterization and weighting methods are found in chapter 4.2.

The interpretation shall give a ranking between the three fabric types and highlight the significant environmental issues. One methodological issue is to know if the choice is consistent with the goal and scope for the LCA study, which is required according to clause 5.3.2 in ISO 14042 (2000) (methodological issue 5).

2.2.7 Data categories

The standard ISO 14041 (1998) requires, in clause 5.3.3 “Initial system boundaries” that: “decisions shall also be made regarding which releases to the environment shall be evaluated and the level of this evaluation”. This is not in accordance with e.g. clause 8 where “data categories” is a separate clause (methodological issue 1).

The choice of data collected was mainly based on which substances have characterization factors for the impact categories. The choice of data to be collected is problematic. There are obvious risks of missing important data and wasting resources on unimportant ones (methodological issue 6).

Data were collected on:

- use of natural resources (materials, water, energy, land),
- non-elementary inputs and outputs,
- discharges to water,
- emissions to air,
- emissions to soil and
- work environment such as dust, noise and smell and sick leave

The specific flows collected are listed in appendix 1 (except for the work environment, owing to poor data).

2.2.7.1 Quantification of energy inputs and outputs

In clause 5.3.4: “Description of data categories” in ISO 14041 (1998) it is stated that: “Energy inputs and outputs shall be treated as any other input or output to an LCA. The various types of energy inputs and outputs shall include inputs and outputs relevant for the production and delivery of fuels, feedstock energy and process energy used within the system being modeled”.

This was done, but delivery of the fuels was not included (see chapter 2.2.4.3) and feedstock energy was not treated separately.

2.2.7.2 Assumptions about electricity production

The goal and scope motivate a change-oriented (Ekvall 1999) approach to investigating the consequences of the alternative choices of the fabrics. In LCA this is often addressed by using marginal LCI data expressing, for example, what will happen if some extra kWh are taken from the electricity grid. So, ideally one may use average data for the electricity use that is “normal” and marginal for the part that is additional. However there are several ways of deciding what is normal. For instance, one may use the average sofa in average use, or one may use average consumption. Therefore, we have used both average data and marginal data. Average data is used in the main study and marginal data are used in the sensitivity analysis (chapter 4.3.5, methodological issue 7).

2.2.7.3 Combustion heat

It is problematic that there is no standardized way of choosing type of combustion heat value (methodological issue 9). The combustion heat value types used in different reports varied. Net was preferred, unless there was a real use of all the energy as described by the gross calorific value. In some cases the type was not reported or only gross were used. In those cases it was assumed that it did not affect the results and that it could be treated as a measurement uncertainty. The assumption was tested for Trevira CS, see chapter 4.3.1.1.

- Combustion heat for the fabrics was found in Ellebäk Laursen et al (1997) for the energy recovery from combustion of the fabrics.
- Combustion heat of energy carriers: If only the mass of the energy carriers were known, the combustion heat for them was assumed according to the energy content reported in Svenska Petroleum Institutet (1999, net calorific values).
- For some aggregated data used in this report (polyester and polyamide 66 fiber production), the gross calorific value was used for the combustion of fuel (methodological issue 9).

2.2.8 Criteria for initial inclusion of inputs and outputs

According to clause 5.3.3 in ISO 14041 (1998) “Initial system boundaries”: “The criteria used to assist in the choice of inputs and outputs should be clearly understood and described”, but in clause 8 of the standard, this item has its own clause as it also has under clause 5.3: “Scope of the study” (methodological issue 1).

2.2.8.1 Description of criteria and assumptions

The major known contributors to environmental impacts in society were included in the base case. An additional criterion was that it should be possible to rank the three fabric types regarding environmental impact according to the chosen assessment methods. One problem is that there is no constant knowledge of which are the major contributors to environmental impact; this changes over time (methodological issue 8). In this study it is assumed that the impact categories reported in Nordic Guidelines on Life-Cycle Assessment (Nord 1995) and the substances associated with each impact category found in the program database used are the most relevant ones according to present knowledge (details regarding specific data and program are found in chapters 2.2.7, 3.1.9 and 4.1).

2.2.8.2 Inclusion of mass, energy and environmental criteria

The criterion for inclusion was that they should affect the comparison of the three fabric types, see also chapter 2.2.8.1.

2.2.8.3 Effect of selection on results

This heading is the last one under the chapter "Criteria for initial inclusion of input and outputs" in order to make the text logical, although it comes as the second last in clause 8 in ISO 14041 (1998).

In the sensitivity analysis, chapter 4.3.4.3, the inclusion of LCI data for chemicals was tested for the cotton fabric. They did not contribute significantly to the comparison results, but since only LCI data for 13 of the 50 chemicals were included, owing to data gaps, the effect of excluding the LCI data for the chemicals is not clarified. In this case, however, the fabric with the highest environmental impact, conventional cotton, clearly used the highest amount of chemicals. Therefore, the fabric comparison would in all probability be valid even if the LCI data for chemical production were included.

2.2.9 Data quality requirements

The data quality requirements were that the precision, completeness, representativity, consistency and reproducibility should be good enough to be able to rank the three fabric types. In general, higher demands were assumed for substances with higher environmental impact as measured using the selected characterization and weighting methods.

2.2.10 Critical review

The critical review is mentioned not in clause 8 in ISO 14041 (1998), but in clause 5.3.7 as a part of the scope. In clause 5.1.2 in ISO 14040 (1997) it also is mentioned as a part of the scope.

Dr. Maria Walenius Henriksson at IFP Research AB did an external critical review. This was done when the study was finished in order to identify possible errors in data. According to ISO 14040 (1997) "the scope of the critical review should be defined during the goal and scope definition phase of the study". This requirement was fulfilled, although the need for the external expert review was not identified until after the initial LCI was already made. My conclusion is based on the statement in clause 5.1.2 in ISO 14041 (1998) that the LCA procedure is iterative. I suspect, however that the implication of ISO 14040 (1997) is that the scope of the critical review should be defined *before* the *initial* goal and scope definition is done (methodological issue 1). The critical review is found in chapter 11.

2.2.11 Type and format of the report required for the study

In clause 5.1.2 in ISO 14040 (1997), the type and format of the report should be considered under the scope of the study. It is not included in clause 8 in ISO 14041 (1998) (methodological issue 1).

The report made should be according to the ISO standards 14040 (1997) to 14043 (2000) with the addition that the methodological issues found should be mapped.

3 Life cycle inventories

3.1 General information about the inventories

This shall be considered in the report according to my interpretation* of clause 8 in ISO 14041 (1998):

1) qualitative and quantitative description of unit processes
2) sources of published literature
3) calculation procedures
4) validation of data
    i) data quality assessment
    ii) treatment of mission data
6) sensitivity analysis for refining the system boundaries
7) allocation principles and procedures
    i) documentation and justification of allocation procedure
    ii) uniform application of allocation procedure

*difficult to be certain whether the items (here the headings) without asterisks and without subheadings or with subheadings without asterisks shall be included. I have assumed that they are not mandatory (methodological issue 1). It is not stated that the headings above shall be included in the report, but since this is a study intended to identify the methodological issues, it is convenient to use the items as headings.

3.1.1 Procedures for data collection

This heading is not mandatory according to my interpretation.
Data according to chapter 2.2.7: “Data categories”, were mainly collected through interviews and/or questionnaires for the foreground system. This method was chosen in order to obtain the most relevant data possible. Respondents were production managers at the different production sites. Data were usually annual, between 1999 and 2002. The goal was to find three companies for each step of the manufacturing, but in some cases it was not possible to find so many that were willing to give data. Comparisons were made with the literature to check reliability, and sometimes only literature data were found. Data about companies involved are found in chapter 3.1.10.

Data for the background system were found in the literature or in databases that refer to the literature.

3.1.2 Qualitative and quantitative description of unit processes

The qualitative and quantitative descriptions of the unit processes are found in chapter 3.2.

3.1.3 Sources of published literature

The sources of published literature are found under each unit process in chapter 3.2.

3.1.4 Calculation procedures

Grid losses for electricity production are found in chapter 3.3.1.

If only the weight of the energy carrier was known, the net calorific value according to The Swedish Petroleum Institute were used, see table 1.

Table 1. Conversion factors and densities found in the report of The Swedish Petroleum Institute (1999)

Fuel type	**Approximately similar**	**Net calorific value (MJ/kg)**	**Density (kg/m^3)**
Hard coal		27.2	800
Diesel Mk1 and Mk2		43.2	815
Diesel Mk3		42.8	845
Eo1	Light fuel oil	42.7	840
Eo5	Heavy fuel oil, crude oil	40.6	950
Gasoline		43.0	730
LPG (Sw: gasol)		46.1	2.4
Natural gas		51.9	0.75

The calorific value for lignite is about 15.0 MJ/kg (Boustead 1997).

Type of electricity and heating value for combustible materials used is also found under chapter 2.2.7. ISO 14041 (1998) requires that information about these items shall be stated and justified according to both clause 6.4: “Calculation procedures” and clause 5.3.3: “Initial system boundaries” (methodological issue 1). See also clause 8 in ISO 14041 (1998) where it is stated that this information should be included both under “Data categories” and under “Calculation procedures”.

3.1.5 Validation of data

3.1.5.1 Data quality assessment

- As far as possible, data were compared with literature data in order to assess the data quality. In practice it was sometimes difficult to find site-specific data and therefore literature data only were used in those cases (methodological issue 11). Sometimes data for a similar process had to be used instead of data for the specific process in the life cycle chain in the base cases. This type of methodological issue, when available data are not exactly the data desired (methodological issue 15) is discussed by von Bahr (2001). He gives an overview of advantages and disadvantages of different data sources. He has also developed a method for how to handle “epistemological uncertainty”, i.e. when data are moved from one context to another, but the method is not directly applicable to this LCA. The principle of the method is that if you know the governing parameters in the process, you can estimate the emissions. He tested the method on NOx emissions in cement production. Based on general input data, such as whether or not the plant has Selective Catalytic Reduction, NO_x emissions can be estimated from a known data set. The disadvantage of the method is, however, that the LCA practitioner must know basic data about the process.

- Data for amount of packaging material varied up to 6 percent by weight between two activities (higher deviation for wool scouring, see chapter 3.2.4.6).

- Type of truck used for the transports was a best estimate. Trucks in Sweden were assumed to fulfill the " Euro 2" emission regulations, while "Euro 1" was assumed for the rest of the world. The "Euro 2" class satisfies higher emission requirements than the "Euro 1" class.

- Data for general energy and water consumption for e.g. air conditioning and light were included, but for some activities they were not found. There were also some data gaps for packaging material use and production, lubricants used for the machines, travel at work and data for the work environment This is commented on under each affected unit operation, and turned out not to be crucial to the study.

- It is a general methodological issue (methodological issue 19) that the same type of emission is reported in different ways in different data sources. For example, sometimes BOD in water was reported as BOD5 and sometimes only as BOD. Moreover the size of the particles emitted to air is not always reported. In this study, data were adapted to the substance and other emission names used in the calculation program, in order to be able to make the impact assessment as complete as possible. The changes in vocabulary from the reports where data were found to the LCAiT standard added uncertainty but were considered not to greatly affect the results in this study. VOC, for example was changed to NMVOC. If methane was not separately reported when VOC was reported, it could not be 100% certain that no methane was included in the value of VOC. It is advisable to separate methane from VOC, since, in the agriculture sector, methane emissions can be high and since it is a potent greenhouse gas. This nomenclature problem could be avoided if reporting was standardized.

- It was assumed that no double reporting occurred in the data from the literature. For instance, COD and BOD could occur in the same data set, and in those cases it was assumed that the measurements were made in waters from two different sub-activities (methodological issue 19). Another example is that discharges to water of Cr and Cr^{3+} are often reported in the same inventory and it is not always known if the amount of Cr^{3+} is part of the amount of Cr.

- Water consumption was extra difficult to assess since the water type was often not known (methodological issue 19).

- The database in the LCA program used has a modified SPINE format (Pålsson 1999). This means that the data were reported in a structured way in order to enhance data transparence. The format promotes data reliability, accessibility and relevance. It is similar to the format proposed in SIS-ISO/TS 14048 (2002).

3.1.5.2 Treatment of missing data

Missing data were discussed after the impact assessment and the sensitivity analysis where the significant issues were identified, see chapter 5.2.

3.1.6 Sensitivity analysis for refining the system boundaries

No sensitivity analysis was done for the LCI data without help from the impact assessment. I find it not important to do sensitivity analysis only on LCI data (methodological issue 10). Not until the impact assessment step does it become clear which substances contribute more to the environmental impact than others.

3.1.7 Allocation principles and procedures

In ISO 14040 (1997), clause 5.1.2, the allocation procedures should be included in the scope. In clause 8 in ISO 14041 (1998) they shall also be included under the inventory analysis, which is confusing (methodological issue 1). The description of how allocation should be done is given in clause 6.5 under the "inventory analysis" in ISO 14041 (1998).

3.1.7.1 Documentation and justification of allocation procedure

Allocations for the agriculture and wool scouring steps were partly avoided by system expansion (alternative 1 in clause 6.5.3 in ISO 14041). For transports and for the production processes allocations were based on weight, often supplemented with a comparison from the literature. Allocation by weight is an application of alternative 2 in clause 6.5.3 in ISO 14041 if there is a linear relationship between the increase of production/transport weight of the studied product and other products in the unit process. It is recommended that alternative 2 be applied when alternative 1 cannot be applied. That results in partition in a way that reflects the underlying physical relationships between the products or functions.

3.1.8 Uniform application of allocation procedure

The allocation procedure by mass was not uniform in applications. The deviations were as follows:

- No flows were allocated to waste, such as edge strips from weaving or cardboard or textile samples. Thus economic allocations belonging to alternative 3 in clause 6.5.3 in ISO 14041 (1998) were used, addressing allocations that reflect other relationships than physical ones.
- Wool was allocated 40% to wool and 60% to meat (economic allocation).
- In the weaving operation, allocation was made per meter fabric.
- Allocations for light fuel oil, heavy fuel oil, LPG and natural gas production were not known (methodological issue 4) as well as for electricity from natural gas or oil and production of sodium hydroxide and ethylene glycol used for the sensitivity analysis.
- For electricity production (Swedish average) the allocation between recycling and virgin materials was according to the 50/50 method. When heat was also produced, the allocation was according to energy output.
- For electricity (European average), exergy values were used to allocate between electricity and heat (methodological issues 4, 14).

3.1.9 Program used

(Not included in clause 8 in ISO 14041 (1998))
LCAiT version 4.1.6 Full edition (Chalmers Industriteknik AB (CIT)) was used for the Life Cycle Inventory (LCI) and LCA calculations.

3.1.10 Companies involved in the study

This heading is not found in ISO 14041 (1998), but is useful for this LCA.
Data from the different companies for each production step of the fabric are found in chapter 3. Best average estimates for each activity step were calculated. These companies participated in the study (some companies have more activities than mentioned below, but only activities relevant for the study are mentioned here):

Table 2: Companies involved in the study and their activities studied

Company	Yarn production	Wet treatment/dyeing	Weaving	Upholstering
Borgstena Textile		Trevira CS fabric		
Borås Wäfveri	Spinning of cotton	Cotton fabric	Cotton	
Bremer Woll-Kämmerei AB (BWK)	Wool scouring			
Bröderna Anderssons Industrier				X
Ihreborn Produktion AB				X
Kinnasand			Trevira CS, wool/PA, cotton	
Marks Pelle Vävare			Trevira CS, wool /PA	
Neckelmann	Trevira CS filament yarn texturing and dyeing			
Rydboholms Textil AB		Cotton fabric		
Saxylle-Kilsund AB		Trevira CS, wool/PA, cotton fabric	Trevira CS, wool/PA, cotton	
Sjuhäradsbygdens Färgeri AB		Trevira CS yarn wool/PA yarn and fabric		
Spinner A	Spinning of wool			
Trevira	Trevira CS filament yarn production from monomers			
Väveriet Uddebo AB			Trevira CS, wool /PA	

All Swedish spinning, weaving and wet treatment companies studied are situated near Borås in southwestern Sweden. The upholstering companies are situated east of the Borås area. All companies below, except BWK and spinner A were visited.

- Borgstena does wet treatment at the Timmele site, which was visited. Their main production is wet treatment of fabrics for the car industry as well as lamination of the backing for the car seat fabrics. They also do wet treatment for weaving mills. They have their own wastewater-treatment plant.

- Borås Wäfveri does rotor spinning of cotton thread and weaving of cotton fabrics at the Kungsfors site. They produce different kinds of cotton fabric e.g for sheets, curtains and upholstery. In Borås, the company does wet treatment of cotton fabric. The fabrics are either dyed or printed. The wastewater is connected to the municipal wastewater-treatment plant.

- BWK in Bremen does wool combing and scouring. About 80% of the fibers treated are wool, the rest are synthetic, and it was assumed that scouring is not done for these fibers.

- Kinnasand in Kinna is a weaving mill. They do weaving of all three fiber types investigated. They also weave flax wallpaper at the Kinna site. Their fabrics are for curtains and upholstery.

- Marks Pelle Vävare is a weaving mill situated in Fritsla. They do weaving of Trevira CS and wool/PA fabric mainly for curtains and upholstery. A minor amount is weaving of terry cloth.

- Neckelmann does texturing and dyeing of Trevira CS yarn at the site in Silkeborg, Denmark.

- Rydboholms textil AB in Rydboholm does wet treatment of yarns and fabrics. About 99% is cotton. Their wastewater is connected to the municipal wastewater-treatment plant.

- Saxylle-Kilsund AB in Borås does weaving and wet treatment of fabrics mainly for garments but to some extent also for upholstery. They weave and treat wool, wool/PA and polyester fabrics.

- Sjuhäradsbygdens Färgeri AB in Kinnahult does wet treatment of yarn and fabrics.

- Trevira produces of Trevira CS yarn, in this case in Guben in Germany.

- Väveriet Uddebo AB in Uddebo does weaving of polyester and wool/synthetic fiber for upholstery fabrics.

3.2 Inventories of the fabrics

The tables in this chapter contain inventory data for the activities (unit operations), but many tables had to be placed in appendix 6 due to confidentiality demand. Energy production is not included in the tables, and fuel combustion is not generally included. These are in most cases set to generic values and added separately in most calculations for the activities. In chapter 3.3.1 the references for these generic data are found. Under each table in chapter 3.2 *whether* data for the emissions from the fuel combustions are generic or specific is specifically clarified.

The problem in finding good data and knowing if data quality is sufficient for the study is a methodological issue (methodological issues 4 and 11), for all activities, and it is therefore not mentioned for each unit process.

In my effort to make the data generic and not to point out certain companies, the specific company names are generally not reported. Where data were obviously from a specific company and the company was not opposed to publication, the company name was reported. Excluding company names affects the transparency of the report (methodological issue 12).

Swedish and European electricity includes nuclear power. The accident risks associated with nuclear power are not in the inventory and are therefore not included in the impact assessment (methodological issue 13). According to ISO 14042 (2000), clause 8, one limitation with LCIA is “LCIA results do not predict impacts on category endpoints, exceeding of thresholds, safety margins or risks”. The meaning of this sentence is that LCIA does not support e.g. risk assessment, but in practice many risks are considered in the characterization factors (methodological issue 1), with exceptions such as risks of accidents from nuclear power. The same yields for risks with mining.

3.2.1 Explanation of some expressions used in the tables

FlowType: Categorization to distinguish between different flows e.g. resource, emission, product, etc.
Non-elementary means that the substance either comes from the technosphere or is emitted to the technosphere.
The technosphere is the man-made environment.

3.2.2 Cotton fabric

Two Swedish weaving mills willing to participate in this study were found. In figure 2, typical production chains are shown.

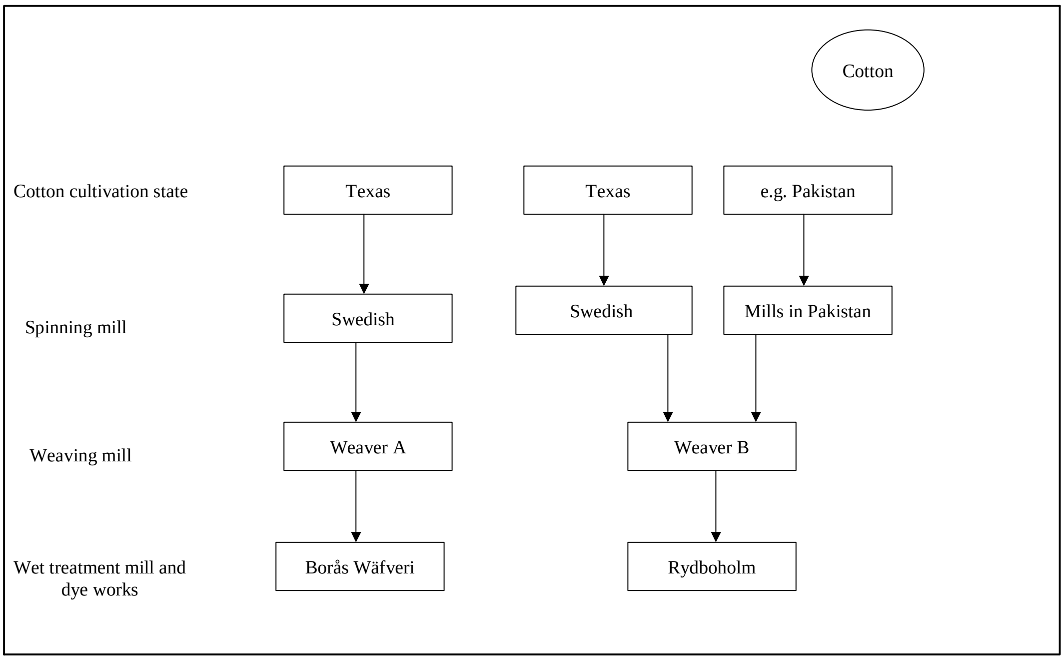


Figure 2: Companies studied and their roles in the production of cotton fabric for a sofa

3.2.2.1 Cotton cultivation

Cultivated cotton is of the annual type, while the wild plant is perennial. Cotton can be cultivated in a belt from 35^o north to 30^o south of the equator. The fibers are attached to the seeds in the seed ball (Wynne, 1997).

Cotton was assumed to be cultivated in Texas. The reason for this assumption was that the Swedish cotton spinner bought their cotton mainly from Texas. The US is the second largest cotton producer (after China) in the World. China and the US produce together about 44% of the world supply (Ellebäk Laursen et al, 1997). Note, however, that data in table 3 originate from a mixture of data sources.

Table 3: Data for cotton cultivation regarding Texas
The table is found in appendix 6.

- Inputs of fertilizers and pesticides were found on the home page of USDA (1999). Data were for Upland cotton, the main type according to the 2000 Crop Production Summary (2001). N, P2O5 and K2O were reported and they were translated to ammonium nitrate, diammonium phosphate and potassium nitrate since LCA data for these chemicals were known for Europe (methodological issue 15, Davis and Haglund 1999). The fertilizers reported are used in Texas (EPA 1999a) but potassium nitrate is the least common, only 0.7% of the potassium is from potassium nitrate.

- Inputs of pesticides were found from the USDA (1999). Desiccants and defoliation agents are probably included in “other chemicals” as well as chemicals for disease control. The herbicide Trifluralin was applied to 74% of the area and the insecticide Malathion was applied to 56% of the area.

- Degree of packaging and salinization of soil were not known, nor were the effects on biodiversity or soil fertility from, for example, emissions of chemicals (methodological issue 17).

- In the US in crop year 1998/99, 45% of the cotton cultivated was genetically engineered (GE) (ICAC 1999). In 2001 about 70-80% of the cotton was GE (Tobler and Schaerer 2002, Haider and Reller 2002). How to include this fact with all the potential risks in the inventory is a methodological issue (methodological issue 18).

- Personnel travel at work was not known, but was probably low and therefore not reported.

- According to Ellebäk Laursen et al (1997) the values globally may range according to table 4:

Table 4. Inputs and outputs in the production of conventional cotton fibers (/kg cotton fibers) according to Ellebäk Laursen et al (1997).

Water consumption	7000-29000 l
Energy consumption	48.65 MJ
Consumption of fertilizers	0-560 g
Consumption of insecticides	0.01-0.83 g (concentrations not known)
Consumption of herbicides	0.96-1.45 g (concentrations not known)
Solid waste from ginning	0.03-2.91 g (depending on harvesting methods)
Emissions of agrochemicals	No data

The data for the base case are within this data range (with the assumption that “water consumption” includes rainwater).

3.2.2.2 Cotton ginning

Ginning includes drying and cleaning of the seed cotton, separation of the fibers from the seeds and further cleaning (Ellebäk Laursen et al 1997). Data were taken from literature; see below.
It was assumed that cotton ginning and baling takes place near the area where the cotton is cultivated. Therefore no transports were accounted for.

Table 5. Inventory data for cotton ginning
The table is found in appendix 6.

- System expansion: 66% of the seed cotton is cotton seed, which gives oil, meal, hulls and linters (short fuzz fibers), which were treated by system expansion.

- Data for amount of cotton fibers, seed and waste origin from Ellebäk Laursen et al (1997). The production of one kg raw cotton fiber generates 0.17 kg foreign matter if machine picking is assumed. According to Ellebäk Laursen et al (1997), 100% of all cotton in the US is machine harvested. Hand picking generates only 0.07 kg foreign matter. Machine stripping generates approximately 1.46 kg foreign matter, but is not assumed here. If it were included, it would not have any impact on energy use since that variable was allocated to the cotton fibers.

- Personnel travel at work was not known, but was probably low and therefore not reported. Use of general energy and water were also not known.

- Health impacts for workers were not known.

3.2.2.3 Cotton baling

Mainly qualitative data were known, and energy use was included in chapter 3.2.2.2: "cotton ginning".

Table 6. Inventory data for cotton baling

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Chlorinated phenol[1]		kg	Technosphere
Input	Non-elementary	Cotton fibers	2.18E+02	kg	Technosphere
Input	Non-elementary	Steel band[1]		kg	Technosphere
Input	Non-elementary	Woven jute[1]		kg	Technosphere
Output	Product	Cotton bale	2.18E+02	kg	Technosphere

1. Amount not known

- The weight of packaging material and chlorinated phenol were not known but these are used in practice (Ellebäk Laursen et al1997).

- Personnel travel at work was not known, but was probably low and therefore not reported. Use of general energy and water were also not known.

3.2.2.4 Truck driving in Texas

The distance was assumed to 300 km. This distance is assumed to be an average from the ginning plants to Houston. Medium truck (total weight: 24 tons, maximum load: 14 tons), fulfilling the "Euro 1" emission regulations (1993-1995), load factor 50% and rural driving mode were assumed.

3.2.2.5 Freighter (cargo ship), large on the Atlantic

The distance Houston-Gothenburg was estimated to 10,279 km. The cotton bales are in containers on freighters. The spinning company sets no demands regarding which fuel should be used by the freighter (Importer 2000).

3.2.2.6 Truck from port to Swedish spinning factory

The distance was assumed to about 80 km and medium truck (total weight: 24 tons, maximum load: 14 tons), fulfilling the "Euro 2" emission regulations (1996-), load factor 50% and rural driving mode were assumed.

3.2.2.7 Rotor spinning of cotton

The data were derived from a spinning and weaving mill (2000) for cotton. Comparisons were made with literature. The spinning mill did also weaving.

Table 7. Inventory results regarding rotor spinning of cotton
The table is found in appendix 6.

- About cardboard and polypropylene: data come from another cotton weaving mill. They claim that cotton thread comes with one time use pallet (wood), which contains 9 boxes with 12 cones per box. One cone weights 65 g and contains 800 g thread. The cone was assumed to be made of polypropylene. The box is made of cardboard and has an estimated weight of 300 g. Note that in this study only the production of the *polymers* are included, not the plastic items.

- Wood was included, but not the production of the pallet.

- In the past, byssinosis, a respiratory disorder caused by dust from cotton and other fibers (Encyclopædia Britannica April 2003) was a problem associated with bale opening, but now the process has been automated, and the problem has disappeared.

- Workers must wear ear protection. The noise level is 89-95 dB. There were no problems with impaired hearing among the workers. Therefore this was not reported.

- Water is used for air conditioning. Here it was assumed to 0 since all water was allocated to the weaving activity, which was in the same mill. For this study this is not important, but it would have been better for the activities to share 50% of the water consumption each.

- Personnel travel at work was not known, but was probably low and therefore not reported.

3.2.2.8 Truck from Swedish spinning plant to weaving plant

The distance was assumed to about 30 km. See chapter 3.2.2.6 for details.

3.2.2.9 Weaving with sizing in Sweden

Weaving includes warping, dressing, weaving and inspection.

Interviews were held at Swedish factories, and comparisons with the literature were also made. Data from the weaving mills of Trevira CS and Wool/PA were also included in order to get a fairer average, see below.

Table 8: Inventory results regarding weaving with sizing in Sweden
The table is found in appendix 6.

- Allocation: All energy and material was allocated to the fabrics without the spillage (thus considered to have zero value, although it can be used for furniture upholstery (methodological issue 14)).

- Liquefied petroleum gas (LPG), light fuel oil, starch: data comes from one cotton-weaving mill. The values of these flows were divided 50:50 between weaving and spinning. Although the representative from the weaving mill actually mentioned propane, here it is approximated to LPG. Not all weaving mills use LPG, it could therefore sometimes be left out. Here it is included, but the amount is not crucial to this study.

- Data for lubricant oil is also a mean value from the three weaving mills. Grease usage is a mean value from two weaving mills. The amount/m was divided by the mean value for cotton weight derived from two cotton-weaving mills and a cotton wet treatment mill, 525 g/m (150 cm wide).

- Data for water for sizing and moisture came from one cotton-weaving mill, and all water was allocated to the weaving mill. The amount that does not go to the wastewater-treatment plant is water that has evaporated. The water amount to wastewater-treatment plant was an estimate. In the original data, water was assumed to unknown type, but a realistic estimate is that industrial water was used, here set to drinking water.

- The cotton weaving mill stated that 1% of the starch was emitted to the wastewater. According to Ellebäk Laursen et al (1997): BOD/kg starch is 900-1000 g.

- Edge strips were reported by two weaving mills and spillage (other) is a value from one weaving mill.

- Noise (95-100 dB according to one weaving mill) and dust could be local human health problems, but did not seem to be. Workers use ear protection.

- The representative from the cotton-weaving mill only mentioned sizing, not oil or paraffin treatment of the thread before weaving.

- The fact that a mean value for the three fiber types was used in the calculation gave the effect of slightly different values for the flows of each fiber, since 10m fabrics is used for a sofa but the fabric is reported by weight (Data of weight of fabric used: cotton: 463-525 g/m, Trevira CS 373 g/m, Wool/PA 560 g/m, average value 465 g/m (150 cm wide)). This was corrected by setting factors for the different fibers on each side of the weaving activity, e g for

Trevira CS: 465/373 before the weaving and 373/465 after the weaving. This resulted in inventory data per meter fabrics (and not per kg).

3.2.2.9.1 Travel at work from cotton weaving mills site

This activity deals with personnel travel in order to sell and inform about the fabric.

Table 9: Inventory results regarding business trips from a cotton weaving mill's site in Sweden.

The data concern per vehicle km (vkm). Only car transports were taken into account. Data regarding gasoline use and emissions were estimated from Blinge (1998).

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Gasoline[1]	3.85E+00	MJ	Technosphere
Input	Cargo	Cargo	1.00E-00	kg	Technosphere
Output	Emission	CO	3.56E+00	g	Air
Output	Emission	CO2	1.84E+02	g	Air
Output	Emission	NMVOC	4.18E-01	g	Air
Output	Emission	NOx	3.38E-01	g	Air
Output	Emission	Particles	1.08E-02	g	Air
Output	Cargo	Cargo	1.00E+00	kg	Technosphere

1. Gasoline production was added outside the table.

Travel information given on an annual basis was translated into travel per m fabric made (including samples). The value 0.35 vkm/m fabric (vkm=vehicle km) was calculated from information from three weaving mill to be 0.67 vkm/kg cotton. Two of them also reported travel by air (0.07 vkm/m fabric) and one also reported train transport. Here only car transport was used. In the concept "vkm" it is assumed that about 1.6 people travel in each car (INFRAS 2000).

3.2.2.10 Truck from weaving mill to wet treatment plant

The distance was assumed to 30 km. Details are found in chapter 3.2.2.6.

3.2.2.11 Wet treatment and dyeing of cotton fabric

Following steps were included:
Singeing, desizing, washing, bleaching with H_2O_2, washing, mercerization, washing, dyeing, washing, finishing. The dyeing machine is a cold foulard and the dyeing agents are reactive.

In table 10 the inventory data for wet treatment and dyeing of cotton fabric (dark red) is found.

Table 10: Inventory of wet treatment of cotton fabrics

The table is found in appendix 6.

- Data are an average from 2 wet treatment mills and dyers of cotton, if not specifically noted under the table. One of the two had specific data for energy and chemical consumption for each step, but the other had only chemical consumption for each step and not specific energy use for the fabric. The lower energy value is from the plant, which knew the energy use for each process step. The plant, which only had data for total energy use, mainly has processes similar to this, although the specific red fabric had a more complicated wet treatment cycle than the average fabric types. Therefore the calculated average energy value is probably an underestimation for this red fabric.

- Values for emissions were only available as plant totals. Therefore these data are a combination: chemicals use was for a specific fabric from one wet treatment mill. Water and energy use was for a specific fabric, for one wet treatment mill, and for the other it was derived from the total water and energy respectively, used in the factory (allocation on mass fabric; the economic value for the fabrics are similar (methodological issue 14)). One factory uses tap water, the other water from a river. Data were an average for the year 2000.

- Packaging material for delivery back to weaving mill plant was collected from a third wet treatment mill (treats polyester and wool fabrics).

- Business trips are included, but both wet treatment mills claim there are hardly any business trips; therefore data were assumed to be 0.

- Chemicals for the machines were included, but according to one wet treatment mill, the value is insignificant, therefore it was assumed to 0.

- The fixation grade of the dyeing agents was reported from one wet treatment mill to be 75%. Where no concentration of the color is reported, a concentration of 50% was assumed. Perfluoric acids, fluor polymer emulsion and nonionic emulsifier were assumed to fixate at 100%. This gave a total of 16.33 g chemical loss/kg undyed fabrics.

- The production manager for one plant reported that Cu discharges to water were mainly from the equipment, and therefore it was not reported here. Dyeing agents fixate to about 75%, most of the rest is trapped in the sludge in either the plant or in the municipal wastewater-treatment plant. These 25% are added manually in appendix 1. All reported contents in sludge are derived from total amounts for the factory.

- 12.9 g of the fabric is from color agent i.e. 1.29 % of the raw fabric (to be compared with 3.4% in EPA (1997)).

- Health effects of e.g. air emissions in the work environment were not included, but they are probably small.

Table 11: Light fuel oil combustion at wet treatment mills site
The table is found in appendix 6.

3.2.2.12 Truck from Swedish wet treatment plant back to weaving mill

The distance was assumed to 30 km. For details, see chapter 3.2.2.6.

3.2.2.13 Textile distribution at weaving mills site in Sweden

This activity deals with sending of the fabric to different upholstering firms and other customers.

Table 12: Inventory results from textile distribution at weaving mills site in Sweden

The table is found in appendix 6.
This activity is set to be used for all three fiber types.

- Allocation was only to dyed and finished fabric with packaging and not samples, except for input of packaging material, which was allocated to both samples and product (methodological issue 14).

- Energy and water consumption was considered to be insignificant.

- Data about samples come from 2 weaving mills. Data about packaging material come from one weaving mill. Often the cardboard rolls are reused for the same application, but here it is assumed that the cardboards is reused elsewhere. The packaging used and total fabrics produced were known (both Trevira CS and Wool/PA).

- Travel at work is insignificant, therefore set to 0.

3.2.2.14 Truck from Swedish weaving mill to upholstery plant

The distance was assumed to 500 km. General information is found chapter 3.2.2.6.

3.2.2.15 Upholstering of a sofa with cotton fabric

This activity concerns sewing of the fabrics onto a sofa.

Table 13: Inventory results from upholstering of a 3-person sofa with cotton fabric

The table is found in appendix 6.

- Energy used was derived from the working time. Two upholstery companies have answered that about 3 hours are used. Assumptions regarding sewing machines, heating and general electricity were made.

- Data regarding amount of fabric and spillage came from two upholstery companies.

- Business trips were not known and set to 0.

- The fabric share of the general energy requirement for the production of a sofa was assumed to 25%.

3.2.2.16 Truck from upholstery site to customer

The distance was assumed to 300 km. General data information is found in chapter 3.2.2.6.

3.2.2.17 Use of the sofa

It was assumed that the fabric is laundered six times during its lifetime.

Table 14: Laundry of cotton fabric (one time washing)
The table is found in appendix 6.

- Data regarding chemical use came from Pulli (1997), where environmental impact of a cotton T-shirt was reported. For the fabrics it was assumed that the machine is filled to maximum and the ironing time is half the time of ironing a cotton T-shirt. Tumble-drying was included.

- It is not clear from the report which machine type was reported, but energy data combined with water consumption indicated an old machine, washing at 40 ^{0}C (methodological issue 19).

- In the report by Pulli (1997), a complete LCI of detergent production and T-shirt laundry is also reported, but since it is impossible to see production data for specific chemicals in the table, and because other activities do not contain data for chemical production, this table was not used (methodological issue 20).

3.2.2.18 Truck from user to incineration plant

Light truck with maximum 14 tons weight, 50% load was assumed. The truck was assumed to be set according to the Euro2 emissions regulations. The distance was assumed to 50 km in urban area. Empty return was assumed; therefore the distance to the incineration plant was assumed to 25 km.

3.2.2.19 Incineration of cotton fabric

Table 15: Inventory data for incineration of cotton fabric.
The table is found in appendix 6.

- Heat recovery regards cotton fabric combustion (Ellebäk Laursen et al1997).

- Emissions are general data for textiles incinerated in Sweden (Sundqvist 1999, methodological issue 15).

- Only one aspect of system expansion is taken into consideration here: the heat recovery. The heat created was assumed to be used for e.g. district heating. If the incineration replaces oil combustion, the carbon dioxide emission would be negative and the SO_x emission would be less, but if it replaces other waste, some methane emission would also have to be added in the table, since materials on landfills create methane. The replacement of other waste can be approximated with the landfill of fabric scenario in the sensitivity analysis, see sensitivity analysis in chapters 4.3.1 and 4.3.4.

3.2.3 Trevira CS fabric

Trevira CS is a flame retardant fiber. The flame retardance is obtained through co-polymerization of the monomers with O-Phospholane (Neckelmann 2001). In figure 3 the different companies and their role in the production of Trevira CS fabric are shown.

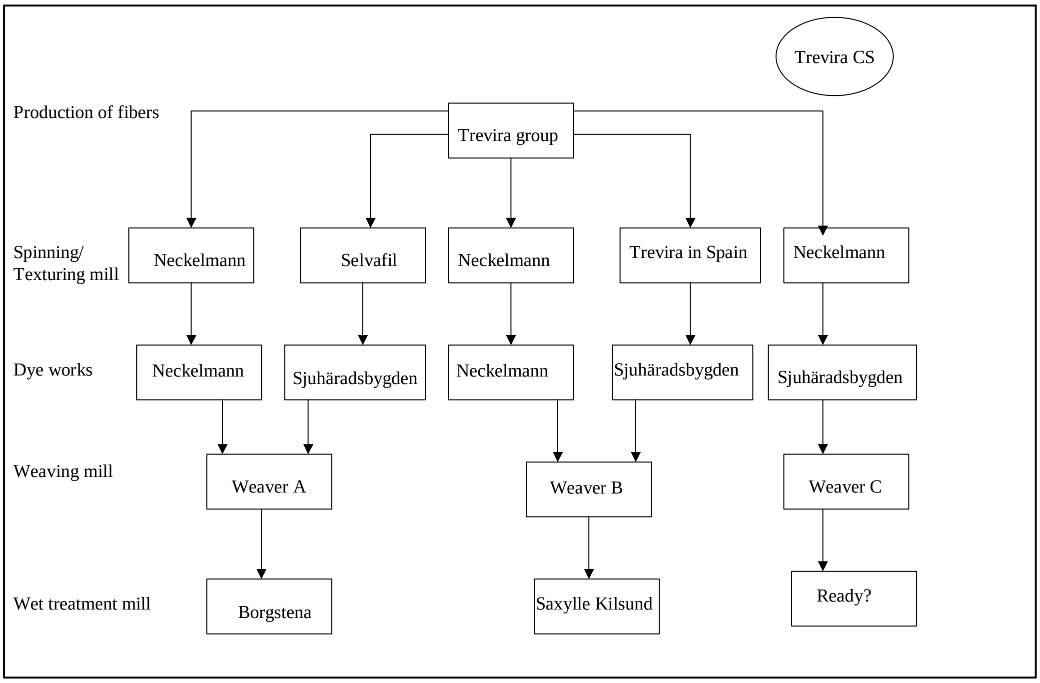


Figure 3: Companies studied and their role in the production of Trevira CS fabric

Neckelmann is a member of the Trevira group. They use filament yarn and do texturing of the yarn. Selvafil makes staple fiber yarn and does spinning.

3.2.3.1 Production of Trevira CS filament yarn

The monomers are terephtalic acid and ethylene glycol. The catalyst is antimony trioxide (possibly carcinogenic to humans (Ellebäk Laursen et al 1997)). This polymerisation is, for instance, done by the Trevira group in their factory in Guben, Germany. The Trevira group also has a factory in Portugal. The spun yarn was assumed to be only filament yarn. For fabrics used on sofas, filament yarn is the main type in the case of Trevira CS.

Table 16: Data for production of Trevira CS yarn. Remark: This inventory data were not used in the calculations in the base case.

The table is found in appendix 6.

The plant has its own wastewater-treatment. The COD reported was assumed to be measured after the wastewater-treatment, therefore the water is assumed to go to water and not the technosphere. The yarn is wound onto a spool. 20-30 kilos are on one spool and the spools are reused (or sent for recycling), therefore they are not reported. General energy use was not reported. The travel at work is not known, but is probably insignificant.

LCI data for an average polyester fiber type was used here, see table 17. Data include yarn manufacturing. Therefore the texturing step, chapter 3.2.3.3 was left out of the calculation in the base case.

The reasons for not using local data in the base case for the Trevira CS fiber production were because of data gaps: that transportation of chemicals are not included in the local data and the LCI data for the production of Sb_2O_3 and spin finish were not known. Thus LCI data for Trevira CS is treated in the same way as LCI data for PA in the wool/PA case by using average European data (methodological issue 15). In the sensitivity analysis (chapter 4.3.4.10) the inclusion of local data was tested.

Table 17: Inventory data for polyester fiber production in Europe
The table is found in appendix 6.

- Data source: average production data in Europe. The data are a weighted average based on production volumes of 7 different plants in Germany, Austria and the Netherlands (about 30% of total European production). Probably no general energy or water consumption was included (methodological issue 19). In this LCA study for fabrics, discharges to water were assumed to end up in water, as reported in the polyester study.

- Data includes production of the yarn. There are several types of yarn manufacturing, and filament or staple yarn is the product.

- In the table, Sb_2O_3 (a common catalyst, see e.g. table 16) was not reported (methodological issue 20).

- In the report wastewater-treatment plants are not mentioned, and discharges to water are reported. Therefore it can be concluded that wastewater-treatment (if there is any) was included in the system under study, but it would have been better if this had been clearly stated (methodological issue 19).

- It is not clear from the report whether or not data for packaging materials are included (methodological issue 19).

3.2.3.2 Truck from production site of Trevira CS yarn to texturing and dyeing site

The distance was assumed to 700 km (data from Neckelmann). Regarding details, see chapter 3.2.2.4. *The distance was not used in the calculation in the base case, since the data for polyester fiber production included a European average for transports to yarn manufacture. Instead, 400 km was assumed to simulate the higher than average distance to Silkeborg in Denmark where texturing and dyeing is done.*

3.2.3.3 Texturing

The data were not used in the calculation in the base case, since the data for polyester fiber production included a European average for yarn manufacture.

The filament yarn needs to be textured before dyeing. There are four main types of texturing (Neckelmann, 2001):

- jet texturing,
- false twist texturing,
- chenille texturing,
- knit-de-knit texturing.

50% jet textured and 50% chenille was assumed as typical contents of a typical fabric for a sofa. In chenille yarn, an effect yarn is added. This yarn is not treated separately, but considered approximately to be of the same quality as the filament yarn.

Table 18: Data for texturing of Trevira CS filament yarn, 50% jet and 50% chenille

The table is found in appendix 6.

The cardboard rolls were assumed to be reused many times, and they were therefore left out. 20-30 kg yarn is wound onto a spool.

3.2.3.4 Dyeing of the yarn

The yarn itself is often dyed in the Trevira CS case of fabrics for a sofa, and therefore dying of Trevira CS yarn is assumed in this study. Most data came from Neckelmann (2001).

Table 19: Data for dyeing of Trevira CS dark red yarn at Neckelmann

The table is found in appendix 6.

Business trips for the texturing and dyeing activities were calculated to about 20 vehicle m/kg and data were therefore set to zero.

It could be suspected that there are metal ions from the dyeing agents emitted via water to soil (in sludge), but no data were available.

3.2.3.5 Truck and freighter from yarn texturer and dyer to Swedish weaving mill

The distance by boat was assumed to 40 km and by truck to 300 km. The freighter was assumed to medium size (2000-8000 dead weight tons), Load factor: 60%. Regarding details for the truck, see chapter 3.2.2.4.

3.2.3.6 Weaving without sizing in Sweden

The data are based on interviews with representatives of Swedish weaving mills and comparisons with the literature.

Table 20: Inventory data for weaving of Trevira CS
The table is found in appendix 6.

- About data, see chapter 3.2.2.9.
- Paraffins or oils are only sometimes used. Here they were assumed as not used.

3.2.3.6.1 Business trips from Trevira CS weaving mills site

See chapter 3.2.2.9.1.

The travel distance was calculated to 0.93 vkm/kg fabric.

3.2.3.7 Truck from weaving mill to wet treatment plant

The distance was assumed to 30 km. See chapter 3.2.2.6 for details.

3.2.3.8 Thermofix

The fabric is fixated with vapor.

Table 21. Inventory results regarding thermofix of Trevira CS
The table is found in appendix 6.

- Data were estimated from one wet treatment plant, and literature values for a comparison are found below. The plant uses light fuel oil and water to generate steam. Unfortunately, only total water and energy use was known and the plant has many different activities. The calculation based on weight gave the value 23 MJ for use of light fuel oil, which is much higher than the literature data; see below. Another plant uses LPG, but that plant had no data about gas and water consumption. One plant uses industrial water and the other uses water from a well.
- According to Ellebäk Laursen et al (1997) finishing (a process where properties of the fabric are changed, often with chemicals) uses 4.05-8.00 MJ/kg fabrics. Dyeing, washing and drying uses 3.40-13.2 MJ/kg. Therefore, the estimated 8 MJ/kg seems realistic. The water consumption in the inventory was estimated from the plant.
- Amount of cardboard is for the rolls and comes from one wet treatment mill.

3.2.3.9 Truck from Swedish wet treatment plant back to weaving mill

The distance was assumed to 30 km. For details see chapter 3.2.2.6.

3.2.3.10 Textile distribution at weaving mill in Sweden

See chapter 3.2.2.13.

3.2.3.11 Truck from Swedish weaving mill to upholstery plant

The distance was assumed to 500 km. Data for the truck is found under chapter 3.2.2.6.

3.2.3.12 Upholstering of Trevira CS fabric on a 3-seat sofa

Table 22: Inventory results from upholstering of Trevira CS fabric on a 3-seat sofa
The table is found in appendix 6.

About data, see chapter 3.2.2.15.

3.2.3.13 Laundry of Trevira CS fabric

Table 23: Laundry of Trevira CS fabric (one washing)
The table is found in appendix 6.

About data, see chapter 2.2.2.17. The difference as compared laundering of cotton is that the load factor in the washing machine was assumed to 2/3 according to instructions from Electrolux (1996). Tumble-drying was assumed to be one third of the time for cotton tumble-drying.

3.2.3.14 Truck from user to incineration plant

The distance to the incineration plant was assumed to 25 km; see chapter 3.2.2.18.

3.2.3.15 Incineration of Trevira CS fabric

Table 24: Inventory data for incineration of Trevira CS fabric.
The table is found in appendix 6.

- Heat recovery concerns polyester fabric combustion (Ellebäk Laursen et al, 1997).

See also chapter 3.2.2.19.

3.2.4 Wool/Polyamide (PA) fabric

Fabric for sofas with wool are usually mixed with a synthetic material, often with polyamide (PA, nylon). The weaving mills investigated used PA 66 in different amounts, from 9% to 15%. Here it was assumed that 15% of the fabric is PA 66. The wool is usually spun with a worsted system, and wool from New Zealand is popular for this application. The fiber diameter varies between 25 and 32 micrometer according to 2 of the weaving mills. In figure 4 the different companies and their roles in the production of wool/PA fiber are shown.

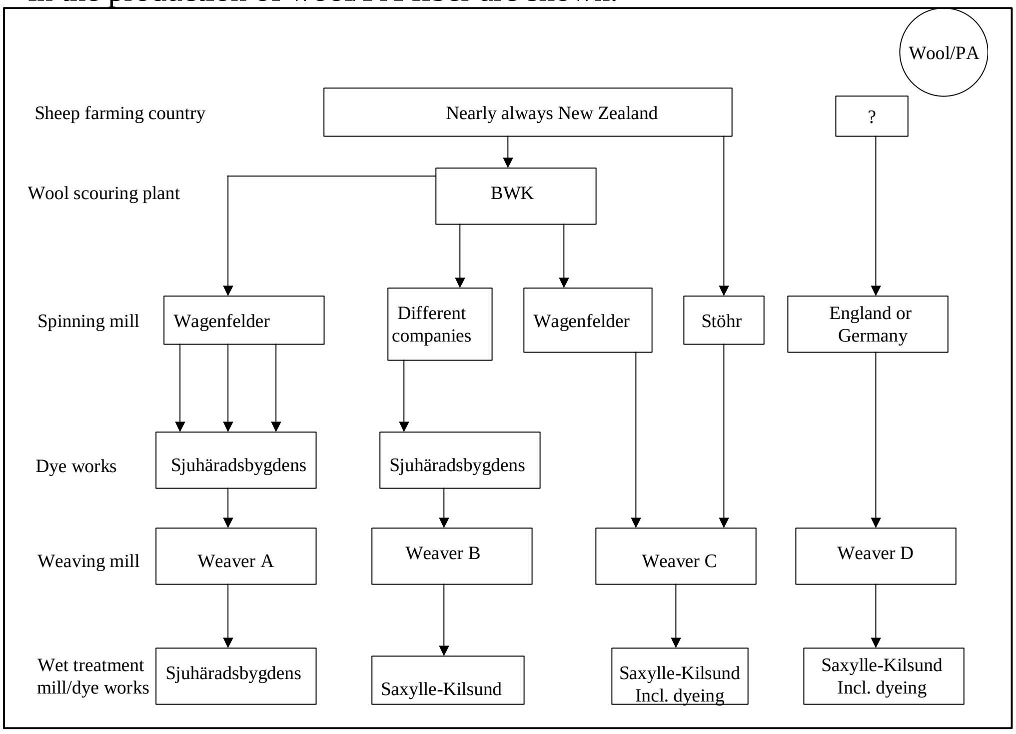


Figure 4: Companies and their roles in the production of Wool/PA fabric
Three arrows from Wagenfelder to Sjuhäradsbygdens indicate that three different yarn types are used for the fabric and that the yarn is dyed. In the study it was assumed that it was the fabric that was dyed, which is the case for two of the four textile chains studied.

3.2.4.1 Sheep farming in New Zealand

Data origin from different sources, see below.

Table 25: Inventory data for sheep farming
The table is found in appendix 6.

- In Ellebäk Laursen et al (1997) 40% of the environmental impact from sheep was allocated to wool and this allocation was also my study. This estimate is based on a global estimation that in most countries sheep are held for meat production with the important exception Australia where sheep are held mainly for wool (methodological issue 14). Sheep give about 4.5-5 kg fleece/year (Ellebäk Laursen et al (1997)). It is fairly clear that Ellebäk Laursen et al mean raw wool with oddments when giving data for ”raw wool” (methodological issue 19). On the assumption that Ellebäk Laursen et al mean wool including oddments, oddments were assumed to have the same environmental impact per kg as first quality raw wool, and also in this case study this is assumed since it can be assumed that wool with oddments can replace first quality wool in some applications.

3.2.4.2 Shearing, removal of oddments

Energy use for shearing is not known but was assumed to be insignificant.

Table 26: Inventory data for shearing

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Fleece with oddments	1.00E+00	kg	Technosphere
Output	Product	Fleece with oddments	1.00E+00	kg	Technosphere

Table 27: Inventory data for removal of oddments

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Fleece with oddments	1.33E+00	kg	Technosphere
Output	Product	Raw wool	1.33E+00	kg	Technosphere
Output	Co-product	Oddments[1]	0	kg	Technosphere

1. Stained wool which is used for lower quality products. In this case oddments are included in system expansion and assumed to replace first class wool in some applications. Therefore the value is 0 kg. If there were no system expansion or allocation to oddments, the value would be 0.33 kg.

The amount of oddments was found in Ellebäk Laursen et al (1997).

3.2.4.3 Truck from shearing to classing and selling of wool

The distance was assumed to 300 km. Regarding details for the truck, see chapter 3.2.2.4.

3.2.4.4 Classing, baling and selling of raw wool

Energy use was not known for classing, baling and selling of raw wool. It was considered insignificant and was assumed to zero.

Table 28: Inventory data for classing of raw wool

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Raw wool	1.00E+00	kg	Technosphere
Output	Product	Raw wool	1.00E+00	kg	Technosphere

Table 29: Inventory data for baling of raw wool

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Plastics[1]	1.09E-02	g	Technosphere
Input	Non-elementary	Raw wool	9.89E-01	kg	Technosphere
Output	Product	Raw wool with packaging	1.00E+00	kg	Technosphere

1. Data for plastics came from Bremer Wool-Kämmerei AG (BWK, 1999). The production of the plastics was not included in the study.

Table 30: Inventory data for selling of raw wool

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Raw wool with packaging	1.00E+00	kg	Technosphere
Output	Product	Raw wool with packaging	1.00E+00	kg	Technosphere

3.2.4.5 Freighter from New Zealand to Bremen (Germany)

The distance was estimated to be 24,753 km. The assumption was made that the freighter goes north of Australia and through the Suez Canal.
The data represents transportation by a large freighter.

3.2.4.6 Wool scouring, combing, shrink proofing, effluent treatment at Bremer Woll-Kämmerei AG (BWK)

The raw wool contains wool, grease, suint (sweat residues), dirt, vegetable matter and agrochemicals. In the wool scouring and combing process, the raw wool is cleaned and combed in order to get wool tops for the spinning of yarn (Ellebäk Laursen et al, 1997). The most common type of scouring takes place in water.

Table 31: Inventory results for scouring, combing, shrink proofing and effluent treatment at BWK. Data origin from BWK (1999).
The table is found in appendix 6.

- Grease was assumed to replace mineral oil, here approximated to be heavy fuel oil.

- Input of energy: Calculations were made on the basis of energy demand for the plant and recognizing that 90% of the energy is for wool. Data are for total energy use including everything in the plant. The total energy use is 23 MJ/kg raw wool. DWI (1997) states that totally 31.30MJ/kg raw wool is used for wool scouring and combing (scouring only: 5.79 MJ). The data above indicate less energy use than in the DWI statement, but energy from incineration of material in the effluent is used at BWK, which could explain the difference.

- The plant does also pure combing activities.

- At BWK, ammonia and soda are recovered. About 50% of the wool wax (grease) is deodorized and sold. Energy from incineration of material in the effluent is used. 90% of the electricity and all heat (steam) are generated in their own plant using coal.

- Inputs of chemicals: It was assumed that only wool needs these chemicals. (80% of the fibers treated are wool, the only fiber that needs scouring at BWK). The rest need only combing. Water consumption reported in the BWK brochure is assumed to be only for wool scouring.

- Discharges to water: BWK reports after water treatment

- Waste: BWK reported total amounts. The following assumptions were made: from wool only (the rest comes from all fibers proportionally): sludge, sand, wool dust, raw wool packaging, fabric. If more than 50% of the waste is recycled it is reported as Non-Elementary to the Technosphere in LCAiT. If more than 49% of the waste is not recycled it is reported as Elementary waste to ground.

- Air emissions come from evaporation, incineration and the coal-fired plant. Data reported are from the total amount. It is calculated on the basis of energy demand and that wool is responsible for 90% of these emissions.

- The amount of packaging material out is more than the plastic that was wrapped on the bales in the baling step, but this is not considered as an important deviation, since amount of packaging material is expected to be less accurate than for instance amount of chemicals used.

- Shrink proofing is not always done.

By comparison, data from Ellebäk Laursen et al (1997) are presented below in table 32. Emissions are difficult to compare, since BWK includes a wastewater-treatment plant in their data (methodological issue 20). BWK is at the lower edge regarding detergent consumption and they do not use soap. The amount of soda at BWK is well within the given range.

Table 32: Data from Ellebäk Laursen et al (1997) regarding wool scouring

Consumption of detergents, Raw wool scouring	1.5-20g/kg raw wool	
Consumption of soap, Raw wool scouring	*2-20 g/kg raw wool*	(soap+soda can replace detergents)
Consumption of soda, Raw wool scouring	*5-30 g/kg raw wool*	
Emissions of BOD(total)Raw wool scouring	460g/kg scoured wool (average)	(before wastewater-treatment plant)
Emissions of BOD(non grease)Raw wool scouring	110g/kg scoured wool (average)	(before wastewater-treatment plant)
Emissions of grease. Raw wool scouring	450 g/kg scoured wool (average)	(before wastewater-treatment plant)
Emissions of SS (non-grease) Raw wool scouring	390g/kg scoured wool (average)	(before wastewater-treatment plant)

The yield for scouring according to Ellebäk Laursen et al (1997) is about 55-74% (including 10-12% water) for the fiber diameters of 25-42 micrometer. Combing is not mentioned. Without water it would be 50-65% (Ellebäk Laursen et al (1997)). The dryness of the scoured wool at BWK is not known. Bolte (2004) at BWK stated that the yield is about 65%.

A comparison between the data above and data from DWI, 1998 is shown below in table 33:

Table 33. Comparison regarding chemicals use for wool scouring at DWI (1998) and in this study

Chemicals	Calculation in this report	DWI, 1998	Unit
Synthetic surfactants	7.75E-03	8.13E-03	kg/kg raw wool
Soda (CaCO3)	1.35E-02	9.22E-03	kg/kg raw wool
Lime	1.33E-02	1.26E-02	kg/kg raw wool
NaOH solution	1.90E-02	3.08E-02	kg/kg raw wool
Acids	1.37E-02	1.68E-02	kg/kg raw wool
Softening agents	3.49E-03	3.94E-03	kg/kg raw wool

Concentrations of active ingredients were not reported.

One weaving mill claims the wool is also carbonized. It is not mentioned in the data from BWK, thus it is uncertain whether carbonizing really is done at BWK. The spinning plant does not report any carbonizing. Carbonizing is only done for 100% wool and the process aims at removing vegetable matter. This is done with certain mineral acids or some of their salts. Usually it is not done for worsted yarns, the type of yarn in this study. The potential environmental impact of carbonizing is mainly health problems attributable to air emissions (Ellebäk Laursen et al 1997).

3.2.4.7 Truck from scouring plant to spinning plant

The distance from Bremen to the spinning mill was assumed to 60 km. Regarding data for the truck, see chapter 3.2.2.4.

3.2.4.8 Production of polyamide 66 (nylon)

Data below was found in Boustead (1997). It is not known whether or not air conditioning and general water and electricity use were included (methodological issue 19).

Table 34: Inventory results for production of polyamide 66 fibers
The table is found in appendix 6.

- Data source: average production data in Europe. The data are a weighted average based on production volume from 7 different plants in Germany, Austria and the Netherlands (about 30% of total European production). The amount of packaging was estimated in this LCA study.

- In the report wastewater-treatment plants are not mentioned, and discharges to water are reported. Therefore one can conclude that wastewater-treatment (if there is any) was included in the system under study (methodological issue 19).

- It is not clear from the report if data for packaging materials were included (methodological issue 19).

3.2.4.9 Truck from polyamide plant to spinning mill

The distance was assumed to 100 km. For data about the truck are found in chapter 3.2.2.4.

3.2.4.10 Spinning of wool yarn

Data came from one spinning mill. Worsted spinning system data for the dimension of Nm 36/2 was reported, since this is what the representatives from the weaving mills state they often use for upholstery qualities. The representative from the spinning mill also claimed that this is the standard type of yarn for upholstery fabrics. The activities included are: preparation, ring spinning, rinsing, and twisting of worsted Nm 36/2 yarn. Energy consumption for light and air conditioning was included. Water consumption was not reported, and is therefore not included here. The data for packaging material come from one weaving mill. All energy was assumed to be electricity.

Table 35: Inventory results from spinning of wool yarn
The table is found in appendix 6.

Paraffins are only sometimes used. Here they were assumed as not used.

3.2.4.11 Truck and boat from spinning mill to Swedish weaving mill

The distance with a large freighter was assumed to 40 km. The distance by truck was assumed to 857 km. For data about the truck are found in chapter 3.2.2.4.

3.2.4.12 Weaving without sizing in Sweden

See chapter 3.2.3.6. The data for Trevira CS are considered also to be valid for wool/PA. Discussion regarding this estimation is found in chapter 3.2.2.9.

3.2.4.13 Business trips from wool/PA weaving mills site

See chapter 3.2.2.9.1.

The travel distance was calculated to 0.63 vkm/kg fabric.

3.2.4.14 Truck from weaving mill to wet treatment plant

The distance was assumed to 30 km. About the truck, see chapter 3.1.6.

3.2.4.15 Dyeing of wool fabric including pretreatment, rinsing and drying

Table 36: Inventory result from dyeing of wool fabric including pre-treatment, rinsing and drying
The table is found in appendix 6.

The drying step also includes fixation. No carbonizing is done.

- Data for energy (not specified) and BOD, came from Ellebäk Laursen et al (1997). The range for energy use is reported there to 3.40-13.2 MJ/kg textile (Dyeing/washing/drying) and 4.05-8.00 MJ/kg textiles for finishing.

- BOD for scouring: 47 g/kg textile, dyeing is reported to 9-34 g/kg textile and finishing 2-80 g/kg textile according to Ellebäk Laursen et al (1997). There was no finishing of the fabric.

- The formulation for dyeing is an average of data from one wet treatment mill and a standard formulation from Clariant Sweden (2001). Data were for a dark red color.

- The dyer used a machine for dyeing called THEN Soft Stream, a kind of HT machine.

- Owing to poor data, general water and energy use were not included.

- Data for water consumption are a combination of the wet treatment mill, data for cotton fabrics rinsing and data from Ellebäk Laursen et al (1997).

- It is approximated that the colorants fixate to 75% on the fiber. This assumption only affected the weight of the fabric here, since the fate of the chemicals was not followed.

- Data for non-elementary discharges to water of metals were not known.

- The packaging is cardboard rolls. PE that is wrapped over was assumed to insignificant.

- Surfactant for the washing was not included, owing to absence of data.

- Some wet treatment mills do singeing. In this case singeing is not assumed. An approximation is that the same amount of LPG as for wet treatment of cotton, 0.38 MJ/kg finished fabric, is used for singeing.

3.2.4.16 Truck from Swedish wet treatment plant back to weaving mill

The distance was assumed to 30 km. Regarding data for the truck, see chapter 3.2.2.6.

3.2.4.17 Textile distribution at weaving mill site in Sweden

See chapter 3.2.2.13.

3.2.4.18 Truck from Swedish weaving mill to upholstery plant

The distance was assumed to 500 km. General information is found in chapter 3.2.2.6.

3.2.4.19 Upholstering of wool/PA fabric on a 3-seat sofa

Table 37: Inventory results from upholstering of wool/PA fabric on a 3-seat sofa
The table is found in appendix 6.

About data: See chapter 3.2.2.15.

3.2.4.20 Dry-cleaning

Table 38: Dry-cleaning of wool/PA fabric (one time)
The table is found in appendix 6.

- Data from Österlund B (2002). The chemicals reported end up in a destruction plant (e.g. incineration). Much more solvent is used, but it is distilled and reused, therefore it is not added as a new chemical for each dry-cleaning. Distillation energy and general energy were included.

3.2.4.21 Truck from user to incineration plant

The distance to the incineration plant was assumed to 25 km. For data about the truck, see chapter 3.2.2.18.

3.2.4.22 Incineration of wool/PA fabric

Table 39: Inventory data for incineration of wool/PA fabric.
The table is found in appendix 6.

- Heat recovery concerns wool fabric combustion (Ellebäk Laursen et al 1997).

See also chapter 3.2.2.19.

3.3 Information about data found in databases for energy production, fuel combustion, transport type and production of packaging materials

3.3.1 Data for energy production

The data for the energy production and fuel combustion were found in the LCAiT database, Energy&TrpDatabase CIT 3h-20010601.mdb. The reason for not publishing actual data here is that the data base creators were opposed to doing so (methodological issue 12).

The data for the activities in table 40 were found in Frees et al (1998).

Table 40. References for the data for the activities found in Frees et al, 1998

Activity	**Refers to**
Diesel production	Frischknecht et al. (1994).
Electricity, coal power (including 9% grid losses) Only used for the "cotton ginning" activity.	Energistyrelsen. (1995), European Commission (1988), Eurostat. (1997a), Eurostat. (1997b), Eurostat. (1997c), Frischknecht et al (1994) and Frishknecht R (ed.) (1996)
Electricity, European average (including 9% grid losses) Used for the activities in Europe (not Sweden)	CORINAIR (1996), CORINAIR (1997), (CORINAIR 94), Eurostat. (1997a), Eurostat. (1997b), Eurostat. (1997c), Eurostat (1997d) and Frishknecht R (ed.) (1996).
Electricity, from natural gas (used in the sensitivity analysis)	Eurostat. (1997c), Frischknecht et al (1994) and O'Callaghan (1993)
Heavy fuel oil production	Frischknecht et al. (1994).
Light fuel oil production	Frischknecht et al. (1994).
LPG production	Frischknecht et al. (1994).
Light fuel oil combustion (small boilers (10-100 kW)).	Frishknecht R (ed.). (1996) and Statoil & Texaco. (1996).
LPG production	Frischknecht et al. (1994).
LPG combustion (thermal)	CORINAIR (1996).
Natural gas combustion (>100 kW)	Frishknecht R (ed.). (1996).

3.3.1.1 Electricity, Swedish average (households)

The data were primarily based on Brännström-Norberg et al (1996). These data were used for the activities in Sweden.

3.3.1.2 Electricity, Oil UCPTE

ETH-ESU (1996) (used in the sensitivity analysis)

3.3.1.3 Gasoline production

Life of fuels, Ecotraffic AB (1992)

3.3.1.4 Natural gas production

Boustead I. (1993)
Frischknecht et al. (1994).
Bakkane K K. (1994).

3.3.2 Data for diesel combustion, forestry machines

Berg (1996) who refers to: Anon. (1990).

3.3.3 Data for gasoline combustion (long distance)

Eriksson et al (1995)
The data represents highway driving (110 km/hour) with a new vehicle (1993) with a catalytic converter.

3.3.4 Transports

The data for the transport types were found in the LCAiT database, Energy&TrpDatabase CIT 3h-20010601.mdb.

The data for the following activities were taken from the homepage of NTM.

3.3.4.1 Freighter, large (>8000 dwt, 60%)

The data were presented per ton*km and represent transportation by large freighter (>8000 dead weight tons) with a load factor of 60%.

3.3.4.2 Freighter, medium (2000-8000 dwt, 60%)

Transportation by freighter, medium size (2000-8000 dead weight tons). Load factor: 60%.

3.3.4.3 Medium truck (rural, 14/24 tons, 50%, Euro 1)

Transportation by medium truck (total weight: 24 tons, maximum load: 14 tons), fulfilling the "Euro 1" emission regulations (1993-1995), load factor 50% and rural driving mode.

3.3.4.4 Medium truck (rural, 14/24 tons, 50%, Euro 2)

Transportation by medium truck (total weight: 24 tons, maximum load: 14 tons), fulfilling the "Euro 2" emission regulations (1996-), load factor 50% and rural driving mode.

3.3.4.5 Light truck (urban, 8,5/14 tons, full + empty return, Euro 2)

Transportation by light truck; full including empty return (total weight: 14 tons, maximum load: 8,5 tons), fulfilling the "Euro 2" emission regulations (1996-) and urban driving mode.

3.3.5 Production of packaging materials

The data were found in the SPINE database.

3.3.5.1 Polyethylene, polypropylene production

Data were derived from Boustead (1993).

In the calculations, additives such as antioxidants, dyes and fillers were excluded, as was all the outer packaging for the final product. However, the calculations do include the conversion of the polymer resin into granules. It was assumed that the neglected activities were not significant for the results of my study (methodological issue 3).

3.3.5.2 Wood pallet

Wood was assumed as a resource. The production of the pallet was not included in the calculations since it was assumed not to be significant for the study (methodological issue 3).

3.3.6 Production of chemicals

- Data for **fertilizer production** were found in Davis and Haglund (1999). Data are for Western European conditions (methodological issue 15) since the cotton was assumed to be cultivated in U.S.A). Transports were included but not coating of the final products. Micronutrients were not included, nor were production and waste treatment of catalysts and production of capital goods. This is reported as a cradle to gate study, but since diesel, electricity and heavy fuel oil were reported, but not traced to the "cradle" (methodological issue 19), the data for the production of these energy carriers were added in my fabrics LCA study. Allocation where different fertilizers were produced at the same plant was made according to mass.
  The fertilizers included in the calculation were: diammonium phosphate, potassium nitrate and ammonium nitrate.

- Data for **production of detergent ingredients** were found in Dall'Acqua et al (1999). Data for the main product line, energy production and the production of additives were included in the study. Transports were also included. The infrastructure was not included. Disposal processes were only included if the route was known. Allocation was according to the polluter pays principle, i.e. the environmental impacts of a process are allocated to the products, by-products and services responsible for their creation. In practice they used the quantity relationships of main and by-products, which I consider allocation according to mass (methodological issue 14).

  The chemicals included in the calculation were: triazinylaminostilbene (DAS-1), linear alkylbenzene sulphonates made from petrochemical raw materials (LAS), alcohol ethoxylates with 7 EO chains from petrochemical raw materials (AE), soap as a mixture of short-chain fatty acids on the basis of coconut or palm oil, Zeolite A (powder), sodium silicate (spray powder), perborate (tetrahydrate), carboxymethyl cellulose (CMC).

- Data for **sodium hydroxide** were found in the database from ETH (1996). No information about the data was found (methodological issue 19).

- Data for **hydrogen peroxide** were from Dall'Acqua et al (1999), see above.

- In this report it is assumed that NaCl and limestone are resources, thus coming from nature without intermediate production.

- Data for **ethylene glycol** were from ETH-ESU (1996).

- Data for **terephtalic acid** were from APME (2002).

3.3.7 Production of drinking water

Data were found in Wallén (1999). The table is found in Appendix 2.

3.3.8 Purification of waste water in a municipal wastewater-treatment plant

Data were found in the annual report for GRYAAB, a municipal wastewater-treatment plant in Gotheburg (Gryaab, 2001). The table is found in Appendix 3.

4 Impact assessment including base cases, scenario and sensitivity analysis

According to ISO 14042 (2000), clause 10, the following items shall be included*:

1) the LCIA procedures, calculations and results of the study (4, 6.1)
2) limitations of the LCIA results relative to the defined goal and scope of the LCA study (5.1)
3) the relationship of LCIA results to the defined goal and scope (6, 9)
4) the relationship of the LCIA to the LCI results (5.2)
5) impact categories considered, including a rationale for their selection and a reference to their source (4.1)
6) descriptions of or reference to characterization models, characterization factors and methods used, including all assumptions and limitations (4.1)
7) descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations (4.1)
8) a statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, exceedence of thresholds, safety margins or risks (4.3.1)
9) an evaluation of the completeness of the LCIA (5.2)
10) a statement as to whether or not there is international acceptance for the selected category indicators, and a justification for their use (4.1)
11) a justification for the scientific and technical validity and environmental relevance of the category indicators used in the study (4.1)
12) the results of the uncertainty and sensitivity analyses (4.3)
13) an evaluation of the significance of the differences found (4.3, especially 4.3.5)
14) the statement that “ISO 14042 (2000) does not specify any specific methodology or support the underlying value choices used to group the impact categories” (4.3.3).

*The chapters in this LCA report where these items are considered are noted in brackets

4.1 Selection of impact categories, category indicators and characterization models plus classification

This is a mandatory element in LCIA according to clause 4.3.2 in ISO 14042 (2000). The text also states that identification of the category endpoints and the associated LCI result the LCA study will address shall be included, but when the text is outlined in the subsequent sections of the standard, it becomes clear in clause 5.3 that it is only a requirement to include these items if new impact categories, category indicators and characterization models are defined (methodological issue 1).

The main two sets of impact categories, category indicators and characterization factors are reported here. One set was at the midpoint level, see table 41, and one at the endpoint of damage level according to the EPS-system, see table 42 (Steen 1999).

The first set of **impact categories** were found in Nordic Guidelines on Life Cycle Assessment (Nord 1995) written by an LCA research team, and therefore the guidelines are scientifically and technically valid, and they deal with the major environmental threats. The following categories were chosen:

- resources – Energy and materials
- resources – Water
- resources – Land
- global warming potential
- stratospheric ozone depletion potential
- acidification potential
- eutrophication potential
- photo-oxidant formation potential
- ecotoxicological impacts (aquatic)
- human toxicity impact potential from air emissions.

The category I only considered briefly owing to a great shortage of data was:
- human health impacts in the work environment.

The Nordic Guidelines also propose the following impacts, which are not studied here owing to shortage of data:
- human health – Non-toxicological impacts (excluding the work environment)
- habitat alterations and impacts on biological diversity.

The Nordic Guidelines propose that the following should be included although they are not impact categories, and they are considered in this LCA:
- inflows, which are not traced back to the system boundary between the technical system and nature
- outflows, which are not followed to the system boundary between the technical system and nature.

One methodological issue (methodological issue 5) is how know whether the chosen impact categories are the most important ones. In this study, I have relied on the relevance of the recommendations in the Nordic Guidelines. Another methodological issue is that the impacts are potential and not actual, which gives a kind of "worst case" result (methodological issue 21). The category indicators are internationally accepted.

Table 41: Selection of impact categories (except use of resources), category indicators and classification

Impact category	Abbreviation	Category indicator	Classification: Assignment of LCI results to the impact category
Global warming potential with 100 year perspective[1]	GWP 100	kg CO_2 equivalents	Emissions to air: Aldehydes, CO_2 , CO, Dichloromethane, Halon-1301, NMVOC, methane, N_2O, PAH, Propene, NO_x
Depletion of stratospheric ozone	ODP	g CFC-11 equivalents	Air emission: Halon-1301
Acidification potential (max)	AP	g SO_2 equivalents	Emissions to air: H_2S, HCl, HF, NH_3, NO_x, SO_2, SO_x Discharges to water: Acid as H^+, H_2S, NH_3, NH_4^+
Eutrophication potential	EP	g NO_x equivalents	Emissions to air: NH_3 and NO_x Discharges to water: COD, NH_4^+, PO_4^3, BOD, BOD5[2], N total, NH_3, Nitrogen, P total, P_2O_5, TOC, NO_3^-, Phosphate, Total organic carbon
Photo-oxidant creation potential[3]	POCP[3]	g ethane equivalents	Emissions to air: Acetaldehyde, Acetylene, Benzene, Ethane, Ethene, Formaldehyde, Methane, Propane, Propene, Toluene
Ecotoxicological potential (aquatic)		1E+04 m^3 polluted water	Discharges to water: As, Cd, Cr, Cr3+, Cu, Hg, Ni, Oil, Pb, Phenol, Zn.
Human toxicity impact from air emissions		g contaminated body mass	Emissions to air: As, CN^-, CO, Cd, Co, Cr, Cr^{3+}, Cu, Dioxin, H_2S, HF, Hg, Mn, Mo, NO_x, Ni, PAH, Pb, SO_2, SO_x, Sn, Toluene, V, Zn.

1.The choice of time horizon is a methodological issue (methodological issue 22).
2. An attempt was made to rename all BOD5 in the databases BOD. However in two cases BOD5 still remains, but they have the same characterization factor.
3. NMVOC was not included. It may be suspected that sometimes only NMVOC is known, and could include some of the components listed. Often aromatics are reported and these could include toluene. They do not have the same characterization factor; therefore it is not possible to include "aromatics" in the calculation (methodological issues 19 and 23).

Table 42. Selection of impact categories at endpoint level, category indicators and classification according to EPS 2000d.

Impact Category	**Category Indicator**	**Unit**	**Classification: Assignment of LCI results to the Impact Category**
Life expectancy	Years of lost life (YOLL)	personyears	Emissions to air: CO_2, CO, NO_x, N_2O, SO_x, H_2S, HF, HCl, NH_3, benzene, ethene, formaldehyde, methane, propene, acetylene, ethane, pentane, propane, NMVOC, toluene, pesticides (only in sensitivity analysis), particles (PM_{10}), As, Cr, Cd, PAH Discharges to water and soil: pesticides (only in sensitivity analysis)
Severe morbidity and suffering	Severe morbidity	personyears	Same as for YOLL
Morbidity	Morbidity	personyears	Emissions to air: CO_2, CO, NO_x, N_2O, SO_x, H_2S, HF, HCl, NH_3, benzene, ethene, formaldehyde, methane, propene, particles (PM_{10}), Cd, Hg, Pb, CFC-11 Discharges to soil: pesticides (only in sensitivity analysis)
Severe nuisance	Severe nuisance	personyears	Emissions to air: Pb
Nuisance	Nuisance	personyears	Emissions to air: CO, NO_x, N_2O, SO_x, H_2S, HF, HCl, NH_3, particles (PM_{10})
Crop production capacity	Crop production capacity	kg	Same as for YOLL but without metals to air
Wood production capacity	Wood production capacity	kg	Same as for YOLL but without metals to air
Fish & meat production capacity	Fish & meat production capacity	kg	Emissions to air: NO_x, N_2O, SO_x, H_2S, HF, HCl, NH_3, Hg Discharges to water: N_{tot}
Base cat-ion capacity	Base cat-ion capacity	H^+ mole equivalents	Emissions to air: NO_x, N_2O, SO_x, H_2S, HF, HCl, NH_3
Production capacity for water	Production capacity for irrigation water	kg	Resource from ground: irrigation water
Production capacity for water	Production capacity for drinking water	kg	-
Depletion of element reserves	=”element name” reserves	kg of element	Resources from ground: copper in ore, iron in ore, lead in ore, nickel in ore, zinc in ore, uranium in ore, chromium in ore
Depletion of fossil reserves	Natural gas reserves	kg	Resource from ground: natural gas
Depletion of fossil reserves	Oil reserves	kg	Resource from ground: crude oil
Depletion of fossil reserves	Coal reserves	kg	Resources from ground: hard coal, lignite
Depletion of mineral reserves	=”mineral name” reserves	kg	Resource from ground: Bauxite
Extinction of species	Normalised extinction of species (NEX)	Dimensionless	Emissions to air: Same as for YOLL for inorganic substances, VOC:s, particles (PM_{10}), Hg Discharges to water: BOD, COD, N_{tot}, P_{tot} Discharges to soil: pesticides (only in sensitivity analysis) Arable land use, forestry

The value choices and assumptions are found in the references for each characterization and weighting method.

It is difficult to assess some effects, such as the effects of land use on biodiversity (methodological issue 24). There are, for instance, possible risks for the biodiversity associated with GE cotton that are not known (methodological issue 25).

4.1.1 Characterization models

In table 43 the derivation of the characterization models are reported.

Table 43. Derivation of the characterization methods

Characterization method	References
Global warming potential 100 years (GWP 100[1])	Mainly IPPC (1995-2001), but also Houghton T.T. et al (1999), The Swedish Environmental Protection Agency (1992) and UMIP
Ozone depletion potential (ODP)	The Swedish Environmental Management Council (1999)
Acidification potential (AP)	Heijungs et al (1992) and calculations on H+ formation made by Anna Ryderg, CIT Ekologik
Eutrophication potential (EP)	Mainly Heijungs et al (1992) but also Baumann et al (1993)
Photooxidant creation potential (POCP)	The Swedish Environmental Management Council (1999)
Ecotoxicological potential (aquatic)	Heijungs et al (1992)
Human toxicity impact from air emissions	Heijungs et al (1992)

1. The choice of time horizon is a methodological issue (methodological issue 22).

4.2 Description of the combined characterization and weighting methods

The weighting factors are not reported here, owing to restrictions from the company selling the LCAiT program (methodological issue 12), but can be found in the references.

The following default combined characterization and weighting methods were used:

- EPS 2000d (Steen 1999)
- Ecoindicator –99 (Goedkoop and Spriensma 1999)
- EDIP (Wenzel et al 1997)

EPS 2000d is the main default weighting method used in this study. The advantages of EPS 2000d are that it has a clear value base, it models actual impacts and it is finance-related. Furthermore, it is normalized to the entire world, which is an advantage in this case, since the production chains contain activities in different parts of the world. This combination is not found in other weighting methods. The other two weighting methods were also used for the comparison of the three fiber types, in accordance with clause 6.4 in ISO 14042 (2000), which states: “it may be desirable to use several different weighting factors and weighting methods, and to conduct sensitivity analysis to assess the consequences on the LCIA results of different value-choices and weighting methods”. The sensitivity analysis for the ranking was, however, only done with EPS 2000d.

4.2.1 Short description of EPS 2000d

The environmental impacts are expressed in terms of “willingness to pay” for the damage of five safeguard subjects: human health, biological diversity, eco-system production, natural resources and aesthetic values. Damage is expressed in category indicators such as “years of lost life” (YOLL), “crop production capacity” or “oil reserves”. The available database is strong in assessing air emissions but weaker in discharges to water. The database is developed for generic use and no site-specific effects are assessed. It is, however, possible to develop site-specific weighting factors.

4.2.2 Short description of Ecoindicator 99

Ecoindicator 99 models damages on ecosystems, human health and finite resources. The weighting is derived from an expert panel that judged, three different perspective considerations:

- the *egalitarian* perspective: long term perspective; even a minimum of scientific proof justifies inclusion
- the *individualist* perspective: short time perspective, only proven effects are included,
- the *hierarchical* perspective: balanced time perspective.

When applying this method one or more perspectives are chosen, but usually the hierarchic perspective is the default. Normalization is made for Europe (methodological issue 26). In this LCA study, the hierarchical perspective was chosen.

4.2.3 Short description of EDIP

EDIP is an acronym for Environmental Development of Industrial Products. The weighting is carried using political goals in the affected area as a basis (in practice Denmark (methodological issue 26)). Normalization is carried out on the basis of the affected area.

4.3 Inventory and impact assessment results including sensitivity analysis

4.3.1 Characterization

According to ISO 14042 (2000) this has to be stated: “The LCIA results are relative expressions and do not predict impacts on category endpoints, exceedence of thresholds, safety margins or risks.” Two methods used here, EPS 2000d and Ecoindicator 99, do however predict impacts on category endpoints.

Clause 5.5 in ISO 14042 (2000) states that: “the method of calculating indicator results shall be identified and documented, including the value-choices and assumptions used”. The classification was done in chapter 4.1 but the characterization factors could not be published in this report owing to restrictions from the company selling the LCAiT program (methodological issue 12).

Data for cotton cultivation includes data for cotton ginning and baling, since the system expansion to cottonseed is found in the ginning process.

4.3.1.1 Use of resources

Fossil energy use is found in figure 5 and total energy use is found in figure 6:

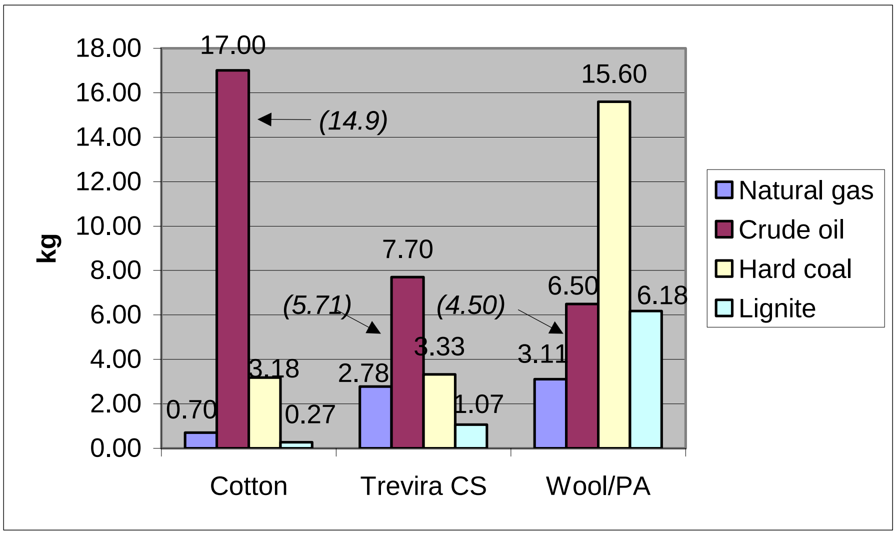
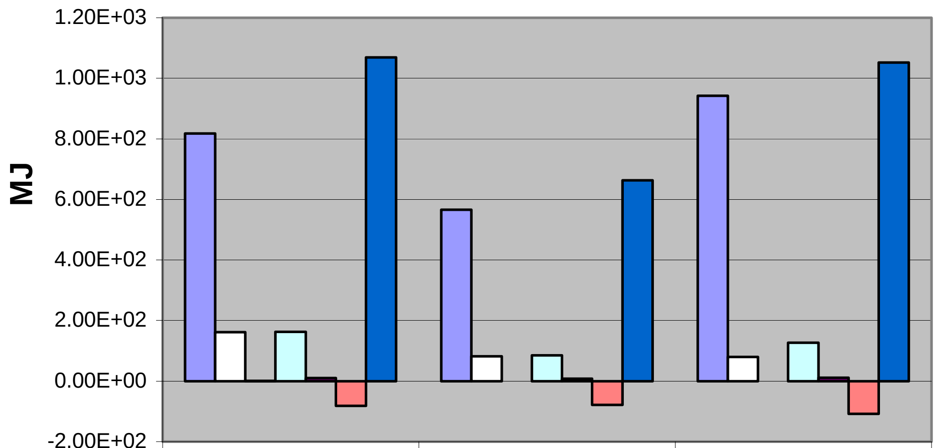


Figure 5. Fossil energy use in kg including feedstock The values in brackets are total oil use if the incineration of the fabric replaces light fuel oil.

- Different types of fossil fuels seem to be dominant for the three fiber types. Crude oil is the major fuel for cotton fabric production and hard coal for wool/PA. For Trevira CS fabric, less of both crude oil and hard coal than for both other fiber types is used. The major use of crude oil for cotton fabric is in the wet treatment and cotton cultivation activities, 60% and 21% of the total use, respectively. In the case of wool/PA it is the spinning of yarn and wool scouring that use most hard coal, 46% and 43% of the total use respectively. Electricity use in the spinning activity and a coal-fired plant in the wool scouring activity are the reasons for the hard coal use.



	Cotton	Trevira CS	Wool/PA
Fossil fuel	8.17E+02	5.66E+02	9.42E+02
Hydro power	1.61E+02	8.19E+01	7.98E+01
Wind power	3.43E-01	1.70E-01	1.21E-01
Nuclear power	1.62E+02	8.54E+01	1.27E+02
Other fuel	1.02E+01	7.66E+00	1.12E+01
Energy recovery from combustion of fabrics	-8.13E+01	-7.83E+01	-1.08E+02
Total	1.07E+03	6.63E+02	1.05E+03

Figure 6. Energy use in MJ including feedstock.

The manufacturing step (all activities before the use of the sofa) consumes approximately for each fabric type:

- Cotton: 928 MJ
- Trevira CS: 646 MJ
- Wool/PA: 1115 MJ

In table 44 the main contributing activities to fossil energy use are shown.

Table 44. The main contributing activities to fossil energy use
The activities reported in brackets are the main activities contributing to the activities with the highest or second highest oil or coal consumption.

Fabric type	Crude oil consumption	Hard coal consumption
Cotton	Fabric manufacture from yarn: 10.8 kg (Wet treatment: 10.2 kg) Yarn manufacture: 4.73 kg (Cotton cultivation: 3.53 kg)	
Trevira CS	Polyester yarn production: 4.75 kg (about 4.84 kg if only net calorific value were used in the calculations)	Polyester yarn production: 2.29 kg (about 2.33 kg if only net calorific value were used in the calculations)
Wool/PA		Yarn manufacture: 15.22 kg (Spinning of yarn: 7.16 kg, wool scouring: 6.78 kg)

Water consumption is found in figure 7.

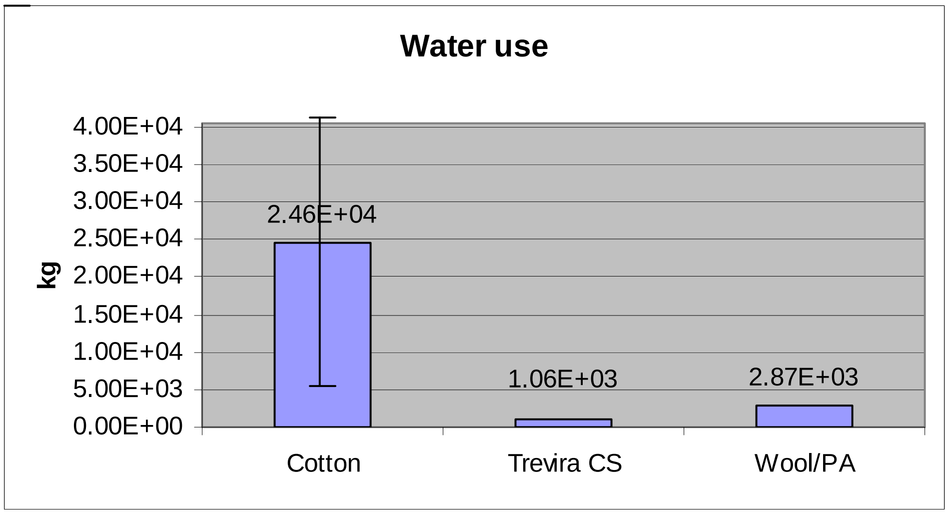


Figure 7: Water consumption

The main water consumption for cotton is in the cotton cultivation, 23 of the 25 tons used are used for irrigation of cotton fields. The range for cotton is 5,200-40,400 kg!

Arable land use is found in figure 8.

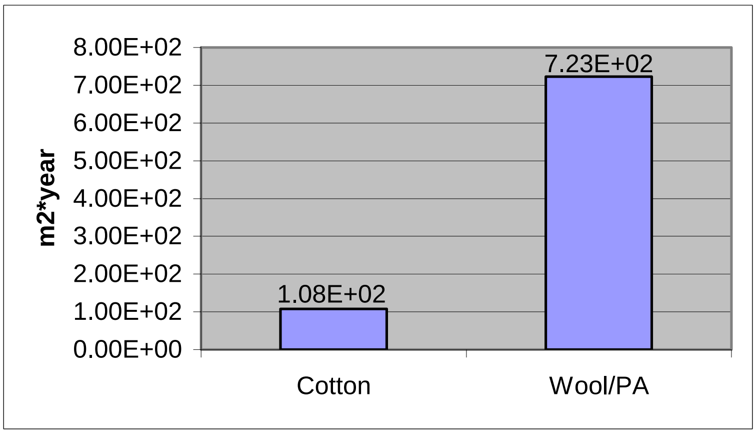


Figure 8. Arable land use for cotton and wool/PA

Only studying how much arable land area is used for cotton cultivation and sheep farming respectively does not say much. There have been many attempts to include land use in the impact assessment in the LCA methodology, e.g. in Vogtländer et al (2004). The problems are that the impact category indicator "arable land use" is an average for all types of land use for agriculture, and that cotton cultivation normally has a high impact on the land.

Land use for sheep farming could be considered positive in some environmental respects, since grazing keeps the landscape open, as does arable land use. This could be positive for the aesthetic values and also, in some cases, for biodiversity. How to include these aspects is a methodological issue (methodological issues 24 and 27).

Below, chemical and packaging material use are reported.

4.3.1.2 Inflows which are not traced back to the system boundary between the technical system and nature (inventory results)

Chemical use is found in figure 9.

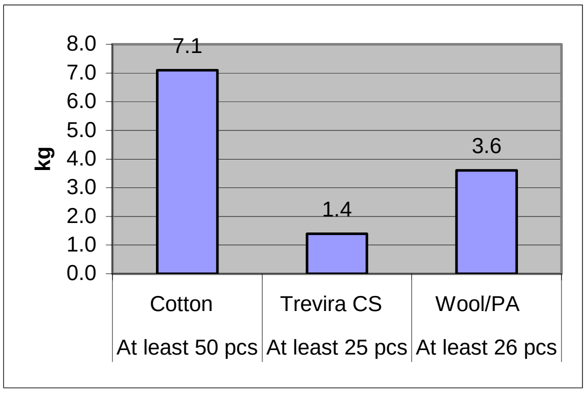


Figure 9. Weight and the amount of chemicals used
The number of chemicals includes chemical mixtures and must not be confused with the number of pure chemical compounds, which is higher,

Especially the production of cotton fabric involves many chemicals, but 2.38 kg of the chemical use is the use of NaOH. It is used in the wet treatment process. The representative for one wet treatment plant reported however, that a part of the NaOH is regenerated and reused. In this case, however, only virgin NaOH was assumed.

Packaging material use is found in figure 10:

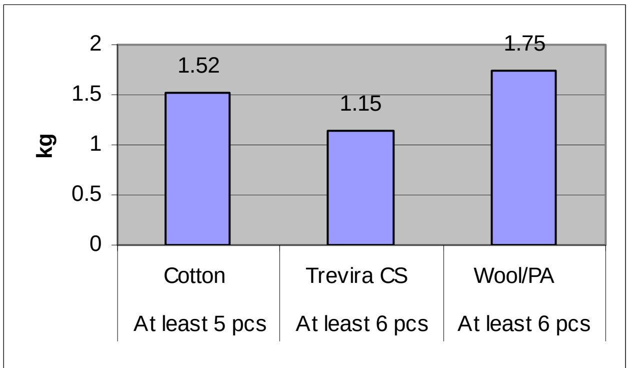


Figure 10: The estimated minimum amount of packaging material used.

The result is a rough picture of the amount and weight of packaging material, since there were data gaps. The packaging material is to a large extent reused or recycled.

4.3.1.3 Outflows which are not followed to the system boundary between the technical system and nature

In figure 11 the minimum amounts of non-elementary flows to the technosphere are shown. Some of the outflows may be recycled or reused.

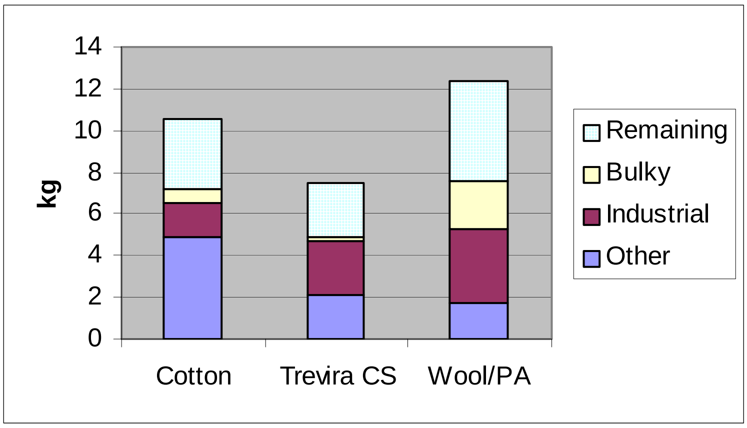


Figure 11: Minimum amounts of non-elementary flows to the technosphere for the life cycles of the fabric types

4.3.2 Environmental impact potentials including sensitivity analysis

4.3.2.1 Global warming potential

The category indicator results for the global warming potential are shown in figure 12.

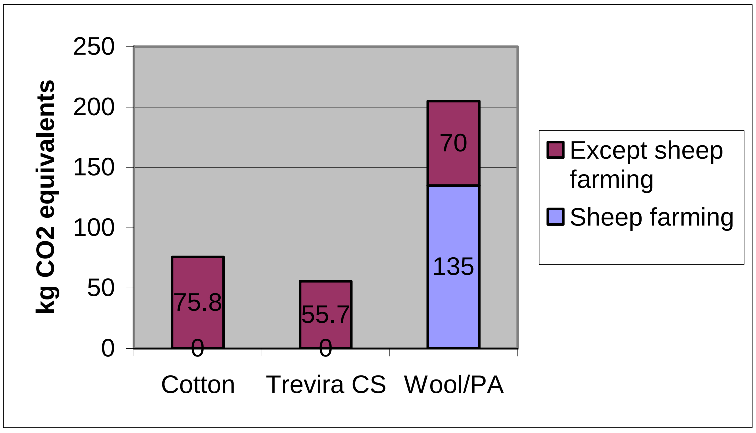


Figure 12. Category indicator results for the global warming potential with 100-year perspective (GWP 100 years)

- The high GWP for sheep farming is due to methane emission from sheep. It is, however, possible to reduce the amount of methane emitted by feeding the sheep plants high in condensed tannins. The reduction of methane emissions would be about 16% (Roach 2002).

- The allocation between wool and meat is important, since sheep farming is the critical issue (methodological issue 14).

- If landfill instead of incineration of the cotton fabric were assumed, the global warming potential would increase by 8.3 kg CO_2 equivalents. 0.0795 kg methane was calculated to be emitted from 1 kg of cellulose-like material according to Sundqvist (1999). 35% of the total methane emissions were estimated to go to the atmosphere and this is calculated for. 50% are collected and methane-consuming microorganisms oxidize 15%. Methane emissions were assumed to take place for 100 years (methodological issue 22). This scenario could also be valid for the scenario where the fabric is incinerated, and replaces other organic waste intended for incineration that is instead ending up in landfill because of limited capacity of the waste incinerator.

- If the incineration of fabrics replaced light fuel oil in the incinerator, the global warming potential would be:
  68.5 g CO_2 equivalents for cotton (decrease of 7.3 kg CO_2 equivalents)
  48.7 g CO_2 equivalents for Trevira CS (decrease of 7.0 kg CO_2 equivalents) and
  195.3 g CO_2 equivalents for wool/PA (decrease of 9.7 kg CO_2 equivalents)

4.3.2.2 Depletion of stratospheric ozone potential

The ODP value for all three fiber types is 0. This is because the characterization method used only covers CFCs, HCFCs and brominated compounds, but not NO_x, which also depletes stratospheric ozone, like halogens.

In the case where production of chemicals for the cotton fabric is included, see chapter 4.3.4.3, the ozone depletion potential is 5.15 E-04 g CFC-11 equivalents owing to emissions of Halon-1301.

4.3.2.3 Acidification potential

The category indicator results for the acidification potential are shown in figure 13:

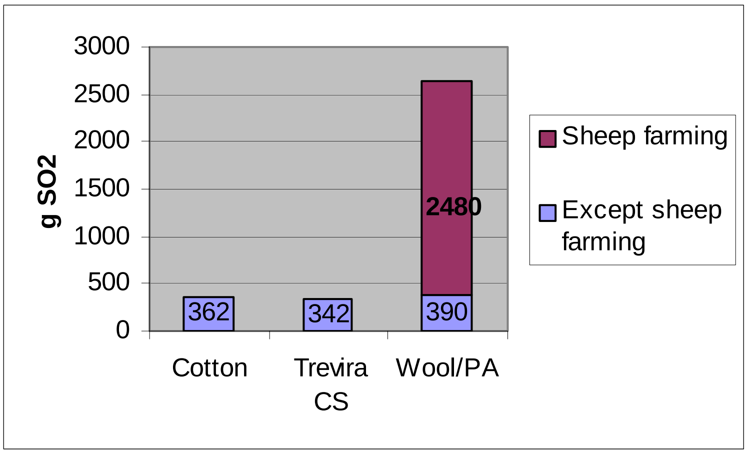


Figure 13. Category indicator results for the maximum acidification potential as g SO_2 equivalents for the three fabric types

- The high value for the wool/PA fabric is attributable to ammonia release in sheep farming (83% of total). The second highest contributor to the acidification potential in the wool/PA case is spinning, owing to energy use.

- For cotton, the main contributor is cotton cultivation (53% of total, credit by 2.7 g SO_2 equivalents for cotton by-products included), for Trevira CS it is the fiber production activity (83% of total).

- If the incineration of the fabrics replace light fuel oil incineration, the maximum acidification potential would decrease by

12.9 g SO_2 equivalents for the cotton fabric
12.4 g SO_2 equivalents for the Trevira CS fabric and
17.2 g SO_2 equivalents for the wool/PA fabric.

- This study did not investigate how severe the acidification problem is in New Zealand. This would depend on the soil composition, and the current deposition levels (methodological issue 21).

4.3.2.4 Eutrophication potential

The category indicator results for maximum eutrophication potential are shown in figure 14:

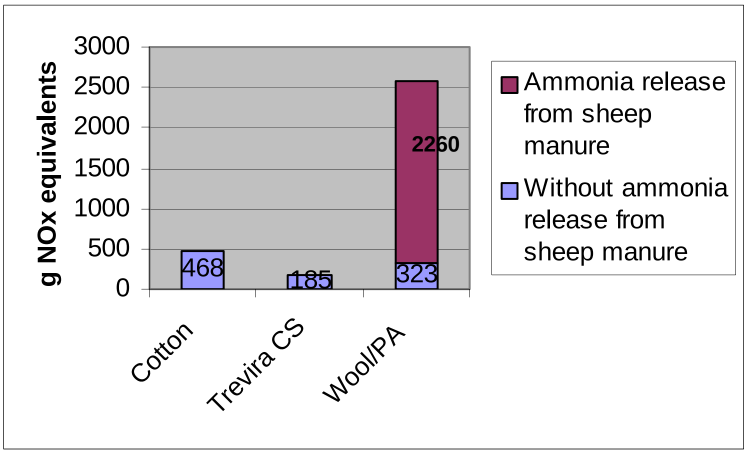


Figure 14. Category indicator results for the maximum eutrophication potential as g NOx equivalents for the three fabric types

- For Trevira CS, NOx emissions from polyester fiber production are the main contributors.
- For cotton, cultivation is the main contributor (261 g NO_x equivalents) mainly due to NO_x emissions to air (220 g NO_x equivalents, credit for cotton by-products included, 4 g NO_x equivalents).

4.3.2.5 Photo-oxidant creation potential

The category indicator results for the photo-oxidant creation potential is found in figure 15:

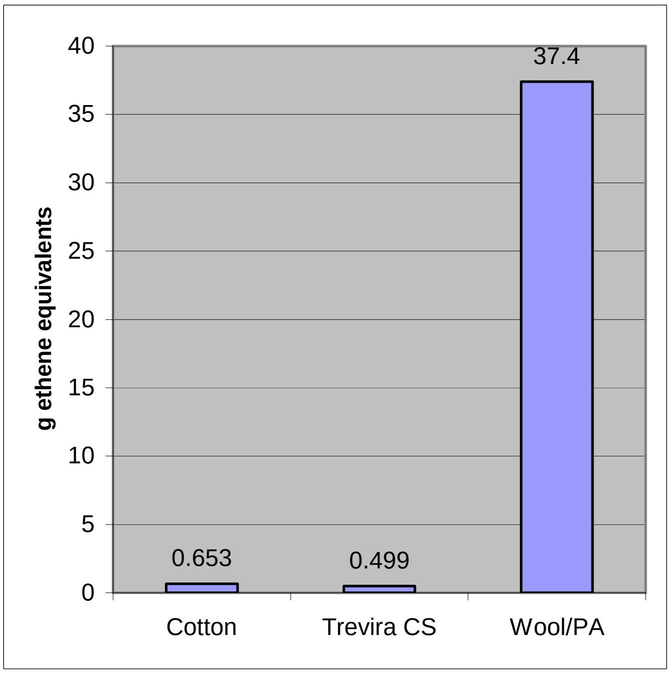


Figure 15: Category indicator results for the photo-oxidant creation potential as g ethene equivalents for the three fabric types

- The high value for Wool/PA fabric is to 100% due to methane emission.

If landfill of cotton instead of incineration of the cotton fabrics were assumed, the photo-oxidant formation potential for the cotton fabric would change from 0,65 to 3.04 g ethene equivalents, owing to methane emissions (increase by 368%).

4.3.2.6 Ecotoxicological impacts potential

The category indicator results for the ecotoxicological potential (aquatic) are found in figure 16:

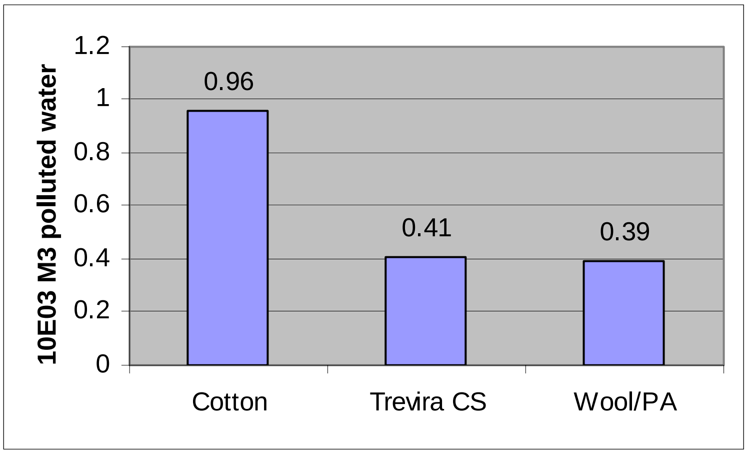


Figure 16: Category indicator results for the ecotoxicological potential (aquatic)

The cotton life cycle has the highest ecotoxicological impact. The main factor is discharges to water in fossil energy production. Oil emissions contribute 74% of the total value for cotton.

Note that only in the case of cotton, certain metal emissions to a wastewater-treatment plant were reported for wet treatment (general figures for the entire plant). Wet treatment includes dyeing. The values for the Trevira CS and wool/PA fabrics should therefore be slightly higher if the metal emissions from dyeing were known. The total ecotoxicological potential was not assessed here, since the environmental impact of the organic chemicals emitted to water was not studied, the inventory is incomplete, and there are no characterization factors for the chemicals (methodological issues 16 and 23). If the metals Cd, Cu, Hg, Ni and Pb in sludge were emitted to water, which would eventually be the case, the ecotoxicological potential (aquatic) for water would increase by 0.38E+04 m^3 polluted water for cotton.

4.3.2.7 Human toxicity impact potential from air emissions

The category indicator results for the human toxicity impact potential from air emissions are found in figure 17:

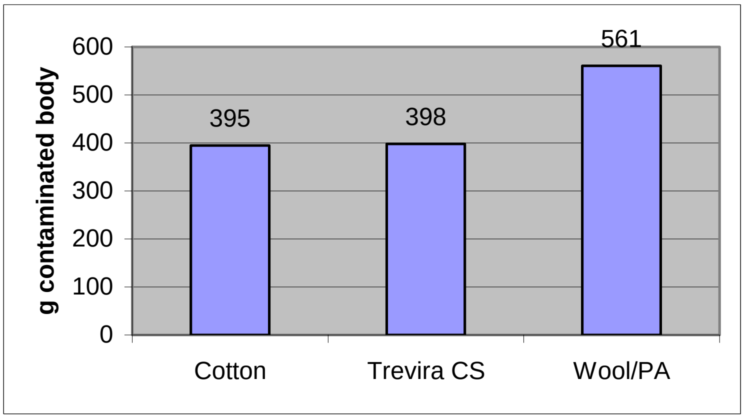


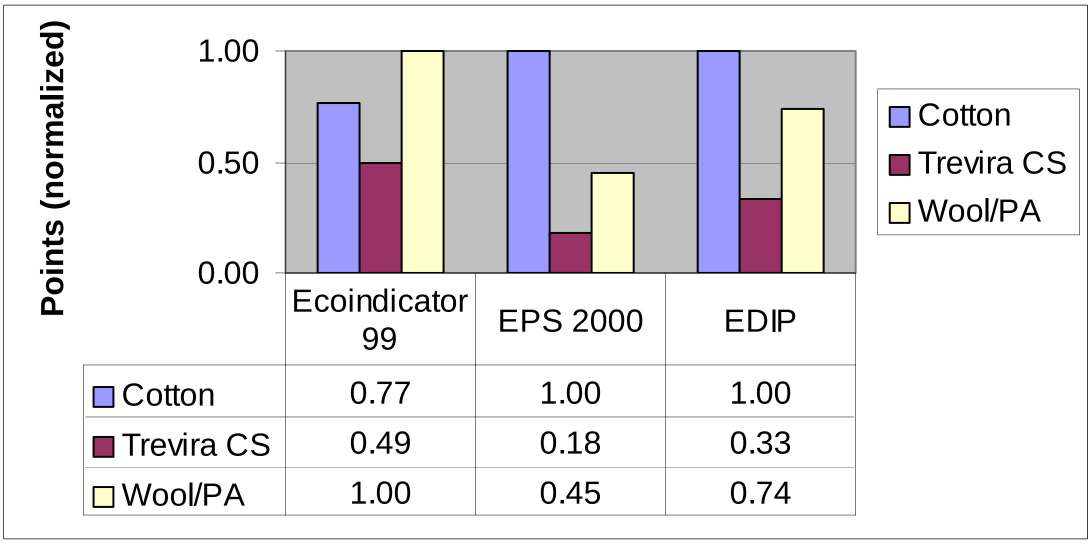
Figure 17. Category indicator results for the human toxicity impact potential from air emissions for the three fiber types

For the wool/PA fabric, that has the highest human toxicity impact potential, the SO_x emissions from spinning and NOx emissions from wool scouring dominate. For the cotton fabric, NOx emissions from cotton cultivation dominate and for the Trevira CS fabric the SOx emissions from polyester fiber production dominate. For all three fiber types this is attributable to energy use, and the differences in human toxicity impact potentials are not significant.

4.3.3 Weighting results

ISO 14042 (2000) does not specify any particular methodology or support the underlying value choices used to group the impact categories.

In figure 18 the normalized weighting results with three different weighting methods are shown. The methods are Ecoindicator 99, EPS 2000d and EDIP. The results according to EPS 2000d are found in chapter 4.3.3.1. The weighting factor for each flow could not be published, since it was a part of the calculation program and the database creators opposed publication (methodological issue 12). An estimation of the ranges for the EPS 2000d results is found in chapter 4.3.5.



	Ecoindicator 99	EPS 2000	EDIP
Cotton	0.77	1.00	1.00
Trevira CS	0.49	0.18	0.33
Wool/PA	1.00	0.45	0.74

Figure 18. Weighting results (normalized) for Cotton, Trevira CS and Wool/PA

All three combined characterization and weighting methods rank Trevira CS as environmentally preferable and cotton as the least preferable.

EPS 2000d was the only one of the three combined characterization and weighting methods used which had a factor for unsustainable use of irrigation water, which was the case for cotton. Unsustainable irrigation water consumption contributed with 77% of the aggregated result.

The significant issues regarding substances differ depending on which default weighting method is used; see figures 19-21:

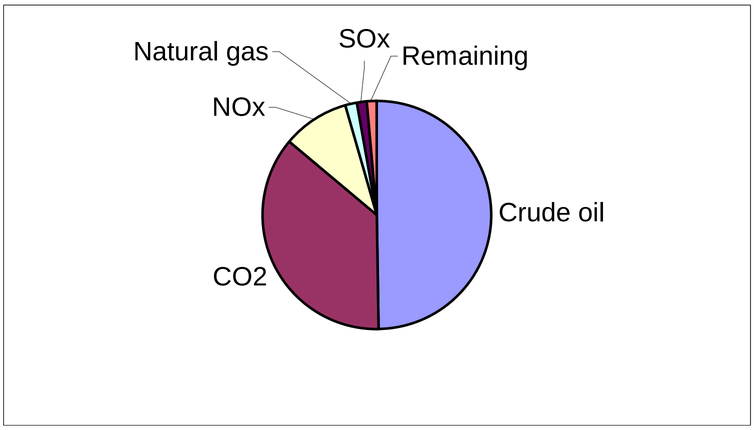


Figure 19: Ecoindicator 99 results for cotton fabrics
The method includes factors for emissions of metals both to water and soil, but no indirect values for discharges to water such as BOD or N total.

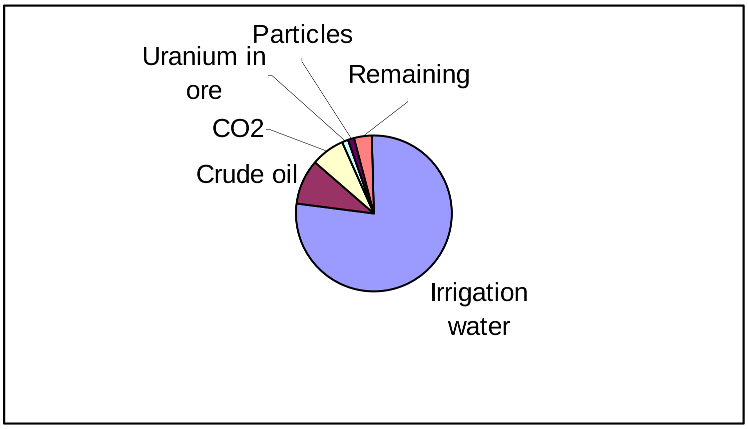


Figure 20: EPS 2000d results for cotton fabrics
The method includes factors for indirect values of discharges to water such as BOD or N total, but no factors for metal emissions to water or soil.

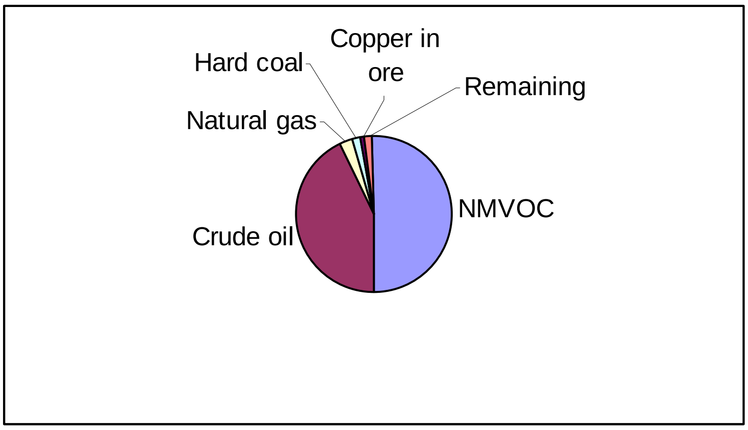


Figure 21: EDIP results for cotton fabrics
The method includes factors for emissions to water but not to soil of metals, N total and P total.

Crude oil is the only significant issue common to all 3 fabric types, and most significant issues are associated with energy use and emissions to air.

Note that the combined characterization and weighting methods are weak in assessing fate of chemicals discharged to water (methodological issue 23).

4.3.3.1 EPS 2000d results for the Trevira CS and wool/PA fabric

Figures 22 and 23 show the relative EPS 2000d results for Trevira CS and wool/PA respectively.

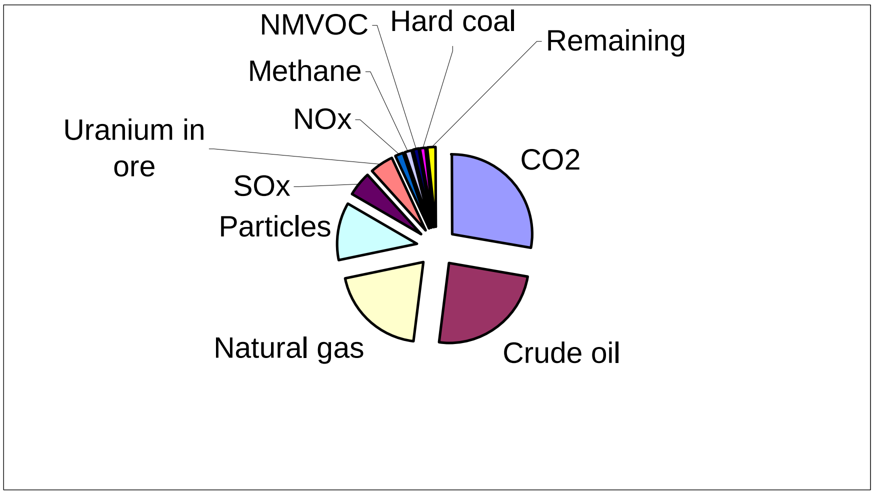


Figure 22. EPS 2000d default weighting method results for the Trevira CS fabric

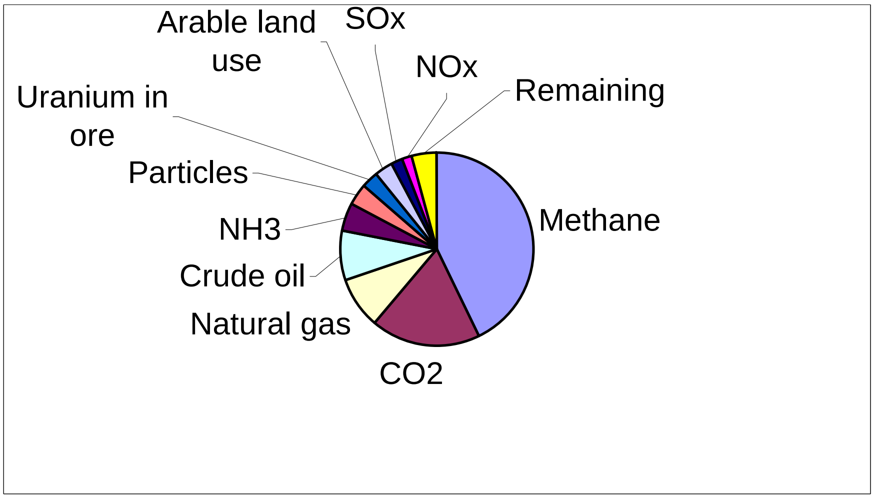


Figure 23. EPS 2000d default weighting method results for the Wool/PA fabric

4.3.3.1.1 The relative importance of the different life cycle phases to the environmental impact

In figures 24 to 26 the relative importance of different life cycle phases of the fabrics are shown for EPS 2000d.

Cotton

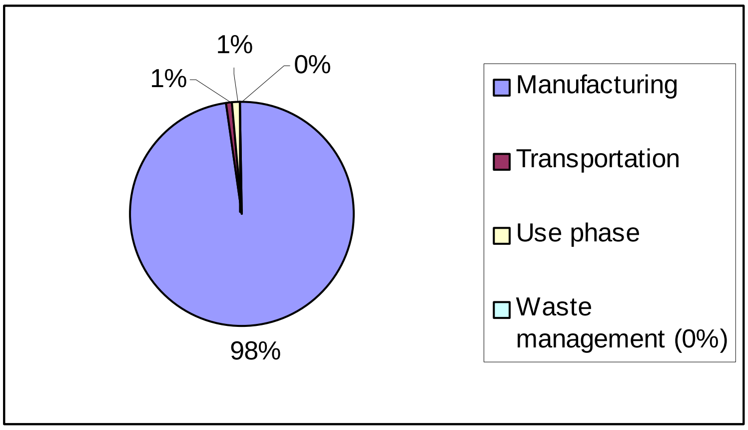


Figure 24. Cotton base case: The relative importance regarding environmental impact of different phases of the life cycle according to the default EPS 2000d method.

The aggregated result of the EPS default method for the manufacturing part is 86.9 ELU. The main activities are:

- Cotton cultivation 72.8 ELU
- Wet treatment 10.8 ELU
- Rotor spinning 1.3 ELU

1. Travel at work corresponds to 0.7% of the total potential environmental impact.
2. Production of drinking water corresponds to 0.08% of the total potential environmental impact.
3. The wastewater-treatment plant consumes a total of about 1.1 MJ electricity (0.1% of total energy use for cotton), and the contribution to the aggregated EPS value from the purified discharges to water is insignificant, see chapter 5.2.
4. Production of polyethylene and polypropylene for packaging contributed with 0.46 ELU.

Trevira CS

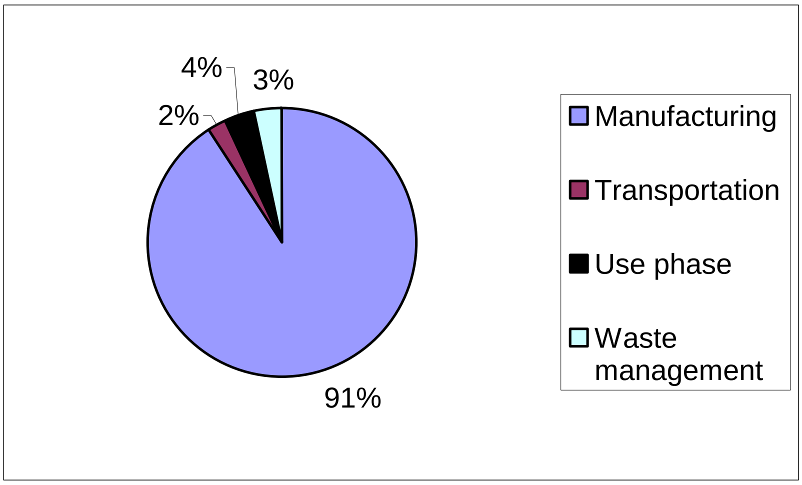


Figure 25. Trevira CS base case: The relative importance regarding environmental impact of different phases of the life cycle according to the default EPS 2000d method.

The aggregated result of the EPS default method for the manufacturing part is 14.6 ELU. The main activities are:

- Polyester fiber production 10.0 ELU
- Dyeing of the yarn 2.1 ELU

Wool/PA

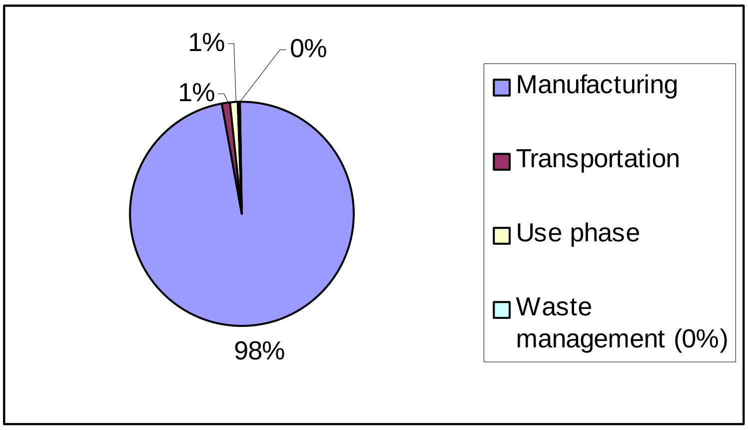


Figure 26. Wool/PA base case: The relative importance regarding environmental impact of different phases of the life cycle according to the default EPS method.

The aggregated result of the EPS default method for the manufacturing part is 38.7 ELU. The main activities are:

- Sheep farming 21.6 ELU (of which 16.6 ELU is attributable to methane emissions)
- Spinning 7.0 ELU
- Nylon fiber production 4.9 ELU
- Wool scouring 2.0 ELU

It is clear that the manufacturing phase is dominant in terms of environmental impact in the life cycle of the three fabric types.

4.3.4 Sensitivity analysis with EPS 2000d

This is part of the sensitivity analysis, which must be done according to e.g. clause 7 in ISO 14041 (1998).

4.3.4.1 Cotton: Irrigation water set to sustainable

If the water consumption were sustainable, the ELU value would be 20.7 instead of 88.6, a decrease by 67.9 ELU.

4.3.4.2 Cotton: Maximum and minimum use of irrigation water

If the irrigation water were set to maximum or minimum use, the ELU value for the irrigation water would range between 15.5 and 120 ELU (the value for the base case is 67.9 ELU).

4.3.4.3 Cotton: production of some chemicals included

As seen in chapter 4.3.1.2, 7.1 kg and at least 50 chemicals are used in the life cycle of the cotton fabric. Since I only had inventory data for 13 of these chemicals, their production was not included in the base cases. Instead the production of these chemicals (5.02 kg) was included in one of the scenarios where the ELU value increased by 2.2 units. The chemicals were: fertilizers, detergent ingredients, sodium hydroxide and sodium chloride. Although the increase in ELU value does not seem to be great, since there are at least 37 chemicals still not investigated for LCI data, it is difficult to say whether the production of the chemicals can be excluded. The chemicals included more or less had the character of bulk chemicals. One might expect that the production of dyeing agents, for instance, would cause higher environmental impact per kg, owing to the more resource demanding process.

The statement in ISO 14041 (1998) is therefore difficult to apply: “Regarding criteria for initial inclusion of inputs and outputs: Several criteria are used in LCA practice to decide which inputs to be studied, including a) mass, b) energy and c) environmental relevance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental relevance should also be used as criteria in this process.” The methodological issue here is when to know whether a chemical is important enough to be within the system under study and when it is not (methodological issue 3).

4.3.4.4 Cotton: maximum and minimum energy use in the cotton life cycle

The main activities according to EPS 2000d for environmental impact of the life cycle of the cotton fabric (base case) are cotton cultivation, wet treatment and rotor spinning. Wet treatment and cotton cultivation have also the highest uncertainty regarding energy use. Figure 27 shows the most impacting substances in the most impacting activities for cotton.

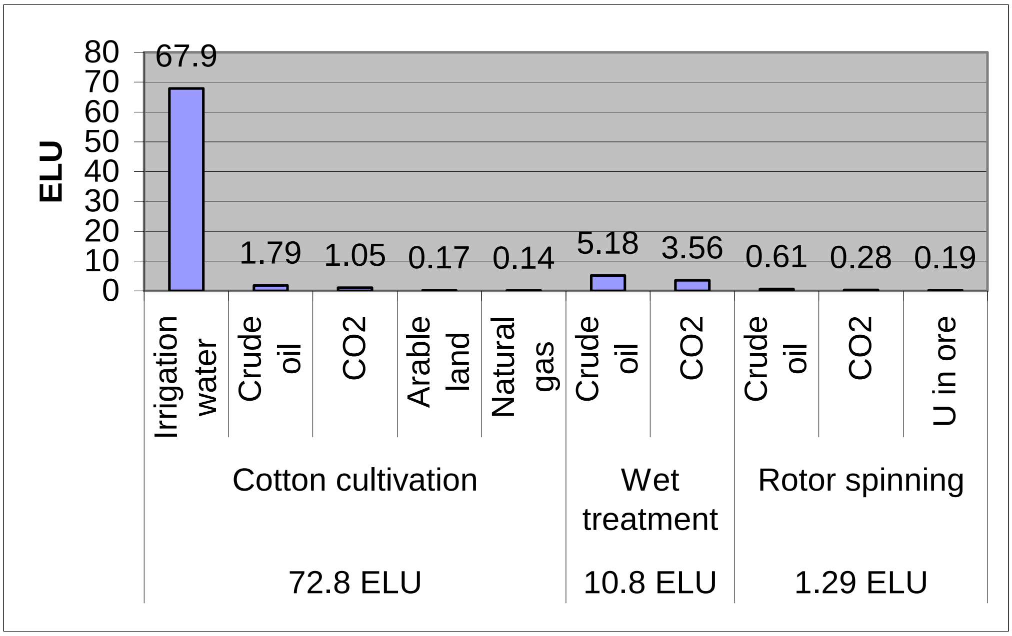


Figure 27: Cotton fabric: Activities having the highest environmental impact according to EPS including highest impacting flows

Maximum and minimum energy use for these activities were tested for the activities where the energy range were known, see table 45:

Table 45. Environmental impact according to EPS 2000 for a cotton fabric if high and low energy use in cotton cultivation and wet treatment, respectively are assumed.

	Cotton cultivation (diesel use)	**Wet treatment (light fuel oil use)**	**Rotor spinning (electricity use, set to be 67% of total energy use as in base case)**	**Change in ELU value**
Base case	25 MJ/kg baled raw cotton	69.92 MJ/kg fabric	5.29 MJ/kg yarn with packaging	0 ELU
High energy use	46.3 MJ/kg baled raw cotton	80.57 MJ/kg fabric	12.30 MJ/kg yarn with packaging	+5.6 ELU
Low energy use	6.11 MJ/kg baled raw cotton	59.3 MJ/kg fabric	4.24 MJ/kg yarn with packaging	-4.8 ELU

4.3.4.5 Cotton: known pesticides included and assumed to end up in water

Malathion is used in 56% of the cotton cultivation area of Texas, was the only pesticide (of 43 available) in this study with an index in EPS 2000d. If the pesticides and other chemicals (except nutrients) used were assumed to be Malathion, the calculated ELU value for Malathion would be insignificant, 0.009 ELU. It is clear that the environmental impacts from pesticide use are not fully covered in the aggregated and weighted LCA results. The lack of coverage is also valid to different extents for the characterization and the other weighting methods (methodological issues 16 and 23).

4.3.4.6 Cotton: landfill of waste

If all the possible organic waste, excluding fabric, ends up in landfills (10.4 kg waste, 10 m landfill height assumed, density of 1 kg/dm^2 is assumed) the calculated area is estimated to be 0.001 m^2, which contributes with 1.6E-06 ELU to the aggregated EPS value. This value is insignificant and the scenario is far from reality, where most waste in the processes is used and where the fabric is incinerated.

- If the waste were only cellulose-like material, the methane emissions would be 0.0795*10.4 kg =0.82 kg (Sundqvist 1999, 100 years emission (methodological issue 22)), which increases the aggregated EPS value by 2.2 ELU. If the fabric, too were landfilled, the aggregated EPS value would increase by another 1.1 ELU (data for cellulose-like material). This scenario could also be valid for the scenario where the fabric is incinerated, and replaces other organic waste intended for incineration but which ends up being landfilled instead owing to limited capacity for waste incineration.

4.3.4.7 Cotton: replacement of oil in the incinerator

If the cotton fabric replaces light fuel oil in the incinerator, the oil saving would give a decrease of environmental impact by 2.1 ELU. If the cotton waste from the manufacturing steps including textile samples (800 g) also replace fuel oil in the incinerator, the oil saving would give another decrease of 0.3 ELU.

4.3.4.8 Cotton: spinning in Pakistan

A scenario with ring spinning in Pakistan was tested. Cotton is often bought from Texas in Pakistan (Sapphire 2004). Electricity use of 10.1 MJ/kg yarn with packaging was assumed ((instead of 5.3 MJ/kg in the base case, Sapphire, 2000). Electricity comes from oil condensing power. All other flows were the same as in the base case. The distance between Houston and Pakistan was assumed to 20,571 km and from Pakistan to Gothenburg to 14,857 km. A large freighter was assumed, as in the base case from Houston to Gothenburg. Distances in Pakistan were assumed to 30 km (medium truck, Euro 2 regulations, load factor 50%)

The aggregated ELU value for the spinning increased by 5.1 units (from 1.3 ELU to 6.4 ELU). 4.8 ELU is due to electricity from oil instead of Swedish average, 0.3 ELU is due to 91% higher electricity use. The aggregated ELU value for the transports increased by 2.0 ELU (from 0.7 ELU to 2.7 ELU).

The difference in transports is that the freighters sail 35,400 km with the goods (cotton bale and cotton yarn) instead of 10,300 km (cotton bale).

4.3.4.9 Trevira CS: maximum and minimum energy use

The activities with the highest aggregated EPS weighting values are:

- Polyester fiber production 9.95 ELU
- Dyeing of the yarn 2.07 ELU
- Thermofix 8.56E-01 ELU

The production of the polyester fiber was assumed to have 20% or lower higher energy demand. The values of crude oil, natural gas, lignite and hard coal use, as well as CO_2, NO_x and SO_x emissions were all raised or lowered by 20%.

The energy range for the dyeing activity is not known, but here the use of natural gas was assumed to ±10% of the value reported.

The energy use for the thermofix activity was assumed to ±20% owing to the low quality of the data.

The EPS 2000d aggregated result increased by 1.9 ELU with the maximum values and decreased by 1.9 ELU with the minimum values.

4.3.4.10 Trevira CS: Inclusion of local data for Trevira CS fiber production

If the local data with the data gaps for Trevira CS fiber production were included, the EPS 2000d result would decrease by 0.89 ELU. These flows for ethylene glycol and terephtalic acid were used in the calculation: use of crude oil, hard coal, natural gas uranium in ore and lignite, air emissions of CO_2, methane, NMVOC, SO_x, NO_x, and discharges to water of BOD COD, and N total.

4.3.4.11 Trevira CS: replacement of oil in the incinerator

If the Trevira CS fabric replaces light fuel oil in the incinerator, the oil saving would give a decrease of environmental impact by 2.1 ELU.

4.3.4.12 Wool/PA: Maximum and minimum for the most impacting activities

The activities with the highest aggregated EPS weighting values are:

- Sheep farming 21.6 ELU (16.6 ELU from methane emissions and 1.9 ELU from ammonia emission)
- Spinning 7.0 ELU
- Nylon fiber production 4.9 ELU

The ranges were not known and therefore a 10% increase or decrease of energy use and methane and ammonia emissions were tested. The aggregated EPS 2000d results increased by 2.8 ELU and decreased by 2.7 ELU, respectively.

4.3.4.13 Wool/PA: No allocation to wool with oddments

If no environmental impact were allocated to wool oddments and if there were no system expansion to the oddments, the aggregated EPS 2000d result would increase by 7.2 ELU to 46.9 ELU.

4.3.4.14 Wool/PA: replacement of oil in the incinerator

If the wool/PA fabric replaces light fuel oil in the incinerator, the oil saving would give a decrease of environmental impact by 2.8 ELU to 36.9 ELU.

4.3.4.15 Wool/PA: Perchloroethylene air emission in dry-cleaning

In chapter 3.3.4.20 it was seen that perchloroethylene is an eye irritatant and can damage the human liver and kidney. A test was made as to what would happen if the perchloroethylene added was emitted to air instead of being treated. There was no index for the human toxicity impact potential or for EPS 2000d or EDIP (methodological issue 23). Ecoindicator 99 has an index, but the amount of perchloroethylene did not affect the aggregated Ecoindicator 99 value.

4.3.5 Range in aggregated EPS 2000d result from the sensitivity analysis using different allocation and estimated ranges in inventory data

In table 46 the ELU range for the fabric types are found.

Table 46. Sensitivity analysis of the weighted and aggregated impacts according to EPS 2000d for different input data and allocation choice.

	Base case EPS 2000d result (ELU)	Max. EPS 2000d result (ELU)	Min. EPS 2000d result (ELU)	Base case EPS 2000d result but with electricity made of natural gas only (ELU)[1]
Cotton	88.6	146.3[2]	15.9[3]	108.3
Trevira CS	16.1	18.0[4]	14.2[5]	33.0
Wool/PA	39.7	49.7[6]	37.0[7]	62.7

1. A worst-case result due to choice of electricity type (illustrates roughly how the use of data for marginal electricity affects the original EPS 2000d result). The difference between the environmental impact from electricity made of natural gas and Swedish average was added to the base case value.
2. Maximum energy use in cotton cultivation, rotor spinning of yarn and wet treatment of fabrics (the most environmental impacting activities) increased the value by 5.6 ELU, and maximum irrigation water use increased the value by 52.1 ELU.
3. Sustainable use of water decreased the value by 67.9 ELU and minimum energy use in cotton cultivation, rotor spinning of yarn and wet treatment of fabrics (the most environmental impacting activities) decreased the value by 4.8 ELU.
4. 20% extra energy use in polyester fiber production, and thermofix, and 10% extra energy use in the dyeing step (the most environmental impacting activities) increased the value by 1.9 ELU.
5. 20% less energy use in polyester fiber production, and thermofix, and 10% less energy use in the dyeing step (the most environmental impacting activities) decreased the value by 1.9 ELU.

6. 10% extra use of energy in sheep farming, spinning of yarn and nylon fiber production (the most environmental impacting activities) increased the value by 2.8 ELU and allocation to first class wool only increased the value by 7.2 ELU.
7. 10% less use of energy in sheep farming, spinning of yarn and nylon fiber production (the most environmental impacting activities) decreased the values by 2.7 ELU.

Note that cotton could have an even higher range, since there are more aspects of cotton cultivation that were not elaborated on, such as cotton yield. More chemicals are also used in the cotton life cycle compared with the life cycles of Trevira CS and wool/PA, but the LCI values of the chemicals are not included in this range.

Note that replacement of light fuel oil in the incinerator is not included in the range.

4.3.6 Aspects regarding sheep farming

Below, some aspects of sheep farming and wool are discussed in order to give a more complete picture of the environmental impact from sheep farming for wool production.

If sheep were not farmed, what would be farmed? Other grazing animals, which also emit methane?
Sheep farming is a dominating part of the landscape in New Zealand today. More than 50% of the land is grazing land, 2% is arable land and 28% is forest (Nationalencyclopedin 2002) Before the Maoris came to New Zealand more than 1000 years ago, there was no high animal life: it was a bird paradise. It was the Europeans who brought the domestic animals to the islands (Encyclopædia Britannica 2002). There do not seem to have been any grazing animals originally. The landscape was probably open thanks to sheep grazing 100 years ago, but this is not studied here. The typical landscape with the typical flora and fauna made by sheep grazing is to some extent important to maintain, both for aesthetic and biodiversity reasons. The question is, to what extent? What land use is natural and how should the deviation from the ideal land use be assessed (methodological issue 24)?

Wool is a unique fiber that has not yet been perfectly copied as a synthetic fiber. Sheep are thus needed for many reasons, but not necessarily in the choice of fabric for a sofa, as in this LCA study.

4.3.7 Aspects regarding abrasion resistance and disposition for stain

In this LCA study, the fabrics were not worn out before they were disposed of. Abrasion resistance and tendency to for stain could also be considered. The abrasion resistance differs within the same fiber types as seen in table 47.

Table 47. Abrasion resistance according to the weaving mills in the study

Fabric type	Abrasion resistance (Martindale)	Number of respondents (weaving mills)
Cotton	30,000	1
Trevira CS	30,000 - 100,000	2
Wool/PA	40,000 - 100,000	3

Normally the abrasion resistance is lower for cotton fabrics than Trevira CS or wool/PA fabrics. Therefore, if the fabrics were worn out before they were thrown away, the cotton fabric would give more environmental impact, since it would have to be replaced more often.

As regards tendency to stain, in this study the cleaning of the fabric activity was not a “significant issue” regarding environmental impact, because it represents at most 4% of the total environmental impact according to EPS 2000d and more frequent laundering is unrealistic, since it is time consuming and inconvenient. Wool/PA fabrics are known to have stain resistance. Cotton fabrics are treated with a fluoride polymer emulsion in order to improve resistance to stains.

4.3.8 Comparison with personal car driving

A comparison between the benefit and environmental impact of the fabrics was also made.

The aggregated EPS weighting result for the cotton base case is 88.6 ELU, which is equivalent to 923 km of car driving. This calculation is based on the data found in chapter 3.2.2.9.1 for a typical car in Sweden with 1.6 people in it. With sustainable irrigation water in cotton cultivation, the EPS value is 20.7, equivalent to 216 km of car driving.
The EPS index for the wool/PA base case is 39.7 ELU, which is equivalent to 414 km car driving. For the base case of Trevira CS, the environmental impact of 16.1 ELU corresponds to 168 km car driving.

According to one weaving mill, the price an upholster pays for wool/PA or Trevira CS fabric is about 30 Euro/meter and the same price for cotton fabrics was assumed here. The upholsterer uses 10 meters, which means that he pays about 300 Euro. The weighted and aggregated EPS results ranged between 16 and 146 ELU (1 ELU is equal to 1 Euro) for the fabric types, which is less than 300 Euro. This means that the value of the environmental impact in the study from the life cycle of the fabrics is low compared to its benefits to the buyer. The total cost of car driving is about 0.3 Euro/vkm and the environmental impact is about 0.1 ELU/vkm, which means that the environmental impact compared to the benefit for car driving is higher than for the wool/PA or Trevira CS fabric. For cotton fabric, the environmental impact compared to the benefit is about the same as for car driving if the cotton is not cultivated in a more sustainable way than in the base case.

5 Interpretation of the results

According to ISO 14043 (2000) the interpretation phase consists of*:

- Identification of significant issues based on the results of the LCI and LCIA phases of LCA (6.1, the significant issues found are only based on LCIA)
- Evaluation, which considers completeness (5.2), sensitivity (4.3) and consistency checks (5.3)
- Conclusions, recommendations and reporting of the significant issues (5.1, 6)

*The chapters where the issues are found are noted in brackets.

The headings are not found in clause 8 in ISO 14043 (2000). Instead the following is stated: “The report shall give a complete and unbiased account of the study, as detailed (described? (authors comment)) in ISO 14040 (1997). In reporting the interpretation phase, full transparency in terms of value choices, rationals and expert judgments made shall be strictly observed”.

5.1 Comparisons regarding environmental impact between the fabrics including determining of the significant issues

According to clause 9 in ISO 14042 (2000): “weighting, as described in 6.4, shall not be used for comparative assertions disclosed to the public”, but this LCA only indicates probable results, it is not an assertion. According to the weighting step in this study, Trevira CS is preferable in terms of minimizing environmental impact when choosing between the three fabric types, see chapter 4.3. According to the characterization, the total picture also shows that Trevira CS is preferable. Note, however, that the conclusion is drawn with the limitations of this study, see below. Table 48 shows the characterization ranking.

Table 48. Characterization ranking

	Cotton	Trevira CS	Wool/PA
Energy use	3	1	2
Chemical use	3	1	2
Water consumption	3	1	2
Arable land use[1]	2	1	3
GWP 100	2	1	3
AP	2	1	3
EP	2	1	3
POCP	2	1	3
Ecotox. (aq)	3	2	1
Human tox.	1	2	3
Amount 1	1	8	1
Amount 2	5	2	3
Amount 3	4	0	6

Grade 1 means lowest environmental impact

1. Only land area considered.

It is, however, impossible to rank cotton and wool/PA, although taking the limits into consideration, see below, it is probable that conventional cotton has a higher environmental impact than wool/PA. If, however cotton is produced without chemicals, with sustainable water irrigation and with the same yield as for conventional cotton, cotton could be ranked as better than wool/PA regarding environmental impact.

It is important to have the limits of this study in mind:

- The environmental effects of the discharges to water of chemicals were not sufficiently inventoried or assessed. The largest question mark is the environmental effects of the discharges to water of the chemicals in the agricultural steps.

- Land use was not properly inventoried and assessed.
- Not all environmental effects of chemicals are known, for instance the effects of fluorocarbons or antimony, which are concerns in Sweden regarding emissions from the Swedish textile industry (Hansson 2004).
- Production of the chemicals was not sufficiently inventoried and assessed owing to shortage of inventory data.
- There are major differences for cotton cultivation in e.g. water consumption and yield from year to year and from farm to farm, which creates uncertainties.
- Health aspects were not sufficiently inventoried and assessed owing to shortage of data. The possible carcinogenic effects of antimony trioxide in the polyester fiber production was not further investigated, but was probably not problematic since the polyester is made in European countries where one could expect the production to be under control.

The first two limitations mainly concern the cotton and wool/PA fabric. They are also the most important ones for this study. Therefore it can be concluded that the cotton and wool/PA fabric could be even more impacting as compared with the Trevira CS than was found in the study.

According to EPS 2000d, none of the costs of the environmental impacts from the three textile types as determined by the EPS 2000d method is high compared to the value of the fabrics determined by their price, see chapter 4.3.8.

The EPS 2000d method gave the following conclusions regarding the different fabric types:

Cotton

- For cotton fabric the type and amount of water consumed in the **cultivation** is a significant issue for the life cycle, see chapter 4.3.4.1 and 4.3.4.2. It is problematic for the assessment that water consumption varies from year to year and the environmental impact of chemical use is not fully known.
- **Wet treatment** (defined here as singeing, desizing, washing, bleaching, washing, merzerization, washing, dyeing, washing and finishing steps) is also a critical factor (chapter 4.3.4.4).

Wool/PA

- For wool/PA fabric **sheep farming** is the essential aspect, owing to methane emissions (16.6 ELU out of 21.6 ELU for sheep farming) see chapter 4.3.3.1.1. The discharges to water of the chemicals in sheep dipping were not followed, which was a shortcoming in the environmental assessment. Therefore this study may possibly wrongly promote farming of sheep with a large amount of fleece in order to obtain large amount wool per kg methane emission. This results in the need for extensive sheep dipping, which is not assessed here.
- **Ring spinning** also seems to be important, if electricity is made from oil condensing power.
- Since nearly all chemicals in dry-cleaning are reused in Sweden, this activity has low environmental impact. Even if the perchloroethylene that is lost

during cleaning evaporates, this study shows possibly erroneously that these emissions have only insignificant effects on the environmental impact. It is even possible that dry-cleaning has less environmental impact than laundering at home. Indications in this study show that energy use is less, and smaller amounts of chemicals are used than for laundering at home.

Trevira CS

- For the Trevira CS fabric the **production of polyester fibers** is the main aspect, see chapter 4.3.3.1.1.

5.2 Completeness check

Data for discharges to water were incomplete for dyeing of Trevira CS and wool/PA fabrics, but since, according to EPS 2000d, for wet treatment of cotton where some discharges to water are known, it is the use of crude oil and emissions of CO_2, which have the highest environmental impact rather than discharges to water, this was not considered to affect the conclusions for the study. The total contribution of the discharges to water to the aggregated EPS 2000d results are insignificant, 0,006 ELU for the life cycle of the cotton fabrics. Discharges to water of metals are, however, not assessed in the default EPS 2000d method, but in the assessment of the ecotoxicological impacts potential (aquatic), which includes assessment of emissions of metals to water. The non-elementary discharges to water purified by the wastewater-treatment plant for cotton contribute 0.04 units of the 0.96 units in total.

Data for production of polyester and polyamide fibers as well as wool scouring, laundry and wet treatment of cotton fabrics are more detailed than the other unit operations. However, according to the impact assessment it is the energy use and some aspects of farming that are the important issues and data for energy use with its emissions are present in all activities except for the very low energy consumption activities: textile distribution and shearing, classing, baling and selling of raw wool.

Note that the conclusion that the data gaps were not problematic depends on which impact assessment methods were chosen and that chemicals emitted to nature was only partly inventoried, and assessed.

5.3 Consistency check

There were several differences in data accuracy, age and sources but they were considered not to affect the conclusions of the study, a statement with some degree of insecurity (methodological issue 4).
The allocation rules and system boundaries have been consistently applied as far as possible. This was difficult for plants with many activities. The deviations are given in chapter 3.1.8. The deviations are considered not to affect the conclusions of the study, a statement with some degree of insecurity (methodological issue 4).

6 Conclusions and recommendations regarding the comparison between the fabrics

6.1 Conclusions

The LCA study with all assumptions and boundaries showed that the polyester type of fabric (Trevira CS) is less environmentally impacting than the natural fibers in the study, but local conditions may alter the ranking. Cotton cultivated in a sustainable way could have about the same environmental impact as Trevira CS according to EPS 2000d.

The environmental impact of these textile types is not high compared to the benefit of the fabrics according to EPS 2000d. Table 49 shows the activities with the highest environmental impact for each fiber type.

Table 49: The most important environmental impacting steps for each fiber type
According to EPS 2000d

Cotton	Cotton cultivation, wet treatment of the fabric (the processes includes dyeing)
Trevira CS	Polyester fiber production
Wool/polyamide	Sheep farming, ring spinning , nylon fiber production, wool scouring

The significant issues found in the case study are:

- the production phase, especially
    - irrigation water type in the cotton growing activity,
    - yield (for example regarding cotton cultivation),
    - air emissions of methane and ammonia from sheep or sheep manure,

and if unsustainable use of irrigation water does not overrule the results:

- fossil energy extraction and use,
- type of electricity used, e.g nuclear power and
- system expansion/allocation choice. The system expansion/allocation choice in sheep farming, where oddments were assumed to replace first class wool had most influence. Fuel replacement in the incinerator and recycling of packaging material had less influence.

Less significant issues are:

- use phase,
- production of drinking water,
- freighter and truck transports,
- business trips,
- waste management of used fabrics or fiber waste and
- type of heating value used (gross or net calorific).

Issues not/not (fully) inventoried or assessed are:

- the effects of chemicals discharged to water,
- inclusion of a wastewater-treatment plant. With the weighting methods used it is not critical but maybe it might be if the chemicals emitted to water had been followed after the wastewater-treatment plant,

- eutrophying discharges to water (with the weighting methods used they are not important, but the agricultural steps were not sufficiently studied),
- land use,
- human health impacts from the working environment,
- the effects of the use of GE cotton,
- the effects of lubricants,
- production of packaging materials,
- production of chemicals and
- risks with e.g. mining or nuclear power.

6.2 Recommendations

If decision makers want to use cotton, it is recommended that they choose cotton cultivated in a sustainable way, especially with sustainable irrigation water and chemical use. They should also take into consideration which type of electricity is used for the activities, since the emissions from electricity production vary depending on which type of electricity is used.

If it is decided to make a more thorough comparison, it is recommended that the data collected be as good as possible for energy use in the LCA procedure, because this plays a significant role according to the impact assessment.

7 Remarks regarding the comparison of the fabrics

- The reason electricity use in Sweden did not highly affect the impact assessment is because of the high degree of hydropower in Swedish average electricity, and that the accident risks with nuclear power were not inventoried and assessed (methodological issue 13).
- In this study “packaging material” is included in the product. It would have been better if “packaging material” had not been included. The data would have been easier to use and more transparent.

8 Surveying and sorting of methodological issues

8.1 List of methodological issues found in the study

In table 50 the methodological issues found and where they were found in the study are listed:

Table 50. Methodological issues found in the LCA study and where in the study they were found

Methodological issue	Description of the methodological issue	Chapter in which the methodological issue was identified
1	Problems with inconsistency in the standard(s).	1.2, 2, 2.2.3, 2.2.4, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.10, 2.2.11, 3.1, 3.1.4, 3.1.7, 3.2, 4.1
2	Problems about including comfort and other “soft” aspects, or more than one quantifiable aspect in the functional unit.	2.2.1.2
3	Problems in choosing system boundaries.	2.2.4, 2.2.4.3, 3.3.5.1, 3.3.5.2, 4.3.4.3
4	Problems in knowing if the collected data is good enough: that the quality is OK, that the practitioner does not miss an important flow, that data are not too old and that data gaps sometimes affecting the process boundaries are acceptable	2.2.4.3, 2.2.4.4, 3.1.8, 3.2, 5.3
5	Problem in knowing if the chosen impact assessment methods are the appropriate ones.	2.2.6, 4.1
6	Problem in knowing which data are to be collected.	2.2.7
7	Problem in knowing if general or marginal electricity use should be calculated.	2.2.7.2
8	Problematic that knowledge about environmental impacts changes.	2.2.8.1
9	Problem with non-standardized way of choosing heating value of energy carriers.	2.2.7.3, 3.2.3.1[1], 3.2.4.8[1]
10	Not important to perform sensitivity analysis on LCI data without LCIA.	3.1.6
11	Problematic to find good LCI data (incomplete, no knowledge of how measured/estimated, only generic data found).	2.2.4.1, 2.2.4.3, 3.1.5.1, 3.2
12	Problems with transparency if company names are left out or publication of data is not permitted.	3.2, 3.3.1, 4.2, 4.3.1, 4.3.3
13	Problematic to make inventory and perform impact assessment on risks of nuclear power.	3.2, 7

Table 50 continued Methodological issue	Description of the methodological issue	Chapter in which the methodological issue was identified
14	Allocation and system expansion in practice problematic.	3.1.7.2, 3.2.2.1, 3.2.2.2[1], 3.2.2.9, 3.2.2.11, 3.2.2.13, 3.2.4.1, 3.2.4.6[1], 3.3.6, 4.3.2.1
15	Problematic to move data from one situation to another (epistemological).	2.2.4.1, 3.1.5.1, 3.2.2.1, 3.2.2.2, 3.2.2.19, 3.2.3.1 3.2.4.1[1], 3.3.6
16	Problematic to inventory the fate of chemicals.	2.2.4.2, 3.2.2.1, 3.2.2.11[1], 3.2.4.1, 4.3.2.6, 4.3.4.5
17	Problematic to inventory the effects of land use.	3.2.2.1, 3.2.4.1[1]
18	Problematic to inventory GE cotton because the risks are not fully known	3.2.2.1
19	Problems with unclear/non-standardized reports for the inventory.	3.1.5.1, 3.2.2.17, 3.2.3.1, 3.2.4.1, 3.2.4.8, 3.3.6, 4.1
20	Problems with too much aggregated data in reports when doing an LCI	3.2.2.17, 3.2.3.1, 3.2.4.1[1], 3.2.4.6
21	Problem that the impact categories are “potentials”, e.g. worst cases. This means there is generally no local and regional impact assessment.	4.1, 4.3.2.3
22	Problematic to choose time horizon	4.1, 4.1.1, 4.3.2.1, 4.3.4.6
23	Problematic that there is often no characterization factors especially for local and regional effects.	2.2.4.1, 2.2.4.2, 4.1, 4.3.2.6, 4.3.3, 4.3.4.5, 4.3.4.16
24	Problematic to perform impact assessment of the effect of land use.	4.1, 4.3.1.1, 4.3.6
25	Problematic to perform impact assessment of risks with GE cotton.	4.1
26	Problematic with default combined characterization and weighting methods normalized to a certain area of the world.	2.2.4.1, 4.2.2, 4.2.3
27	Absence of procedures for inventorying and assessing cultural and recreational values.	2.2.6, 4.3.1.1

1. In appendix 6

The problems of including social (methodological issue 28) and financial (methodological issue 29) aspects are not found in the case study, since this was not a part of the goal and scope. Neither is the non-linearity or threshold problem (methodological issue 30) found, because they did not exist in the study, where average values were asked for. One company explained, however, that they tap new water every day to a bath, no matter how much fabric they rinse in the bath. In a recession, more energy and water might be used/kg fabrics in a wet treatment plant than in a boom because the plant would not be efficiently used. A similar type of problem is that there are threshold and non-threshold impacts from the emissions.

8.2 Definition of the methodological issues

Two main types of methodological issues are recognized in the case study:

1. Problems in following the LCA methodology, as defined by ISO 14040 (1997) to ISO 14043 (2000). These are referred to as methodological issues regarding the *procedure*.

2. Methodological issues in the LCA methodology influencing the ability of the LCA model as defined by ISO 14040 (1997) to 14043 (2000) to fulfill the expectations or answer the questions raised in a specific problem situation. These types are referred to as methodological issues regarding the *model.*

This division into two kinds of problems is in accordance with the distinction between the LCA model and the LCA procedure of Baumann (1998). She claims that: “the LCA model is a product of the procedure”. The methodological issues regarding the procedure are thus problems with the procedure, and the methodological issues regarding the model are problems associated with the ability of the model to fulfill the goal(s) of the LCA study.

8.3 Methodological issues regarding the procedure

All methodological issues regarding the procedure give rise to uncertainty, and therefore sensitivity analysis is important. How severe the methodological issue regarding the procedure is, is among other things dependent on how much resources that are put into the LCA study. The methodological issues regarding the procedure are discussed below for the comparison between the fabrics in this LCA and the texts in italics are found in figure 28.

1) *Inventorying and assessing local and regional data*

This issue also has to do with the model since the LCA method typically aggregates inventory data (clause 8 in ISO 14042), which makes it difficult take local conditions into account. The impact categories are reported as “potentials” regardless of where the emission occurs (methodological issues 21 and 23).

- In this study the effects of *land use* (impacts on biological diversity, productivity, the global carbon cycle, and aesthetic, recreational and cultural values and demand for the resource productive land area (Ekvall 2000)) are also seen as very important, since cotton is studied with the intense cotton cultivation in the life cycle, but poorly inventoried and assessed (methodological issues 17, 24 and 27). EPS 2000d characterizes land use in arable land use, forestland use and use of hardmade forest land. Thus, arable land use for sheep farming and cotton cultivation have the same index, although the environmental impacts differ very greatly. *Cultural and recreational values* were not assessed in EPS 2000d owing to lack of data. In Udo de Haes et al (2002) different proposed assessment methods are discussed, but no recommendation is given.

- To get inventory data and to do impact assessment of fate (the environmental effects) of discharges to water of chemicals is problematic (methodological issues 16 and 23 (*missing relevant characterization factors for discharges of chemicals to water*). This issue is more important for the textile sector than for many other sectors, since there are many types of discharges to water from fiber production and the wet treatment of the fabrics. It is a type of local or regional effect, which can be characterized in models, but at present there are no internationally accepted assessment methods (Molander et al (2004), Udo de Haes et al (2002)). Beck et al (2000) assessed residence time in water by using a model called USES-LCA. Thereafter they made a three dimensional diagram presenting the relations between toxicity, residence time in water and weighting results for the chemical production. The problem to know whether residence time or toxicity is worst and how they are related to other environmental impacts however remains. The uncertainty lies in that the persistent chemicals can have effect when the amount becomes high or in future new environmental effects are found. The Swedish textile industry are e.g. concerned about the accumulation of antimony in nature due to emissions from polyester fibers. Antimony is used as a catalyst in the polymerization of polyester. Antimony is not considered to have great environmental impact, but how large amounts affects nature has to be further investigated (Hansson 2004). In the case in this report, no attempt was made to follow the fate of chemicals in discharged water from e.g. wet treatment, except in terms of eutrophication and ecotoxicological potential. Only metals, oil and phenol were assessed in the ecotoxicological potential.

- It is difficult to do an LCA in the textile field with impact assessment based on a specific geographical area, since the production steps usually is in different parts of the world and *combined characterization and weighting methods are missing for many parts of the world* (methodological issues 23 and 26). In our case, some unit operations occur outside Europe, but EDIP is normalized to Denmark and Ecoindicator 99 to Europe.

- It is problematic to inventory and assess the environmental effects of the accident risks associated with nuclear power or mining owing to shortage of data (*risks e.g. associated with nuclear power*, methodological issue 13). According to ISO 14042 clause 8, risks are not assessed in LCA studies, but it is possible to use risk data if they are known.

- It can be difficult to find data for and to assess, for example, the work environment if data are overly aggregated or missing, because the aggregation can sometimes conceal important intermediate products (*health effects in e.g. the work environment*). For the textile sector in general, this is an important issue, since a large part of the textile industry is situated in developing countries. For the Swedish plants, there were no problems with work-related diseases, but for the other activities data were difficult to find. There may be health problems with pesticide use in the agriculture activities, but no such data were found; only general data used for different pesticides in the characterization methods were given. In the case of polyester production antimony trioxide (possibly carcinogenic and therefore negative for the work environment) is not found in the inventory (Boustead 1997). One reason could be that it was considered unimportant (there is no impact assessment in the report by Boustead (1997), in which case it is not a problem of aggregation. Another reason could be that antimony trioxide is an intermediate product and is therefore left out of the inventory table. The mineral use for antimony trioxide production was not reported, probably because of the small amount. Much of the antimony trioxide is included in the polyester produced. Probably, then, it is not found in the emission part. Antimony trioxide does not have a characterization factor in the default impact assessment methods used (methodological issue 23). The problem with antimony trioxide and also with perchloroethylene in the dry-cleaning step of wool/PA is that the total volumes are small and are probably therefore not taken into account in the default impact assessment systems, although they could have a significant local impact on the particular life cycles studied (methodological issue 23).

2) *Choice of System Boundaries*

The issue of choice of system boundaries can be related to difficulties in finding good data, since these difficulties can result in a non-ideal system boundary choice such as in our case where we have non-elementary outputs and inputs of chemicals and lubricants to the system. One may also wish to have another time horizon for emissions and impact assessment than the available (methodological issues 3, 22). In this study, for example, production of chemicals was excluded in the base case on the assumption that is not significant to the study. The rules of thumb for the choice of system boundaries are different for each product sector and type of decision to be made. It is necessary for LCA experts to know if their assumptions regarding where to put the system boundaries are realistic when doing or ordering an LCA study. Therefore it is necessary to inventory of the outside "world" to establish the rules of thumb. An attempt was made in this study to *include production of chemicals*. As seen in figure 28, this problem is inherent in many of the other problems found below, such as in the problem of assessing the fate of chemicals.

3) There were *difficulties in finding good data* (methodological issue 11). There is also often too little information in the reports regarding data about data, which creates uncertainty (*non-standardized reporting such as nomenclature and data types*, methodological issue 19). This is also an issue regarding the model; see model issue c in chapter 8.4. The SPINE format (Pålsson 1999) is developed to deal with such information shortages.

Below are some examples of problems in finding good data for the purpose:

- It is, for example, a problem that there is no standardization about which heating value for the energy carriers to calculate for, since the practitioner often includes ready-made LCI studies in his/her own LCA (methodological issue 9). Moreover, the type of heating value is not always reported. There may also be inconsistencies regarding electricity type (methodological issue 7). Some reports may use marginal electricity and some average. Sometimes the dimension of the air emissions of particles is not reported. Another problem is to know whether data about BOD and COD are for different water streams. If they are for the same stream, the inclusion of both BOD and COD values could induce double counting in the impact assessment. The same type of problem occurs when both Cr^{3+} and Cr is reported (methodological issue 19).

- Some companies have only total energy and water data, and the processes are so diverse that often it made no sense to use the data from these companies (*overly aggregated data*). Sometimes the data were used and allocation had to be done, but it was often problematic (methodological issue 14).

- Type of water consumed and where water is discharged was often not reported in the literature. Do the companies have their own wastewater-treatment plant and is it included (methodological issue 19).

- It is not always known if packaging material is included in the reports (methodological issue19).

- In the reports often it is not clarified if biomass and wood come from the nature or the technosphere (methodological issue19).

- Difficulties in assessing photooxidant formation potential when some inventories report “aromatics” and not benzene and toluene separately. On the other hand double reporting may cause confusion if it is not clarified. If they are included in “aromatics” they are left out in the characterization (methodological issue 19 and 20). Some characterization factors such as for xylene were not included at all (methodological issue 23).

- Difficulties in assessing the fate of chemicals in general if not all the impacting chemicals are measured/estimated or if the emissions are aggregated to e.g. AOX (methodological issues 16 and 23).

- Data can be *overly aggregated* causing *transparency problems*, as in the report regarding laundry of a cotton T-shirt (Pulli 1997), where a summary table of all activities is published but not the data for the production of chemicals (methodological issue 20). Since the rest of the life cycle in the base case did not have chemical production within the system boundaries, it was not possible to use the aggregated data. If data for the production of the chemicals had also been reported, the data would have been much more useful. In our case study, confidentiality demand allows only aggregated data to be reported to public (methodological issue 12).

- Data for different activities vary regarding details (*data gaps*). The practitioner gets general data from the database he/she uses with default data categories. Also, data may be lacking for one activity and not the other, to what extent is often not known by the practitioner (methodological issue 4). Should one exclude one type of flow for all other activities because of the data gap in one activity? This problem might have the effect that activities with detailed data are given unfairly relatively higher environmental impacts than activities where data are less detailed. In this LCA, there are significant data gaps for emissions to water. Moreover, since fate of the organic chemicals from the wet processes were not sufficiently assessed, their environmental impact could not be assessed. One example of what the consequence could be when differences in activities vary regarding detail is that in Ellebäk Laursen et al (1997), who report on environmental impact from different fiber types, methane emissions from sheep were not included. If only data from their report were used, I would have missed the methane emissions from sheep, which was discovered to be crucial to the assessment of the environmental impact of the wool/PA fabric.

- It is problematic to know whether a data set from slightly different conditions than the ones actually conditions studied can be used (*epistemological uncertainties*, methodological issues 4 and 15). In this study one example was when the LCI data for production of fertilizers were for Europe with other electricity types than in Texas, where the fertilizer was used. Another epistemological uncertainty is to know how much the technology has changed from the time when the data were reported (*how much have data changed*, methodological issues 4 and 15). This type of methodological issue, when available data are not exactly the data desired is discussed by von Bahr (2001).

- It could be problematic to know if *data quality is high enough for the purpose*. It is also an issue regarding the model (methodological issue 4).

4) Allocation choices often cause ambivalence for the practitioner (*allocation in practice*, methodological issue 14).

1. Often data were for the entire plant, resulting in data with high uncertainty when data were allocated to mass of fabrics produced in the plant.
2. When including data from literature, we have to accept the allocation method that was chosen. Also, sometimes the allocation procedure is not clearly reported.
3. Allocation or system expansion choices can have a great impact on the results, such as in the case of wool, where the oddments, the second class wool, was assumed to replace pure wool in the base case.
4. Data about allocation procedures can be difficult to find, as in this case for certain energy carriers.

5) It can be difficult to include more than one function in the functional unit (*including more than one aspect in the functional unit*, methodological issue 2). In this case study the function was the same for the three fabric types. The difference in comfort is small and therefore considered unimportant. The case is different, for example, for clothing, where different fabrics often have major comfort differences. If the differences in comfort could be quantified and were added as a second function in the functional unit, system expansion would be required, which would increase the size of the study considerably. It is, however, questionable whether there is always a need for the functional unit to cover all aspects. Nowadays there is a discussion in the LCA society whether it is really necessary to have exactly the same functions for comparison. It is argued that differences in function could be handled by decision makers separately from the LCA study (Lindfors 2002).

6) *Inconsistencies in the ISO standards*.
Since the ISO 14040 (1997) - 14043 (2000) standards are inconsistent, they can be difficult to follow (methodological issue 1). The statement with the word “should” instead of “shall” in the introduction in ISO 14040 (1997): “However, in all cases, the principles and framework established in this International Standard should be followed” makes it possible for anyone to claim they follow the standard, even if they deviate significantly from the intentions underpinning the standards. Some requirements for the scope differ between ISO 14040 (1997) and ISO 14041 (1998). For instance, according to ISO 14040, the product system to be studied and the allocation procedures shall be considered and clearly described in the scope, but this is not required for the scope according to ISO 14041 (1998). Also the requirements for reporting in ISO 14041 (1998) (clause 8) do not completely correspond with the previous texts in the standard.

7) The ISO 14041 (1998) standard requires sensitivity analysis to be performed on LCI data. It is not interesting to this except in combination with LCIA (methodological issue 10). This issue is not reported in figure 28, since it is just a matter of interpreting the standard.

8.3.1 Surveying of the methodological issues regarding the procedure

In figure 28, the interrelationships between the methodological issues regarding procedure found in this study are shown.

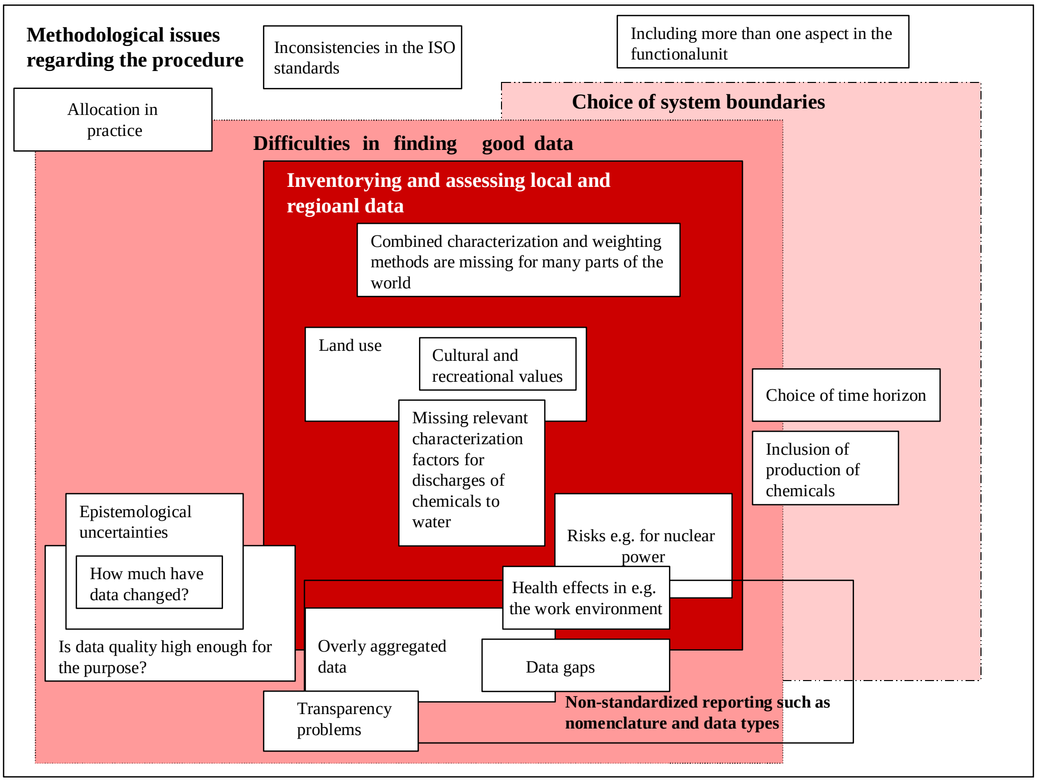


Figure 28: The methodological issues regarding procedure found in this study
The sizes of the squares do not indicate the size of the problems, but the way they overlap is to show how they are interlinked.

8.4 Methodological issues regarding the model

a) Our LCA model does not assess impacts for which there is little if any scientific consensus, such as:

1. impacts from GE cotton. This is a methodological problem regarding the model since the risks are partly unknown and not quantified (methodological issues 18 and 25).
2. impacts from materials accumulating in nature with unknown environmental effects, such as antimony originating from polyester production or dyeing agents (methodological issues 16 and 23).

b) Our LCA model does not consider non-linear or threshold properties of emissions and impacts (methodological issue 30).

c) Our LCA model:

1. does not consider all relevant impacts, but favors the internationally accepted ones. On the other hand, our model considers category endpoints, which is more than expected in the ISO standards. In clause 8 in ISO 14042 (2000) it is said: “LCIA results do not predict impacts on category endpoints…”
2. is weak in assessing local impacts (methodological issue 23).
3. includes assumptions regarding the reporting in the literature (methodological issue 19).
4. does not consider financial or social aspects (except from monetarization of impacts in EPS 2000d, methodological issues 28 and 29)

This means that the LCA methodology would benefit from

- improvements on procedures to handle uncertainties,
- more international acceptance for endpoint types of category indicators,
- development of databases on local impact category indicators,
- development of model validation procedures (the critical review only validates the procedure, not the model) and
- inclusion of the requirement to follow ISO 14048 (2002) in the standards ISO 14040 (1997) – ISO 14043 (2000).

8.5 Methodological issues found compared with the limitations mentioned in the ISO 14040 (1997) and ISO 14042 (2000) standards

In the introduction in ISO 14040 (1997), the following methodological issues are mentioned*:

- “The nature of choices and assumptions made in LCA (e.g. system boundary setting, selection of data sources and impact categories) may be subjective”
- “Models used for inventory analysis or to assess environmental impacts are limited by their assumptions and may not be available for all potential impacts or applications”.
- “Results of LCA studies focused on global and regional issues may not be appropriate for local applications, i.e. local conditions might not be adequately represented by regional or global conditions”.
- “The accuracy of LCA studies may be limited by accessibility or availability of relevant data, or by data quality, e.g. gaps, types of data, aggregation, average, site-specific”.
- “The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each impact category”.

In clause 8 in ISO 14042 (2000) the limitations are stated*:

- “LCIA is, wherever possible, a technical and scientific procedure. However, value-choices are used in the selection of impact categories, category indicators and characterization models, and in normalization, grouping, weighting and other procedures”.

- “LCIA typically excludes spatial, temporal, threshold and dose-response information, and combines emissions or activities over space and/or time. This may diminish the environmental relevance of the indicator result”.
- “Category indicators may vary in precision among impact categories, due to differences
  1. between the characterization model and the corresponding environmental mechanism, e.g. spatial and temporal scales,
  2. in the use of simplifying assumptions and
  3. within available scientific knowledge”.
- “LCIA results do not predict impacts on category endpoints” (*they do in e.g. EPS 2000d*), “exceeding of thresholds, safety margins or risks” (*if the risks are known, they can be included*).
- “LCIA cannot always demonstrate significant differences among impact categories and the related indicator results of alternative product systems. This may be due to the limited development of the characterization models used in characterization, sensitivity analysis and uncertainty analysis for the LCIA phase” (*this is often a result of all other issues*).
- “Limitations of the LCI phase, such as setting system boundaries” (*setting boundaries is done during goal and scope definition*) “that do not encompass all possible unit processes for a product system or include all inputs and outputs of every unit process, since there are cut-offs and data gaps”.
- “Limitations in the collection of inventory data appropriate and representative for each impact category”.

*The texts in parenthesis are my comments.

Apart from the limitations described in the standards, we have noted: the issues of how to know if data quality is high enough for the purpose, problems with including more than one aspect in the functional unit, and inconsistencies in the ISO standards.

9 Conclusions regarding the methodological issues

A division into procedure and model issues was made, in accordance with the terminology of Baumann (1998). The procedure issues were mapped in order to see their interrelations.

The LCA method is still immature in several aspects, both when looking at procedural aspects and when looking at model performance aspects. The gravity of the methodological issues generally depends on how the results will be used, but we find that the following methodological issues are important for the textile sector:

- To improve the resolution of inventory data, especially for cotton cultivation including land and irrigation water use, but also for land use in sheep farming or for the production of chemicals.
- To develop impact assessment methods with higher resolution for the agriculture activities especially for cotton cultivation including assessment of land and irrigation water use, but also for land use in sheep farming.

The following methodological issues were only approximately dealt with in the sensitivity analysis, thus uncertainty remains to what extent they are important issues:

- The need to obtain better inventory data and to perform impact assessment of health effects in the work environment. When more of the production than in this case takes place in the developing world, this issue may be particularly important.
- The need to collect inventory data for and to assess the effects of chemicals discharged to water. Moreover, if most of the fabric production takes place in countries without wastewater-treatment and where more environmentally impacting chemicals are used, the effects of chemicals emitted to water become more important.
- The need to collect inventory data for and to assess the use of GE cotton.

There are other significant methodological issues, such as:

- non-standardized nomenclature and data types
- data gaps and
- problems with carrying out allocations in practice.

These are however general problems for most LCAs.

ISO 14040 (1997) and ISO 14042 (2000) mainly give general characteristics of the methodological issues, while this LCA study has highlighted more specific methodological issues for the textile sector.

10 Discussion

The map describing the procedural issues (figure 28) is probably valid for more sectors than the textile, but the analysis of which methodological issues are the most important ones varies, depending on the sector concerned and the scope of the study. Some aspects of the procedure also become issues regarding the model. This means that the issues can be dealt with if sufficiently resources are invested in the study for the inventory and sensitivity analysis, but more specific advice in the ISO 14040-series would facilitate the LCA procedure. On the other hand, the degree of freedom would then decrease, and the choices of e.g. impact assessment methods, depend on the type of decisions that is supposed to be made. Such specific advice is difficult to give in a standard. It is also important to bear in mind that the main purpose of most LCA studies is to give an overview; more detail implies a risk of losing some aspects of that overview. The effects of chemicals discharged to water could, for instance, be treated separately in the environmental risk assessment (ERA) method. The textile sector is very labor intensive and has a large part of its production in developing countries, why social and financial aspects of sustainability become important in explaining impacts on human health and welfare. Including these aspects into the LCA procedure would give valuable perspectives on some environmental issues.

The ranking of Trevira CS by the methods used also applies to normal polyester and it is only valid with the constraints in the study, such as in comparisons with conventional cotton and wool/PA fabric, and if the use phase (cleaning of the fabric) is not of importance. If the fabrics were intended for clothing, the methods used would probably show that Trevira CS had a higher impact owing to smaller loads in the washing machine than for cotton, and owing to the need for more frequent cleaning than wool/PA or cotton fabrics. Normally, cotton fabrics have lower abrasion resistance than wool/PA or Trevira CS fabrics, resulting in an even higher environmental impact of the cotton fabrics than the other two types, if the fabrics were assumed to be worn out before they are thrown away.

11 Critical review

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11.1 The assignment

The undersigner Maria Walenius Henriksson, IFP Research AB, on behalf of Lisbeth Dahllöf, has performed a review of the above mentioned Life Cycle Assessment "Methodological issues in the LCA Procedure for the Textile Sector – A Case Study Concerning Fabric for a Sofa" during the spring of 2004. The purpose was to review the numerical data and the reporting.

11.2 The examination

The data from the various steps of the above-mentioned study was, when possible, checked against general knowledge about processing conditions in the textile and laundering industry as well as by the comparison, whenever possible, with data collected by IFP Research in other studies.

11.3 Results of the examination

The aim of the study was to serve as basic data for a thesis regarding methodological issues and problems seen when trying to adopt the rules stated in 14040-43 for writing reports.

The fundamental system boundaries of the product system fulfil in all essentials the demands of the EN ISO 14040-43. The system boundaries and the assumptions are well documented and motivated, including excluded impact categories. The conclusions are restricted to the studied impact categories. The studied technical system is also well documented. The definition of the system boundaries (flows not followed to the "cradle" or the "grave" or processes that has been excluded) have a marginal influence on the results and will not influence the conclusions.

The sources and the quality of data have been described clearly. The data are assessed as being representative in a requisite way. Data gaps are being described and does not imply anything out of the ordinary. The study is a comparison of three types of textiles for a sofa, which means that processes that are identical can be excluded. In that respect, the results can only be used for this particular comparison. However, in this study the exclusion of any identical process would probably not influence the results to a high degree.

The study includes an assessment of the impact on the environment – characterisation, which has been well documented.

The interpretation of the results are shown clearly and includes sensitivity analyses, which includes critical assumptions, data gaps and boundaries. This also gives support to the conclusions of the study.

The results from the study are relatively clear. The conclusions are formulated in a balanced way and motivated by the results of the study.

To sum up, the choice of methods, accomplishment and reporting is as a whole of high quality in comparison with good practice in the area and it also follows in most details the demands of EN ISO 14040-43, which has been very clearly stated in the report.

The undersigner would finally like to give many thanks to Lisbeth Dahllöf for her forthcoming towards the reviewer during this work.

Mölndal on the 2nd of June 2004
Maria Walenius Henriksson

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Appendix 1

Inventory results for the life cycles of the three fabric types
Non-elementary input/output = input/output to the technosphere
Elementary waste = waste leaving the technosphere
Blank cells are data gaps.

INVENTORY RESULTS		Unit	Cotton[1] (4.99 kg on the sofa)	Trevira CS (3.56 kg on the sofa)	Wool/PA[2] (5.27 kg on the sofa)
Resources from ground	Arable land use	m2*year	1.08E+02	0	7.23E+02
	Barytes	kg			1.08E-05
	Bauxite	kg	2.67E-02	2.49E-02	1.92E-02
	Bentonite	kg	4.55E-04	2.56E-04	2.69E-04
	Biomass	kg	8.31E-01	4.12E-01	2.93E-01
	Calcium sulphate	kg	0	0	1.08E-05
	Chalk	kg	4.46E-06	1.30E-06	1.58E-05
	Chromium in ore	kg	1.57E-12	3.45E-05	1.06E-12
	Clay	kg	9.53E-07	2.78E-07	1.82E-05
	Copper in ore	kg	6.61E-04	3.28E-04	2.33E-04
	Crude oil	kg	1.70E+01	7.70E+00	6.50E+00
	Dolomite	kg		2.03E-04	1.18E-05
	Ferromanganese in ore	kg		1.30E-05	
	Fluorspar	kg			3.94E-06
	Gravel	kg		6.04E-05	
	Hard coal	kg	3.18E+00	3.33E+00	1.56E+01
	Hydro power	MJ	1.61E+02	8.19E+01	7.98E+01
	Iron in ore	kg	3.27E-03	1.80E-02	2.24E-03
	Iron ore	kg	1.26E-03	1.09E-03	9.23E-04
	Irrigation water	kg	2.26E+04	0	0
	Lead in ore	kg	1.17E-05	1.88E-05	9.07E-06
	Lignite	kg	2.71E-01	1.16E+00	6.18E+00
	Limestone	kg	4.38E-02	1.33E-01	3.13E-01
	Metallurgical coal	kg			3.94E-04
	NaCl	kg	9.42E-05	6.88E-05	9.96E-05
	Natural gas	kg	6.98E-01	2.80E+00	3.11E+00
	Nickel in ore	kg	1.56E-09	9.07E-10	1.05E-09
	Olivine	kg		1.55E-04	8.87E-06
	Potassium chloide	kg			2.07E-03
	Rutile	kg		7.77E-04	2.86E-03
	Sand	kg		4.19E-04	8.28E-04
	Shale	kg		4.32E-06	3.16E-05
	Sodium chloride	kg	2.12E-02	2.56E-02	8.42E-02
	Softwood	kg	5.80E-04	3.03E-04	3.69E-03
	Soil and loose earth material	kg	1.43E-05	1.08E-05	1.57E-05
	Sulphur in ore	kg		2.46E-04	2.65E-02
	Surface water	kg	1.17E-09	3.36E-10	4.09E-09
	TiO2	kg	0		0
	Unspecified fuel	MJ	2.55E-05	7.28E-06	8.87E-05

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Resources from ground continued	Uranium in ore	kg	1.24E-03	6.54E-04	9.72E-04
	Water	kg	4.01E+02	8.51E+01	
	Wind power	MJ	3.43E-01	1.70E-01	1.21E-01
	Wood	kg	8.27E-01	6.33E-01	9.91E-01
	Zinc in ore	kg	1.51E-09	8.80E-10	2.37E-05
Resources from water	Water unspecified	kg	1.56E+03	9.79E+02	2.87E+03
Non-elementary inputs	AE	kg	6.39E-02	6.84E-02	0
	Acetic acid	kg	4.51E-01	3.89E-02	1.84E-01
	Acids	kg	0	0	1.18E-01
	Alkyl polyethylene glycol ether in water	kg	1.08E-01	0	0
	Aluminium	kg	2.55E-06	7.40E-07	9.01E-06
	Ammonium nitrate	kg	1.44E+00	0	0
	Antistatic agent	kg	0	0	1.20E-02
	Antraquinone colorant	kg	0	0	5.58E-03
	Avivages/Softening agents	kg	0	0	3.01E-02
	Azocolorant anionic	kg	0	0	1.14E-01
	Calcium Carbonate (soda)	kg	0	0	1.16E-01
	Azo-copper complex colorant powder mixture	kg	3.90E-03	0	0
	Azo-reactive colorant powder mixture	kg	1.46E-01	0	0
	CMC	kg	7.99E-03	8.50E-03	0
	Cardboard	kg	2.22E-01	1.69E-01	2.33E-01
	Chlorinated phenol	kg		0	0
	DAS-1	kg	1.60E-03	1.70E-03	0
	Diammonium phosphate	kg	1.94E-01	0	0
	Diazo colorant powder	kg	4.29E-02	0	0
	Dispersant	kg	0	2.16E-02	0
	Dyeing agents	kg	0	1.28E-01	0
	Emulsifying agent	kg	0	0	6.59E-02
	Enzyme	kg	3.98E-03	4.25E-03	0
	Enzyme solution	kg	1.56E-02	0	0
	Even out agent	kg	0	7.56E-02	0
	Fat alcohol polyglycol ether	kg	3.90E-02	0	0
	Fatty alcohol ethoxylate	kg	1.17E-01	0	0
	Fatamine polyglycol ether	kg	0	0	1.19E-01
	FeSO4	kg	6.15E-02	3.58E-02	4.13E-02
	Fluoric polymer emulsion	kg	1.56E-01	0	0
	Fungicide	kg	9.62E-05	0	0
	Herbicide	kg	1.39E-02	0	0
	Hydrogen peroxide	kg	1.06E-01	0	0
	Insecticide	kg	4.60E-02	0	0
	Iron	kg	2.64E-06	7.69E-07	9.36E-06
	Iron chloride sulphate solution	kg	0	0	5.94E-02
	LAS	kg	7.98E-02	8.50E-02	0

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Non-elementary inputs continued	Lime	kg	4.43E-03	2.20E-03	1.56E-03
	Lubricant grease	kg	2.06E-04	1.69E-04	1.93E-04
	Lubricant oil	m3	5.68E-06	1.08E-03	5.31E-06
	Magnesium chloride	kg	1.56E-02	0	0
	Manganese	kg	1.50E-08	4.30E-09	5.24E-08
	Methoxymethylated 4,5-dihydroxyethylurea in water	kg	2.73E-02	0	0
	Na carbonate	kg	7.98E-02	8.54E-02	0
	Na perborate	kg	1.20E-01	1.28E-01	0
	Na sulphate	kg	9.82E-02	1.07E-01	0
	Nonionic emulsifier	kg	5.57E-03	0	0
	Organic phosphourous compound in water	kg	3.57E-02	0	0
	Other chemicals	kg	3.61E-03		7.78E-01
	Other fuel	MJ	1.02E+01	7.66E+00	1.12E+01
	Other supply materials	kg			3.07E-01
	Packaging materials	kg			9.92E-02
	Paper	kg	2.41E-02	1.76E-02	2.55E-02
	Paraffine mixture, anionic	kg	1.95E-02	0	
	Perchlorethylene	kg	0	0	3.95E-02
	Perfluoric acids in water solution	kg	1.95E-02	0	0
	Pesticide	m^3		0	1.12E-05
	Phosphate	kg	0	0	5.80E-01
	Phosphonate	kg	7.99E-03	8.50E-03	0
	Phosphoric acid ester, anionic	kg	1.84E-02	0	0
	Polyacrylic and phosphoric acid derivate, anionic	kg	1.56E-02	0	0
	Polycarboxylate	kg	2.40E-02	2.14E-02	0
	Polymer	kg	9.21E-05	5.36E-05	6.19E-05
	Potassium nitrate	kg	9.86E-02	0	
	Proteine derivate in solution	kg	2.23E-02	0	0
	Soap	kg	2.40E-02	2.55E-02	0
	Sodium acetate	kg	0	0	9.18E-02
	Sodium carbonate, anhydrous	kg	6.46E-02	0	0
	Sodium chloride	kg	7.80E-03		
	Sodium hydro sulphite		0	8.64E-02	0
	Sodium hydroxide	kg	2.38E+00	1.34E-01	1.64E-01
	Sodium salt of highly sulphatized fatty acid	kg	3.90E-02	0	0
	Sodium silicate	kg	2.51E-01	9.07E-02	
	Sodium sulphate	kg	0	0	5.56E-01
	Starch	kg	3.61E-01	0	0
	Steel band			0	0
	Sulphuric acid	kg	7.39E-03	3.67E-03	2.61E-03
	Surfactants	kg			9.31E-02
	Surfactants with terpene hydrocarbons	kg	2.67E-02	0	0
	TAED	kg	1.60E-02	1.71E-02	0

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Non-elementary inputs continued	Water	kg	1.69E+00	1.27E+00	
	Woven jute	kg		0	
	Zeolite A	kg	2.40E-01	2.56E-01	0
Emissions to air	Acetaldehyde	kg	-3.50E-09	3.78E-08	1.49E-08
	Acetylene	kg	1.63E-05	1.54E-06	2.22E-06
	Aldehydes	kg	1.07E-07	6.06E-08	4.15E-06
	Alkanes	kg	4.06E-04	3.86E-05	5.56E-05
	Alkenes	kg	3.25E-05	3.09E-06	4.45E-06
	Aromates (C9-C10)	kg	3.31E-05	3.40E-06	8.17E-06
	Aromatics	kg		8.64E-06	5.92E-04
	As	kg	3.14E-07	9.16E-08	8.09E-07
	B	kg	4.80E-06	1.85E-05	2.25E-04
	Benzene	kg	5.64E-05	2.64E-05	1.56E-05
	Benzo(a)pyrene	kg	1.70E-11	4.89E-10	1.49E-09
	Butane	kg	-2.45E-06	2.65E-05	1.04E-05
	CN-	kg	2.58E-07	8.24E-08	5.39E-08
	CO	kg	1.07E-01	1.39E-01	9.09E-02
	CO_2	kg	5.82E+01	4.16E+01	6.77E+01
	CO_2 (renewable)	kg	6.39E+00	0	5.75E+00
	Cd	kg	5.50E-07	8.89E-08	4.73E-07
	Co	kg	1.44E-08	4.57E-08	5.57E-07
	Cr	kg	5.57E-07	1.17E-07	1.40E-06
	Cu	kg	1.92E-07	2.96E-07	3.44E-06
	Dioxin	kg	5.23E-11	5.71E-12	2.35E-09
	Ethane	kg	3.25E-05	3.09E-06	4.45E-06
	Ethene	kg	8.13E-05	7.72E-06	1.11E-05
	Formaldehyde	kg	9.40E-06	4.71E-06	2.82E-06
	H_2	kg	1.35E-08	1.12E-03	1.42E-08
	H_2S	kg	7.55E-06	3.83E-06	9.87E-06
	HCl	kg	1.20E-03	2.42E-03	2.63E-03
	HF	kg	2.98E-05	5.82E-05	3.81E-05
	Heavy metals	kg	1.56E-19	4.45E-20	5.42E-19
	Hg	kg	5.05E-07	1.30E-07	1.28E-06
	Metals	kg	2.38E-06	9.52E-04	1.55E-05
	Methane	kg	8.23E-02	7.94E-02	6.23E+00
	Mg	kg	3.36E-06	5.45E-06	6.63E-05
	Mn	kg	3.98E-08	1.87E-07	2.28E-06
	Mo	kg	1.62E-08	2.56E-08	3.12E-07
	N_2O	kg	7.13E-03	1.64E-04	9.88E-03
	NH_3	kg	1.43E-02	6.79E-07	9.47E-01
	NMVOC	kg	1.40E-01	8.63E-02	4.96E-02
	NMVOC, diesel engine	kg	1.90E-02	4.04E-05	1.02E-02
	NMVOC, el-coal	kg	6.12E-05	4.57E-07	5.57E-06
	NMVOC, natural gas combustion	kg	6.45E-05	9.46E-05	1.24E-04
	NMVOC, oil combustion	kg	7.42E-03	2.42E-03	1.79E-03
	NMVOC, petrol engines	kg	1.19E-14	3.41E-15	4.15E-14
	NMVOC, power plants	kg	2.95E-05	1.55E-05	1.89E-04
	NOx	kg	3.29E-01	1.38E-01	2.80E-01

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Emissions to air continued	Ni	kg	2.52E-05	4.08E-06	2.30E-05
	Organic compounds	kg	6.73E-08	4.92E-08	7.12E-08
	Other organics	kg	7.98E-08	4.32E-02	2.79E-07
	PAH	kg	2.02E-07	4.32E-07	2.27E-07
	Particles	kg	2.88E-02	5.26E-02	3.95E-02
	Pb	kg	2.26E-06	4.56E-07	3.22E-06
	Pentane	kg	-4.20E-06	4.54E-05	1.79E-05
	Propane	kg	4.81E-05	1.22E-05	9.65E-06
	Propene	kg	3.25E-05	3.09E-06	4.45E-06
	Radioactive	Bq	1.08E+12	1.03E+11	1.48E+11
	Rn-222	Bq	4.55E+06	2.26E+06	1.61E+06
	SOx	kg	1.08E-01	2.14E-01	3.45E-01
	Sb	kg	4.89E-09	2.35E-08	2.86E-07
	Se	kg	3.52E-07	2.81E-07	3.42E-06
	Sn	kg	5.51E-09	4.22E-09	5.14E-08
	Sr	kg	2.76E-08	1.90E-07	2.32E-06
	Th	kg	2.45E-09	3.02E-09	3.68E-08
	Tl	kg	1.23E-09	5.21E-10	6.34E-09
	Toluene	kg	1.56E-05	9.11E-06	5.20E-06
	U	kg	1.83E-09	2.90E-09	3.53E-08
	V	kg	3.48E-08	4.79E-06	5.83E-05
	Zn	kg	3.69E-07	5.17E-07	6.09E-06
Discharges to water	AOX	kg			4.99E-05
	Acid as H^+	kg	4.40E-05	1.58E-04	1.10E-04
	Al	kg	4.45E-04	4.10E-05	1.32E-04
	Aromates (C9-C10)	kg	1.82E-07	9.56E-08	1.16E-06
	As	kg	1.55E-06	1.66E-07	4.16E-07
	BOD	kg	2.14E-04	3.92E-03	2.36E-02
	BOD_5	kg	6.43E-05	5.88E-06	1.75E-05
	CN-	kg	3.41E-06	3.12E-07	9.30E-07
	CO_3^-	kg		1.75E-05	
	CO_3^{2-}	kg			1.28E-04
	COD	kg	1.43E-01	4.37E-02	3.57E-02
	Ca++	kg		4.32E-06	1.18E-05
	Cd	kg	8.93E-07	1.29E-07	2.30E-07
	Chloride	kg	3.76E-04	2.83E-04	4.14E-04
	Cl-	kg	4.28E-01	5.19E-02	1.92E-01
	ClO^{3-}	kg	1.07E-05		
	Co	kg	8.73E-07	7.98E-08	2.37E-07
	Cr	kg	1.70E-05	1.88E-06	3.08E-06
	Cu	kg	1.00E-05	7.24E-06	1.28E-05
	Detergents[3]	kg		1.08E-04	7.00E-05
	Dissolved organic carbon	kg	8.33E-15	2.39E-15	
	Dissolved organics	kg	1.43E-05	4.75E-02	4.99E-04
	Dissolved solids	kg	1.83E-03	1.01E-03	
	F-	kg	3.06E-05	6.00E-06	1.98E-05
	Fe	kg	2.53E-06	7.54E-04	9.18E-03
	H_2S	kg	1.12E-07	1.02E-08	3.05E-08
	HC	kg	1.42E-04	6.69E-04	2.06E-04
	K	kg			6.31E-05

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Discharges to water continued	Metals	kg	1.45E-04	4.24E-04	3.76E-04
	Mn	kg	1.26E-06	9.35E-08	1.14E-06
	N total	kg	1.62E-02	1.59E-03	5.38E-03
	NH_3	kg	4.77E-06	3.59E-06	5.23E-06
	NH_4+	kg		8.64E-06	2.37E-03
	NH_4+ as N	kg	1.01E-06	5.27E-06	6.42E-05
	NO_3^- as N	kg	9.27E-09	2.81E-09	3.42E-08
	NO_3^-	kg			2.76E-02
	Ni	kg	6.51E-06	2.37E-06	1.35E-05
	Oil	kg	1.40E-02	1.50E-03	3.80E-03
	Organic compounds	kg	1.17E-04	8.82E-05	1.29E-04
	Other organics	kg	1.16E-02	1.61E-03	3.14E-03
	P total	kg	1.00E-03	1.07E-03	1.19E-05
	P_2O_5	kg		2.59E-05	1.08E-04
	PO_4^{3-}	kg	3.66E-05	3.94E-06	9.80E-06
	Pb	kg	6.94E-06	1.65E-06	1.61E-06
	Pesticides	kg		0	1.33E-08
	Phenol	kg	1.35E-08	5.18E-05	1.18E-05
	Radioactive	Bq	1.02E+10	9.66E+08	1.39E+09
	SO_4^{2-}	kg	1.70E-02	6.63E-03	7.09E-02
	Sb	kg	1.22E-08	1.12E-09	3.33E-09
	Sn	kg	9.57E-04	8.75E-05	2.61E-04
	Sodium chloride	kg	1.26E-04	1.69E-03	2.05E-02
	Sr	kg	6.33E-06	1.81E-06	2.20E-05
	Sulphates	kg	1.35E-07	9.83E-08	1.42E-07
	Suspended solids	kg	5.01E-03	4.58E-03	1.86E-03
	Total organic carbon	kg	1.02E-04	9.66E-06	1.39E-05
	V	kg	2.86E-06	2.62E-07	
	Water	kg	1.51E+03	8.80E+02	1.08E+03
	Zn	kg	5.17E-05	2.69E-05	2.36E-05
Discharges to soil	Pesticides	kg	6.00E-02	0	
	Pesticides	m3		0	1.12E-05
Discharges to soil via sludge	AOX	kg	5.02E-06		
	Cd	kg	3.82E-08	7.00E-08	
	Cr	kg	5.87E-06	7.02E-07	
	Cu	kg	2.26E-04	4.01E-05	
	Detergents	kg			
	Dyeing agents	kg	4.82E-02		
	Hg	kg	1.11E-09		
	Ni	kg	9.95E-07	1.83E-06	
	Nonylphenol	kg	7.36E-07		
	Ntotal	kg		5.03E-04	
	PAH	kg	2.06E-09		
	PCB	kg	1.34E-09		
	Pb	kg	2.98E-06	2.89E-06	
	Ptotal	kg		7.42E-03	
	Sb	kg	3.18E-07		
	Sn	kg	3.34E-08		
	Zn	kg	1.88E-04		

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Non-elementary water discharges (substances not covered in data for wastewater treatment plant)	Total organic carbon	kg	7.19E-02	7.69E-02	
	Cl^-	kg	1.17E-02	1.26E-02	
Elementary waste via non-elementary outputs	Slag	kg		1.68E-01	
	Sludge	kg	6.80E-01	3.82E-01	1.13E+00
Non-elementary outputs	Ashes	kg	2.43E-03	1.83E-03	2.68E-03
	Bulky	kg	6.65E-01	1.90E-01	2.32E+00
	Cardboard	kg	2.09E-01	2.51E-01	2.05E-01
	Chemicals	kg	5.10E-06	1.46E-06	1.77E-05
	Construction	kg			4.82E-02
	Cotton fibers	kg	1.59E-01	0	0
	Demolition	kg	3.08E-03		1.09E-03
	Domestic waste	kg			2.58E-02
	Edge strips	kg	1.63E-01	1.26E-01	1.45E-01
	Fabric	kg	3.06E-01	1.90E-01	2.78E-01
	Filter dust and boiler slag	kg			1.69E-01
	Fly ash and slag	kg			3.91E-01
	Hazardous	kg	1.13E-02	3.22E-01	3.19E-02
	Heat	MJ	-8.13E+01	-7.83E+01	-1.08E+02
	Highly radioactive	kg	2.06E-03	1.00E-03	7.23E-04
	Industrial	kg	1.56E+00	2.44E+00	3.65E+00
	Industrial waste	kg	1.91E-03	1.44E-03	1.59E-02
	Lubricant grease	kg	2.06E-04	1.69E-04	1.93E-04
	Lubricant oil	m3	5.68E-06	4.64E-06	5.31E-06
	Metals (unspecified)	kg		1.51E-02	3.01E-02
	Mineral	kg	6.59E-05	5.61E-01	2.96E-01
	Mineral waste	kg	6.84E-03	5.15E-03	7.53E-03
	Non-toxic chemicals	kg	3.77E-03	2.84E-03	4.15E-03
	Other	kg	4.87E+00	2.42E+00	1.72E+00
	Packaging material	kg			1.92E-01
	Paper	kg	2.30E-02	1.70E-02	8.61E-03
	Perchlorethylene	kg	0	0	3.95E-02
	Plastics	kg		1.25E-04	
	Polyethylene	kg	1.30E-02	9.00E-02	1.34E-02
	Polypropylene	kg	4.18E-01	3.63E-01	4.15E-01
	Radioactive	kg	7.95E-06	1.31E-04	1.58E-03
	Regulated chemicals	kg		2.25E-03	5.13E-03
	Rubber	kg	7.74E-07	2.21E-07	2.69E-06
	Sand	kg			6.63E-01
	Slags & ashes	kg		1.03E-03	1.25E-02
	Slags & ashes (energy production)	kg	1.79E-02	4.38E-02	6.08E-01
	Slags & ashes (waste incineration)	kg	9.89E-09	2.83E-09	3.45E-08
	Sludge	kg	5.31E-13	4.94E-05	6.01E-04
	Spillage (other)	kg	1.55E-02	1.26E-02	6.07E-01
	Steel band	kg		0	0
	Textile sample with packaging	kg	3.14E-01	2.29E-01	3.32E-01

INVENTORY RESULTS continued		**Unit**	**Cotton**[1]	**Trevira**	**Wool/PA**[2]
Non-elementary outputs continued	To incinerator	kg			1.87E-03
	Toxic chemicals	kg	1.50E-05	1.13E-05	1.65E-05
	Waste	kg	9.75E-01	4.32E-04	
	Wood	kg	7.47E-01	6.30E-01	7.34E-01
	Wool dust	kg	0	0	3.37E-01
	Woven jute	kg		0	0
	Yarn spillage	kg		2.16E-01	

1. In the life cycle of the cotton fabric, 10.1 kg cottonseed is also generated, but is not an output here because its benefit is calculated (system expansion).
2. In the life cycle of the wool/PA fabric 1.03 kg grease and 2.87 kg wool oddments (stained wool) are also generated, but are not outputs here because their benefits are calculated (system expansion).
3. Minimum amount

Appendix 2

Inventory data for drinking water production derived from Wallén (1999)

Transports and production of chemicals are included but not distribution of the water. The plant studied is situated in Göteborg, Sweden. Data were from 1997 (some from 1993).

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Resource	Bauxite	2.37E+01	g	Ground
Input	Resource	Crude oil	1.43E-02	kg	Ground
Input	Resource	Hard coal	8.92E-03	kg	Ground
Input	Resource	Iron ore	1.00E+00	g	Ground
Input	Resource	Limestone	3.90E+01	g	Ground
Input	Resource	Natural gas	2.63E-03	kg	Ground
Input	Resource	Sodium chloride	1.68E+01	g	Ground
Input	Resource	Water unspecified	1.00E+00	ton	Other
Input	Non-elementary	Diesel	2.42E-01	MJ	Ground
Input	Non-elementary	Electricity	3.24E+00	MJ	Ground
Output	Emission	CO	8.00E-02	g	Air
Output	Emission	CO2	1.21E+02	g	Air
Output	Emission	NMVOC	5.00E-02	g	Air
Output	Emission	NOx	4.50E-01	g	Air
Output	Emission	Particles	2.10E-01	g	Air
Output	Emission	SO2	2.70E-01	g	Air
Output	Emission	BOD	1.00E-02	g	Water
Output	Emission	COD	2.30E-01	g	Water
Output	Product	Drinking water	1.00E+00	ton	Technosphere

Appendix 3

Inventory data for the municipal wastewater treatment plant Ryaverket in Gotheburg (Gryaab, 2001)

Direction	FlowType	Substance	Quantity	Unit	Environment
Input	Non-elementary	Water to sewage plant	1	kg	Technosphere
Input	Non-elementary	Electricity	1.14E-03	MJ	Technosphere
Input	Resourse	Zink in ore	1E-12	kg	Ground
Input	Resourse	Nickel in ore	1.03E-12	kg	Ground
Input	Resourse	Chromium in ore	1.04E-15	kg	Ground
Input	Resourse	Lead in ore	1.13E-15	kg	Ground
Input	Non-elementary	Polymer	6.09E-08	kg	Technosphere
Input	Non-elementary	FeSO4	4.07E-05	kg	Technosphere
Output	Emission	Water	1	kg	Water

The purification efficiency to water was:

Substance	In	Out	Share left in water to river	Share left in water to river according to Nordic Guidelines (Nord 1995)
SS	22520	1166	0.051776199	
BOD	15930	850	0.053358443	0.03 (BOD_7)
COD	34200	4442	0.129883041	0.20
N	2910	1230	0.422680412	
P	501	48	0.095808383	0.06
Zn	11	2.14	0.194545455	
Cu	7880	1218	0.154568528	
Ni	1120	693	0.61875	0.75
Pb	621	209	0.336553945	
Cr	1220	415	0.340163934	
Cd	28	10.3	0.367857143	
Hg	20	15	0.75	
AOX	8400	5200	0.619047619	
Polar org. components	1370	78	0.056934307	
Unpolar org. components	124	20	0.161290323	

The purification efficiency to sludge was:
For Pb and Hg, the total purification efficiency exceeded 1, which may indicate an error.

Substance	In	Out in sludge	Share in sludge
N	2910000	506000	0.173883162
P	621000	435000	0.700483092
Zn	11000	10000	0.909090909
Cu	7880	6850	0.86928934
Ni	1120	250	0.223214286
Pb	621	600	0.966183575
Cr	1220	440	0.360655738
Cd	28	19	0.678571429
Hg	20	13	0.65

Appendix 4

Substances with impact factors for the combined characterization and weighting step

EPS 2000d

Resources from ground:
arable land use, bauxite, biomass, chromium in ore, copper in ore, crude oil, hard coal, iron in ore, iron ore, irrigation water, lead in ore, lignite, natural gas, nickel in ore, softwood, uranium in ore, wood, zinc in ore
Emissions to air:
Acetylene, As, benzene, butane, CO, CO_2, Cd, Cr, Cr^{3+}, Cu, ethane, ethene, formaldehyde, H_2S, HCl, HF, Hg, methane, N_2O, NH_3, NMVOC, NO_x, Ni, PAH, particles (PM_{10}), Pb, pentane, propane, propene, SO_2, SO_x, toluene Zn
Discharges to water:
BOD, BOD5, COD, N total (the amounts of NH_4 as N, $NH_{3,}$ NO_3^- were very small and therefore not converted to N total, but for wool/PA, $NH4^+$ and NO_3^- was converted to N total because of higher amounts, but the total ELU value did not change), nitrogen, P total, phosphate

EDIP

Resources from ground:
Copper in ore, crude oil, hard coal, iron in ore, lead in ore, natural gas, nickel in ore, zinc in ore
Emissions to air:
Acetylene, aldehydes, alkanes, alkenes, aromates (C9-C10), As, benzene, CO, CO_2, Cd, Co, Cr, Cr^{3+}, Cu, dioxin, ethane, ethene, formaldehyde, H_2S, HCl, HF, Hg, hydrocarbons, methane, Mn, Mo, N_2O, NH_3, NMVOC, NO_x, Ni, Pb, pentane, propane, propene, SO_2, SO_x, Sb, Se, Sr, Tl, Toluene, V, VOC, Zn
Discharges to water:
Acid as H+, As, CN^-, Cd, Co, Cr, Cr^{3+}, Cu, F^-, Fe, H_2S, Mn, N total, NH_3, NH^{4+}, NH^{4+} as N, NO^{3-}, NO^{3-} as N, Ni, P total, $PO4^{3-}$, Pb, phenol, phosphate, Sb, Sr, V, Zn

Ecoindicator 99

Resources from ground:
Bauxite, chromium, copper in ore, crude oil, hard coal, iron in ore, iron ore, lead in ore, natural gas, nickel in ore, zinc in ore
Emissions to air:
Acetylene, aldehydes, alkanes, alkenes, As, benzene, butane, CO_2, Cd, Cr, Cu, ethane, ethene, formaldehyde, Hg, metals, methane, $NH_{3,}$ N_2O, NMVOC, NO_x, Ni, PAH, Pb, pentane, propane, propene, SO_2, SO_x, toluene, VOC, Zn
Discharges to water:
As, Cd, Cr, Cu, Ni, Pb, Zn
Discharges to soil:
Cd, Cu, Hg, Ni, Pb

Appendix 5

Substances in energy production and combustion reported for selected activities

Diesel production

Resource:
Crude oil, hard coal, lignite, natural gas, uranium in ore, wood
Emissions to air:
As, Cd, CN^-, CO, CO_2, Cr, Dioxin, H_2S, HCl, HF, Hg, Methane, N_2O, NH_3, Ni, NMVOC, NO_x, particles, Pb, Radioactive, SO_2
Discharges to water:
Al, As, BOD5, Cd, Cl^-, Co, COD, Cr, Cu, F^-, H_2S, N total, Ni, oil, other organics, Pb, $PO4^{3-}$, Radioactive, Sb, Sn, SO_4^{2-}, V, Zn
Non-elementary waste:
Hazardous, highly radioactive, industrial

Diesel combustion, in trucks, freighters and forestry machines

Emissions to air:
CO, CO_2, NMVOC, NO_x, particles (not for forestry machines) and SO_2

Light fuel oil combustion

Emissions to air:
Acetylene, alkanes, alkenes, aromates (C9-C10), benzene, CO, CO_2, Cu, ethane, ethane, formaldehyde, HF, Hg, methane, NO_x, PAH, particles, propane, propene, SO_2, toluene, Zn, total organic carbon, light fuel oil

Electricity production, European average

Resources:
biomass, chalk, clay, crude oil, ground water, hard coal, hydro power, lignite, natural gas, sodium chloride, softwood, surface water, unspecified fuel, uranium in ore
Non-elementary (input):
Aluminium, iron, manganese
Emissions to air:
Aldehydes, aromates (C9-C10), As, B, benzene, benzo(a)pyrene, Cd, CN^-, Co, CO, CO_2, Cr, Cr^{3+}, Cu, dioxin, H_2S, HCl, heavy metals, Hf, Hg, metals, methane, Mg, Mn, Mo, N_2O, NH_3, Ni, NMVOC, NO_x, other organics, PAH, particles, Pb, radioactive, Sb, Se, Sn, SO_2, Sr, Th, Tl, U, V, Zn
Discharges to water:
Acid as H^+, Al, aromates (C9-C10), As, BOD, Cd, Cl^-, COD, Cr^{3+}, dissolved organic carbon, dissolved solids, F^-, Fe, hydrocarbons, metals, Mn, N total, $NH4^+$ as N, Ni, Nitrogen, NO_3^- as N, oil, other organics, P total, Pb, phenol, $PO4^{3-}$, radioactive, SO_4^{2-}, sodium chloride, Sr, suspended solids, Zn
Non-elementary waste: Bulky, chemicals, hazardous, industrial, mineral, radioactive, rubber, slags&ashes, sludge