Life Cycle Assessment (LCA) applied in the Textile Sector: the Usefulness, Limitations and Methodological Problems – A Literature Review

LISBETH DAHLLÖF

Environmental Systems Analysis
Chalmers Tekniska Högskola
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©Lisbeth Dahllöf
COMESA
Environmental Systems Analysis
Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telephone: +46 (0) 31 772 1000
Fax: +46 (0) 31 772 2172
E-mail: Lisbeth.Dahllof@esa.chalmers.se

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Abstract

Life Cycle Assessment (LCA) is a tool for assessing a product, process or service regarding its environmental impact during its entire life cycle from the "cradle-to-grave". In this report the LCA tool is described with focus on the textile sector. Some LCA studies on textiles are listed as well as useful inventories. The use of LCA for environmental labeling and certified environmental product declarations is described as well as method problems found in the literature regarding LCA in the textile sector. Specific environmental impacts that are not yet fully considered in the LCA tool are mentioned as well as some ideas how to include them. Important problems for the textile sector is assessing of land use and fate of chemicals as well as working health problems. Although the report points out problems with the LCA tool for assessment of the environmental impact, it is concluded that LCA is strong in that sense that it grasps the entire life cycle or value chain. Therefore the potential for identifying the most efficient measures in a product's life cycle in order to reduce the environmental impact is high.

Preface

This work was done as the first step in my doctoral studies. The overall purpose of the studies is to give solution suggestions to some of the methodological problems within the LCA method use in the textile sector.

The doctoral studies are performed at the Environmental Systems Analysis Department at Chalmers University of Technology in Gothenburg, Sweden and is mainly financed 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 financing and adj. Prof Bengt Steen for supervising me.

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1 Introduction

This is a report mainly concerning method problems within the Life Cycle Assessment (LCA) methodology found in the literature. Another way of finding method problems, to perform a case study, was also done and reported in Dahllöf, 2003. There the method problems were more thoroughly investigated.

The increase in society's awareness of environmental problems has sped up the development of assessment methods. Life Cycle Assessment (LCA) is an important method and is described in this report with focus on the textile sector.

LCA is a tool for assessing the environmental impact of a product, process or service during its entire life cycle from the "cradle-to-grave". It may be used, for example, for product development and improvement, strategic planning, public policymaking and marketing. The LCA tool is e.g. used for finding the hot spots in the life cycle in order to be able to make the best decisions on minimizing the environmental burdens of the product, process or service. It is also used for comparisons between for instance different products regarding environmental impact. The main development of this method has taken place in the 1990s (Kalliala, 1997) and it has been standardized in ISO standards no. 14040 to 14043. Although it has been standardized, methodological problems still remain some of which will be discussed in this report with focus on textiles.

2 General principles for an LCA study

According to ISO 14040 an LCA study contains the steps shown in figure 1.

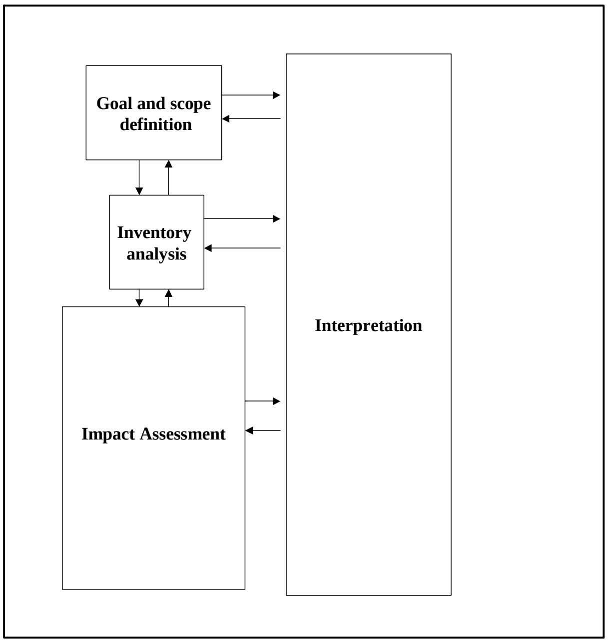

Figure 1. Phases of an LCA

All steps must be transparent in order give the study and its report credibility. The reader should be able to follow the steps. The content of an LCA study is dependent on the application(s) such as strategic planning or marketing.

The **goal** states the intended application, the reason for carrying out the study and the target audience. The **scope** describes the breadth, the depth and the detail of the study. It is important to define a functional unit and the system boundaries. The data quality requirements should be carefully specified.

Inventory analysis (ISO 14041) aims at determining flows of material and energy between the technical product system and the environment. Data for input and output flows are collected for each unit operation and aggregated for the whole life cycle. Input flows could be resources such as raw materials, energy or land and output flows could be emissions to air, water or land.

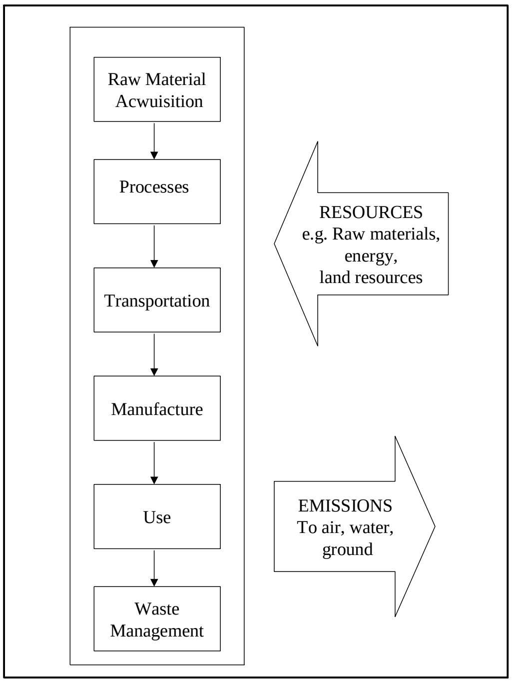

Figure 2. The life cycle model (Baumann and Tillman, 2004)

Impact assessment *(Life Cycle Impact Assessment, LCIA)*, (ISO 14042) aims at evaluating the significance of potential environmental impact based on the result of the life cycle inventory analysis. Impact assessment includes:

Definition of impact categories and category indicators: Common impact categories (and indicators) are:

- Stratospheric ozone depletion (CFC-11 equivalents)
- Climate change (CO_2 equivalents)
- Photo-oxidant Creation Potential (Ethylene equivalents)
- Acidification (SO_2 equivalents)
- Eutrophication of waters (PO_4 equivalents) (Nord, 1995)

Classification, assignment of Life Cycle Inventory (LCI) results to the impact categories

Characterization, calculation of the size of the impact indicators. This is done by using characterization factors for the substances. As one example, in the case of acidification, HCl has the characterization factor 0.88 because 1 kg releases 88% of the protons from 1 kg of SO_2.

After characterization comes an optional step called *weighting* (ready-made LCIAs) (ISO 14042). It is used when there is a need to compare the relative importance of various impact categories. If the environmental burdens are summarized, a single value is obtained that can be used for comparing different products, processes or services.

The **interpretation** (ISO 14043) step means that conclusions are drawn and that recommendations can be given.

The entire process is usually iterative as shown by the arrows in figure 2.

Sometimes you want to compare a new process in a life cycle chain with the old one. It is possible to make such a comparative LCA. A part of the life cycle is calculated and compared with the corresponding part of another. It is important that the other stages of the life cycles are identical.

Some practitioners consider an inventory assessment of a part of a life cycle as an LCA. An example is the study by Tobler (2002), where the life cycle of cotton growing is studied. The cotton growing is considered to be the product system for which the life cycle is studied.

3 LCAs and useful inventories found in the literature

Table 1 lists some LCAs performed in the textile sector. There have been many other LCA studies done in the industry but they are usually only for internal use.

Title, country	**Purpose (and method)**	**Main conclusions**
Resource and Environmental Profile Analysis of a Man-Made Apparel Product: Woman's Knit Polyester Blouse; Franklin Associates Ltd, USA, (Franklin, 1993)	To assess the energy requirements and environmental emissions and solid waste for the life cycle of a polyester blouse	The consumer use corresponds to 86% of the life cycle energy needs. Cold wash with line drying reduces laundering energy by more than 90%. Air emissions and solid waste are also very dominant in the consumer phase.
The ecology of hotel textiles and textile services – an LCA study on best available applications and technologies (Kalliala, 1997)	To find the present best ecological solutions for hotel textiles and services, to develop an ecological index for products and processes with "Best Available Technology".	The use of polyester-cotton sheets has less environmental consequences than the use of 100% cotton sheets.
Comparative LCA of Three Textile Dyestuffs, Switzerland (Weidenhaupt et al, 1996)	Comparison between three red cotton reactive-dyestuffs. ECOSYS, a software from Ciba-Geigy, was used.	The fixation rates (low for the dyestuffs studied) is the most important factor, the dyeing process is the most emissive.
Textile Products, Impact assessment and Criteria for Eco-labelling (draft) (Astrup Jensen et al,1994)	Impact assessment of cotton and polyester for T-shirts and bedlinen. Based on the LCI report: Life cycle inventory for textile products: Bed linen and T-shirts by Ian Holme & John Hansen (not official)	EU label criteria for T-shirts and bed linen were proposed.
The life cycle of cotton rolls for hand drying, Denmark, (Schmidt, 1999)	Simplified LCA on cotton-based towel rolls used for 10 000 handdryings	The laundering process is the most important process related to environmental burdens.
Ökobilanz eines Baumwoll-T-Shirts mit Schwerpunkt auf den verwendeten Chemikalien, Zwitzerland, (Pulli, 1997)	Comparison between the production of textiles (not fibers) and the use phase. To develop a method to study how persistent chemicals are degraded.	The use phase creates by far the highest environmental burdens. The energy used has the highest environmental impact. The method for fate developed gave e.g. the conclusion that dyes are very persistent.
Produktlinienanalyse Waschen und Waschmittel, Umweltbundesamt, (Grieshammer, 1997)	Compartative product system assessment (LCA plus social, health, safety and economical aspects) of washing agents to optimize the use	The three component system (washing agent, softener and bleaching agent separated) is the best. There is much to save in both environmental impacts and money if a household becomes conscientious.
De milieugerichte levenscyclusanalyse van vier typen vloerbedekking, the Netherlands (Potting, 1993)	LCA comparison between a wool broadloom carpet and one made of polyamide	For most impact categories wool has the lowest impact (except eutrophication and non chemical waste).
Livscyklusvurdering of produktorienteret miljöledelse hos Gabriel A/S (von Benzon, 2000)	LCA comparison between three different padding textiles: Wool, Wool/nylon, polyester	Due to lack of data, this study cannot be used for rules for EPD´s. Only characterization, no weighting. Prod. of chemicals included. The inventory data was not reported.

Table 1: Examples of LCAs performed in the textile sector

In table 2 some inventory reports useful for the performing of LCA studies in the textile field are found

Report	Description
Environmental Assessment of Textiles (Ellebäk Laursen et al, 1997)	Describes the life cycles regarding environmental issues for cotton, wool, viscose and acrylic textiles
Establishment of ecological criteria for textile products (DWI, 1998)	Describes the life cycles regarding environmental issues for flax/linen, wool, silk, viscose, lyocell, acetate, triacetate polyamide, acrylic, modacrylic, elastomeric and polypropylene fabrics
Ecoprofiles of selected Man-made fibres (Boustead, 1997)	European average LCI data for polyacrylic, polyester, polyamide 66 and viscose fibers
Reference Document on Best Available Techniques for the Textiles Industry (European Commission, 2002)	This document has much information regarding water emissions from each production step and also information regarding residue amounts of chemicals after a sewage plant.

Table 2. Reports useful for the performing of LCA studies in the textile field

4 Applications of LCA for environmental labeling and certified environmental product declarations

There are three types of labeling identified in the ISO standards (14020, 14021, 14024 and 14025). Type I (ISO 14024) is based on indicators developed from the life cycle of the product, process or service. Type II (ISO 14021) is based on the company's of organization's own declarations, not necessarily based on the life cycle. Type III (ISO/TR 14025) is quantified life cycle based environmental information. ISO 14020 regards the general principles for the environmental labels and declarations.

In Europe the following eco-labels based on LCA studies (type I) are used in the textile sector: the EU eco-label, the Nordic Swan and the GuT scheme (for carpets). LCA studies provide the criteria to be fulfilled for eco-labeling for each specific product group (Burdett, 1997).

Certified environmental product declarations (EPDs, type III environmental declarations) are produced by using the LCA tool (Swedish Environmental Management Council, 2000). The aim of EPDs is to describe the environmental properties of a product or a service in an objective, comparable and credible way. They can be used by purchasers within industry or administration and also by private consumers. Palm (1998) argues that complex EPD information is only interesting for consumers when capital goods are purchased because only then they are willing to spend time on reading extensive product information.

In contrast to the labels described above there are no limits set regarding different environmental impacts in EPDs (Swedish Environmental Management Council, 2000). They do not include any systematic evaluation of the environmental properties of the product; this is the purchaser's task. Because there is no attempt at evaluation, EPDs are not regarded as trade hindrance (Ryding, 1999). On the other hand, they *could become* trade hindrances, since not all companies can be expected to afford to get this type of label. Also if the product were made in countries where energy production is made by fossil fuels, this would have negative impact on the EPD. These factors could possibly create an indirect trade hindrance if the EPDs are considered important for the purchasers. The establishment of a national system of this type of declaration is based on existing ways of working for implementing environmental management systems (e.g. ISO 14001 and EMAS). The declaration is open to the public, in Sweden via the internet (www.miljostyrning.se). There were no EPDs for textiles found when searching for all countries on the internet site in February 2003.

It is important to decide on strict rules regarding data quality, allocations (explanation, see chapter 5.2) and system boundaries for each specific product or process in order to achieve comparability between different fabrics (Swedish Environmental Management Council, 2000). The method of doing EPDs is harmonized through ISO/TR 14025.

5 Method problems and pitfalls regarding the LCA tool with examples from the textile sector

5.1 Data quality and system boundaries

LCA studies contain a lot of data, but almost always some data are lacking and must be estimated. Data could be out of date, or possibly the way in which the data has been measured is unknown. Site-specific data could be needed, but often only average data from different sites is available. All these situations affect the credibility and must be clearly reported. To increase credibility, sensitivity and uncertainty analyses are recommended (ISO 14041). An example from the textile sector where site-specific data often is missing is for cotton cultivation. Often it is unknown where the cotton has been grown because retailers prefer to mix cotton to get an even quality (Åsnes, 1997). It is then hard to estimate the environmental impact. Water consumption for cotton cultivation varies for instance between 7,000 and 29,000 l/kg. The use of pesticides and fertilizers also differ much between locations (Ellebäk Laursen et al, 1997).

Because LCA studies usually are extensive they are often time consuming, so it is difficult for small companies to perform LCAs. They may choose to make simplified LCAs where data from other reports are used. Simplified LCAs do fit into the ISO standards, but it could be tempting to exclude side processes or products such as help chemicals without really knowing the extent of environmental burden they cause, with misleading results. Simplified LCAs require experienced practitioners conducting the studies, and dominance and sensitivity analyses are important to maintain reliability.

One attempt to estimate missing data is made in the “Miet” program (Suh, 2001). It uses extended Input-Output Analysis (IOA). It is based on matrixes showing how industries are interlinked through supply and other commodities.

5.2 Allocation

According to ISO 14040 allocation means “partitioning the input and output flows of a unit process to the product system under study”. Allocation is a complicated but important matter because the results of the study rely to a large extent on the allocation method choices. In figure 3 the two types of processes are shown where allocation must be considered, multi-input and multi-output.

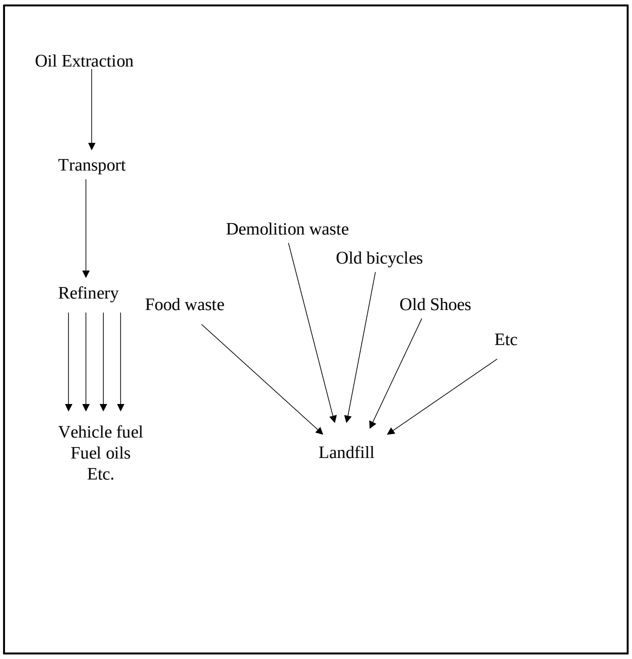

Figure 3. Schematic illustration of a multi-input (refinery) and a multi-output process (landfill)

ISO 14041 states some rules for the allocation:

- Whenever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes. The product system should also be expanded to include the additional functions related to the co-products.

- Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are altered by quantitative changes in the products or functions delivered by the system. The resulting allocation will not necessarily be in proportion to any simple measurement such as the mass or molar flows of co-products.

- Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

On this issue, the standard is questioned by researchers. Ekvall points more at the aim of the LCA study and suggests the following procedure (Ekvall, 1999)

- Use the most easily applicable allocation method when the choice of allocation approach is expected unimportant for any decision that is based on, or inspired by, the LCA results.

- When the allocation can be important for a decision but the effects on exported functions are not expected to be significant, avoid allocation through subdivision, allocate based on the physical, causal relationships between the functions and environmental burdens, or use an adequate approximation thereof.

- When the effects on the exported functions can be important for a decision, use system expansion or an adequate approximation thereof.

Allocation must be done often. One example is the cultivation of cotton. To get 1 kg of cotton fibers 2.4 kg of harvested seed cotton is required (Kalliala, 1997). In one study (Schmidt, 1999) allocation of cotton and side products such as cottonseed was based on economic values, but in another (Kalliala, 1997) a “worst-case scenario” was used which means that the entire environmental burden was assigned to the cotton fiber. The purpose behind the first method of allocation is to be able to interpret the causalities. The question is why the cotton is cultivated: Is it only for the cotton fibers or is it also to obtain the side products? The idea behind the second method could also have been interpreting causalities, but it could also be lack of data that was the reason for choosing a “worst-case scenario”. The standard states: “whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach”.

Another allocation problem is faced when viscose is produced. A co-product, sodium sulfate, can be used in the production of sulfate pulp (Boustead, 1997).

Wool production also gives rise to an allocation problem: For almost all countries producing wool, it is a secondary product of sheep meat production, but in Australia, the largest wool producing country in the world, wool is the primary product (Ellebäk Laursen, et al, 1997). It is therefore not evident how to allocate, and it is necessary to allocate differently for different cases.

Recycling also creates allocation problems. There are two types of recycling: **open loop** and **closed loop**. Open loop recycling means that the product leaves the technical system under study and closed loop recycling means that the recycling occurs within the technical system.

If, for instance, PET bottles become raw material for sweatshirts (Drury, 1995) and the sweatshirts are not within the technical system under study, this is considered **open loop** recycling. As mentioned in the ISO 14041 standard, the system can be expanded to take the sweatshirts into account. The system then becomes closed loop recycling. This particular instance of closed loop recycling is in the form of a **cascade**. This type of recycling can still give rise to problems in how to allocate. The easiest way of counting is the cut-off method: Only impacts directly caused by a product are assigned to that product (Baumann and Tillman, 2004). Another method is to relate the impacts to the relative loss of quality of the products. It is also important to consider that if the PET bottles had been thrown away, they might have been incinerated as replacements for heating oil or other heat sources. One must thus consider expanding the system to include the heat-source replacement.

Closed loop recycling where the waste can replace virgin material does not need allocation. In e.g. the case of reusing of PET bottles, the washing required for the dirty bottles is accounted for in the use phase. This type of recycling is usually called "reuse".

5.3 Drawing general conclusions

It can be dangerous to draw general conclusions from an LCA study. In a U.S. study regarding a polyester blouse, it was clearly seen that the use phase has the largest environmental impact due to laundering (Franklin, 1993). When laundry data from the U.S. and from Sweden was compared, the conclusion of the U.S.-only study was not as evident because Swedish washing machines do not use as much energy and water as those in the U.S. (Svensson S., 1994).

5.4 Weighting

Often an LCA study is used to compare different materials for one specific use such as milk bottles compared to milk cartons or disposable diapers compared to washable ones. Because the materials compared differ very much from each other, it is usually difficult to give a clear answer as to which one is the most favorable from an environmental perspective. Even if the products compared are so similar as to have the same impact categories, it is hard to know whether, e.g., eutrophication is more severe than the acidification. Also, the selection of impact categories is to some extent subjective. The commissioner of the study must be aware of these limitations before the study starts so that the right expectations can be in place.

As mentioned above, some weighting methods are used to compare different impact categories. These methods, such as Ecoindicator 99 (Goedkoop, 1999) and EPS 2000 (Steen, 1999), are inevitably based on value choices. Ecoindicator 99 models damages on ecosystems, human health and finite resources. The weighting is derived from a panel consisting of LCA experts and LCA users with different cultural perspectives. When applying this method one or more perspectives are chosen. In the default EPS 2000 weighting method, five safeguard subjects similar to issues from the UN's Rio declaration (human health, biological diversity, biological production, resources and aesthetic values) are defined. Several impact category indicators are defined for each safeguard subject. For instance, "depletion of ore resources containing 1 kg of a metal" is an impact category indicator of the safeguard subject "resources". The weighting factor for the corresponding category indicator is calculated as the willingness-to-pay by the affected people to avoid the change as measured by the OECD-inhabitant.

Because weighting methods are based on value choices it is recommended to compare different methods in the LCA study in order to get a more complete picture (Nord, 1995).

5.5 *Functional unit*

According to ISO 14041 "one of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore the functional unit shall be clearly defined and measurable". It shall be consistent with the goal and scope of the study. It could be 5 years of jeans use for one person. In this case, washability and durability will automatically be considered. The functional unit is sometimes difficult to define, as when fashion is an important factor. In the industrialized world, clothes are not used right up to the point that they are worn out. The reasons could be both fashion and the feeling. If you want to compare a cotton shirt with a shirt made of polyester, not only the quality but also the feeling could be an important factor in how long the shirt will be used. This type of "soft" considerations is better done outside the LCA study. Decision makers are aware of that the LCA is only a part of the environmental assessment. In some cases, a more general functional unit could be used such as "wearing clean clothes per person during a year" which is done in the SusHouse project (Bras-Klapwijk, 2001).

It is presently questioned if a stringent functional unit always is really needed. The environmental impact could be separated from questions related to other aspects such as comfort.

6 Specific environmental impacts from the textile sector only partly considered in LCA practice.

Several environmental impacts are usually not considered in LCA studies of textiles, so it is unknown how serious they are compared to other impacts. Many of them are serious on a local scale but possibly are unimportant globally. Noise and dust in the working environment are such impacts. This in combination with the different origins makes it difficult to compare e.g. polyester and cotton fabrics objectively regarding environmental impact. Some researchers explicitly state that products cannot be compared in an adequate way (e.g. Werner, 2002). Still, studies made to compare these textile types show the need for weighting suited to the textile sector (Kalliala, 1997, Svensson E., 1995, Svensson E., 1997).

Below four impact types that are only partially considered are discussed:

1. The irrigation of cotton field is a great problem in parts of the world. Cotton growing is the main reason why the volume of water in the Aral Sea has been reduced by 60% over the past 40 years (Rainey, 1994). In the U.S. Southwest, cotton is cultivated using groundwater, which is being consumed at a faster rate than it is being renewed (Tobler, 2002) In connection with irrigation, the problem with salinization of the soil is large. In Pakistan and Egypt about 40% of the irrigated areas suffer from this problem (Kalliala, 1997). Feitz (2002) has done development of the characterization method for soil salinization.

2. The use of pesticides and other chemicals in the cotton cultivation causes environmental impacts. About 20,000 people die every year due to pesticide application (Ellebäk Laursen et al (1997)), the reference refers to the World Health Organization. About 50% of all pesticides used in the Third World are used for cotton cultivation (Ellebäk Laursen et al (1997), Rainey, 1994). ICAC (1995) gives a much more positive picture: during 1994/95 only 248 cases of intoxication were reported but only two countries had reported any cases. Characterization of potential human toxicity of chemicals emitted to water or air is e.g. made by Hertwich et al (2001). In EPS 2000 (Steen 1999) the pesticides considered having the highest potential human toxicity are given characterization and impact factors

3. Sheep are often treated with pesticides to avoid parasites (Ellebäk Laursen et al (1997)). Most of the pesticides are lost as liquid waste directly after dipping because the sheep are often dipped shortly after shearing. Some is still in the wool (European Commission, 2002)

4. Persistent chemicals from wet treatment such as phosphonates (stabilizers) and dyes are emitted to watercourses (Pulli, 1997). Phosphonates are also used as flame retardants and their environmental impacts depend on the chemical composition (Kemikalieinspektionen, 1997). Beck (2000) has done interesting fate modelling with the USES-LCA model in order to characterize the fate of chemicals in water. The comparison with reality is difficult and the question still remains of what is worst: high persistence with low toxicity or high toxicity with low persistence.

It should be possible to incorporate all four of these impacts in existing or new characterization and weighting methods. One of the problems could be to get time to collect site specific data if necessary. Other impacts are more difficult to account for:

- Fertilizer leakage is often hard to quantify because it is usually difficult to get information regarding the specific case (Schmidt, 1999). Brentrup et al (2000) have proposed a method to calculate the nitrogen emission.

- Land use is a complicated item within the research area of LCA. It is important within LCA methodology because it is highly related to food production. Land use is considered in impact assessment but not in a satisfactory way. Lindeijer (2000) has made a review of different proposals for handling the characterization of land use.

- Human health problems can be caused by cotton dust in connection with ginning (Astrup Jensen, 1994), blending, carding, spinning and weaving (Ellebäk Laursen, 1997). The indicators for human health problems are still under development within LCA research.

7 Limitations of the LCA tool

It is important to realize that LCA is a tool among other tools to evaluate environmental impacts. Other tools include Environmental Impact Assessment (EIA) and Sustainable Development Records (SDR) (Tillman et al, 1997).

LCA is sometimes used in a broader context where the need for a certain product, process or service is questioned. The LCA tool itself does not contain such considerations. As described in ISO 14040, LCA studies do not take social aspects into consideration. They do also not take into account the risk/opportunity that, if a product becomes produced more efficiently and environmentally friendly, consumer demand may as a consequence increase, causing more environmental impact (and benefit).

When reading an LCA report, it is important to know that LCA studies usually describe global or regional effects and not local ones, although they may assess these. Solvent emission from a plant may be insignificant on a global scale but still cause problems to man and nature in the immediate surroundings. Research is being done on describing the local effects and fitting them into the LCA framework (Baumann and Tillman 2004).

8 Summary and conclusions

The Life Cycle Assessment (LCA) method is still under development although its framework has been standardized. It is used for decisionmaking regarding environmental impact but it is not the only tool available. LCA is used in the growing field of Certified Environmental Product Declarations.

With present knowledge it is hard to make complete comparisons between different materials in textile fabrics because the impact assessment is incomplete and it is unknown how important the missing impact categories are compared to the known ones.

In this report problems with LCA are discussed, and one reason is to show that one should read LCA reports with a critical mind. Some of the method problems can be solved. In spite of all its problems, LCA is a powerful tool. Grasping the entire life cycle makes LCA strong because it increases the chance of taking the most efficient measures to reduce a product’s environmental impact.

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