TEXTILE SPECIFICATIONS, ENVIRONMENTAL IMPACTS AND COSTS OF TEXTILE PROCESSING IN EUROPE

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Abstract

European companies and consumers do not only care for quality and costs of products but also for environmental impacts associated with textile processing. Although quality of the individual process technology is well known, communication based on technical specifications along the value added chain is poor. A system of Textile Specifications including product quality would provide a database for the required information in product development. On the other hand the method of Life Cycle Assessment (LCA) has recently been developed for calculation of environmental impacts. LCA bases on inventory data (LCI) including all inputs and outputs in a products lifecycle. This paper investigates if a common database for communication (TS) and LCA including costs can be generated. TS were elaborated as indicators by a group of researcher in textile technology, including production of raw material (cotton, polyester, polyamide and viscose), yarn production, fabric production, finishing and manufacturing. The proposals for LCA modeling are based on modern process technology, comparable values for consumer's use and feasible costs in production. This inventory was elaborated by means of computer software, easy case, allowing connecting all flows of material, energy and information. The selected products are Jeans and T-Shirt (ladies outerwear) made of cotton and synthetic fibers. Modeling includes transportation, spinning, weaving and finishing of Swiss fabrics. Since energy use was supposed to be of great importance, different process technologies in cotton production, spinning and weaving were elaborated and their cost as well environmental impacts were compared.

The study shows, that textile specifications can be used as a common base for communication as well as for calculation of process costs and environmental impacts (LCA), indicating also the relation between the two of them. However, the inventory for LCA of products may require more detailed information if it is based on processes of individual machinery.

LCA Results show that transportation as well as the energy prime source cause a major impact, followed by process technology and tissue construction: The production of a tissue with high warp density causes only two third of the impacts of a tissue with high filling density. The impacts can be lowered, if OE spinning technology is used. Knitting technology causes a very low impact, whereby the lower fabric weight has to be taken into account.

Costs are mainly influenced by the degree of automation achieved in the company. Generally a reduction in cost also means a reduction of environmental impacts. The opening of the European energy market might result in lower costs, but higher environmental impacts.

Introduction

The value-added chain of apparel, representing the Life Cycle from cradle to grave, includes a great number of businesses with different process technology. For each product specific properties are defined, according to the requirements of the market. Such properties have to be verified by selecting appropriate raw material according their inherent parameters and adapted textile processing. Mainly natural fibers like cotton show a large variety in parameters, which are expressed in later processing. An overview on these relations for cotton is given in fig. 1. On the other hand textile processing increases fiber properties by means of yarn construction, tissue construction and mainly by finishing. Similar results can be achieved by different processing e.g. in yarn construction or finishing, but also with different costs. Research in fiber production and processing contributes to increasingly better adaptation of fiber parameters and processing for a required product quality. The following indications represent only a selection of actual research step by step: Cotton breeding is focused on improving fibers in order to get yarn parameters positively influenced (May and Taylor 1998, Hsien and Wang 2000). Simulation models (El Mogahzy et al. 1998) help to predict yarn properties and selected yarn construction contributes to improvements of yarn parameters (Koo and Suh 1999). Great efforts are undertaken in adaptation of sizing for weaving processes (Stegmayr, Trauter and da Rosa), whereby environmental impacts are reduced as far as possible. In finishing highly specialized treatments with new substances (Buschle-Diller et al. 1998) and /or process technology (Mueller 2001) are developed in order to improve quality of the fabrics. Although research and practices in quality aspects of the individual process technology is highly specialized, communication in business, based on technical terms towards clients along the value added chain, is poor. There is no allover "push" of information from fiber to finishing, since cotton breeders do not develop products. Consequently sound experiments and testing have to be carried out at each production step, in order to achieve the required quality. If "pulled" by the market, special treatment is often applied to improve quality of a yam or fabric, since earlier production steps (cotton growing, ginning and spinning) are not involved in product development. In both cases costs are considerable. In product development the" pull" by the market is the driving force. Products, that are considered to meet consumer's preferences, are specified in all properties. Hereby activities and styles of consumers are addressed. According to a desired quality of the product, fibers, which provide the required properties, have to be selected and processing defined, also in reference to the set price level (see fig. 2). A system including all relevant process and quality parameters (Textile Specifications = TS) from fiber production to apparel would determinate the value added chain of individual products. It could be used for communication along the value added chain as well as for information of consumers. It would also allow optimizing of quality and costs.

European companies, consumers and especially governments care for environmental impacts associated with textile processing. Attempts are made to favor "Best Available Technology" (BAT) in textile processing. So far, in European Community research mainly indicators are used as arguments for sound environmental technology (Schaefer 2001). In the last decade methods for Life Cycle Assessment (LCA) have been developed for calculation of environmental impacts (Heijungs 1992 and SETAC 1996). The results provide the first quantitative and independent information for impacts, based on scientific knowledge. In order to facilitate calculation, several computer tools have been developed, including a database for average impacts of different substances and processing. However, companies are not satisfied with LCA data based on average production, as given in such database. Based on Life Cycle Inventories (LCIs) of individual products the associated environmental impacts (LCA) can be calculated. Many companies, performing LCAs, use their own data for product development and/or for ISO 14 001 where "significance of environmental impacts" is required.

LCIs seem to provide a similar if not common system to Textile specifications (TS). In this paper both systems "Textile Specifications" and "LCI" are modeled for selected products in order to verify if they have a common base. Such finding would harmonize quality aspects as well as LCA systems for comparison of products.

Material and System

Products

For this study we selected two of products, whereby not the entire value added chain was considered (see fig.3). This decision was taken in order to present coherent data for Textile Specifications (TS), environmental impacts (LCA) and costs. The selected products are Jeans and T-Shirt (ladies outerwear) most of them made of cotton and an alternative made of synthetic fibers. This decision is also based on the European market where cotton is the most important raw material, followed by man made fibers. For classical application of the selected apparel cotton is by far the most important fiber. Criteria for this choice are the natural fiber, a nice hand, and comfort in wear as well as properties for washing. Although the trend towards elastic apparel is growing, pure cotton products were selected. Regarding consumer's preferences, a tendency for specific fashion apparels like shirts made of synthetic fibers can be observed, particularly with young people. This trend might be based on the influence of sports wear. Besides fashion, properties like fast drying, wrinkleless and non-ironing are considered to be criteria for this market (see fig. 2). The chosen fabrics are: T-shirts (cotton and PA) of 150 g / m^2 and Jeans (ring spun and OE-spun) of 231 g / m^2. The scope of comparing two T-shirt types (cotton or PA) is not based on equal quality (regarding chemical and physical properties) but simply on the consumer's choice on fashion.

Textile Specifications (TS)

Textile specifications (TS) should include all relevant information about processing, quality and byproducts /emissions along the value added chain. Processing and quality are strongly related because quality is achieved as an addition of natural fiber quality and integrated textile processing. The list of Textile Specifications (TS) is divided in two parts for each process step, indicating product parameters and process parameters. TS include information that is suited for communication with the end user (E) and the client (C) in the value added chain. All other parameters are used for process control. TS have been elaborated in a first step by researchers of different institutes[1] and will later be confirmed by experts from textile industry. A section of these specifications is presented in this paper. The system developed so far refers to apparel made of cotton, polyester, polyamide and viscose. It includes production of raw material, yarn production, fabric production, finishing and manufacturing, based on modern process technology, comparable values for consumer's use.

Calculation of Costs

The LCI data was also used for calculation of costs. The system for cost includes all processing by machinery and infrastructure (air conditioning and illumination), but no wages. Each company has its own cost structure, dependent on quality requirements, the installed equipment, the degree of automation, productivity and order structure. Moreover, national economy and prices for energy determine costs. In this case the base for cost are prices for electricity, gas and oil in Switzerland.

LCA Method

The Classical LCA method, as described by Heijungs (1992), SETAC (1996), Goedkoep (1995) and ISO 14040 ff, was applied. The methods applied are CML 92 and Eco Indicator 95 and the calculations were elaborated by means of the computer software SimaPro. A so-called functional unit indicates to what all impacts are referred to. Both methods include the three steps classification & characterization, normalization and evaluation.

In the classification step, all substances are sorted into classes according to the impact type they have on the environment, for example to the greenhouse effect or to ozone layer depletion. For each impact category a lead substance has been selected and all other contributions are set in relevance to that lead substance, according to the proved effect. The magnitude is dealt with by applying weighting factors. This step is referred to as the characterization step. The calculated effect scores can be displayed as a graph, giving the highest calculated effect score 100%. Thus, in classification the effects of materials can be compared within the impact category but not against other impact categories. These scores are not shown here.

In the normalization step the impacts are set in relation to an average effect. The CML 92 method normalizes with effects caused by the average European during a year. Normalization enables you to see the relative contribution from the material production to each already existing effect.

In the CML evaluation phase the normalized effect scores are multiplied by a weighting factor representing the relative importance of the effect. Eco Indicator 95 aggregates all impacts, indicating the sum of all impacts categories.

Life Cycle Inventory (LCI) is elaborated by means of computer software, easy case (see fig. 4). The software includes a rule check that requires a definition and linking of all material, energy and data flows. Therefore the system can be considered as complete, since it includes all inputs and outputs. Sub-processes can be defined on all desired levels.

Based on the LCI data environmental impacts were calculated. However, specific knowledge on behavior of substances, applied in process or a formula, is required. The magnitude of substance flows into the product to air, water or solid waste has to be measured or modeled. Only after these clarifications processes can be designed by means of software “easy case”. All inventory parameters are measured or calculated based on formulas or information of machinery manufacturers. In this study all inventory data of processes was measured on the site. Nylon production was calculated (Kaspar and Kaspar 2000), whereas transportation data was taken from the computer software (source ETH and BUWAL). The system (fig. 3) includes energy of the individual transportation of the raw material as well as process technology (spinning, knitting, weaving) for the fabric ($1m^2$) being the functional unit (see table 2). In LCA auxiliaries like wax, sizing and lubricants for machinery are not included so far.

Results

Textile Specifications (TS)

A presentation of the entire system in a printed version would require too much of space. A selected part, weaving, is shown in table 3. The goal of the presented system is standardization for product quality as well as a base for comparison with costs and environmental impacts. The division into two parts quality parameters and process parameters allows separation of product information and technical settings. However, also some process parameters like energy consumption are relevant for communication. The so-called “functional unit” refers to the calculation for prices and environmental impacts. Proposals for communications are marked in the first row, indicating the address communication: **C**ustomer or **E**nd user. Blank marks mean that the parameter is used for internal communication and process control. The entire system can be visited on our homepage (www.texma.org/). It is planned to produce computer software for individual product development and application.

Environmental Impacts (LCA)

LCA of a specified product shows where relevant environmental impacts are produced. Most results are presented in EcoIndicator 95 method, giving a number for aggregated impacts, but allowing also a tracing of the contributing impact categories. Where comparison of a greater number of processes is emphasized (e.g. in finishing) CML method is applied. Due to a lack of information (product specific inventory data), growing of cotton as well as production of the raw material for synthetic fibers is not included in the results[2]. A comparison of all processes of OE spun and ring spun jeans fabrics is shown in fig. 5. Greatest impacts are caused by overseas transportation and weaving processes, whereby the impact caused by air conditioning is considerable. Different continental transportation (truck/inland vessel or railway) cause smaller changes than different spinning technology, the later influencing also the values for air conditioning. Main impact categories for the production of all fabrics are acidification, heavy metals, followed by winter smog (see fig. 5). In fig. 6 only production of ring spun jeans fabric, OE spun jeans fabric and T-shirt fabric is compared by means of Eco Indicator 95. The low impact of the T-shirt fabric is related to the lower weight and the prime source for energy used in production. Amounts within individual categories as well as involved impact categories will change if different technology and/or different energy prime sources is used. In fig 7 the same fabrics are compared including transportations. The impacts are generally higher due to transportation, and the differences between the fabrics become a little smaller, because impacts in production are balanced by impacts in transportation.

The effect of the choice of a knitted or a woven fabric, made of cotton, or nylon knitwear is given in fig. 8. Differences between knitwear and woven fabric are greater than differences caused by processing of different raw material of the same weight. The use of different raw material (cotton and nylon) gives a slightly higher impact for nylon. Differences in quality and chemical/physical properties as well as possibly lighter weight, as requirements in product development, are neglected.

Considerable differences are also caused by applying different setting in weaving, like high weft density or high warp density of the same fabric weight, as shown in fig. 9. The results are based on production with air jet weaving technology (without transportation of raw material). Different energy sources in production and different transportation system prove a great effect. Fig 10 gives impacts of European Mix (production only), impacts of hydro power (production only) and impacts of hydro power plus transportation all through the European continent with truck. The impacts of production, using a European Mix as energy source, is as high as if the same fabric was produced by means of hydro power in production and additionally was transported by truck.

Impacts of finishing processes (CML 92 method) are shown in fig. 11, whereby the printing process causes a high impact.

Costs

Costs are most relevant for product development of apparel. The presented result only include cost of processes, whereby growing of cotton / production of nylon raw material as well as manual work (wages) are excluded. Al results base on specific production sites and may not be generally applied. Fig. 12 shows cost for different fabrics: jeans (OE spun and ring spun), a ring spun T-shirt and a nylon T-shirt. Costs for the OE technology are somewhat smaller than for ring-spun technology. On the other hand cost for knitwear made of nylon are a little higher than for a cotton product, assuming the same weight of the fabric. Differences for knitwear and woven fabrics are given in fig. 13, indicating considerable higher costs for the woven fabric.

Conclusions

Including the countless options in processing, a system of Textile Specifications (TS) of the entire value added chain represents a too large database. Therefore, only relevant parameters are listed. The benefit of the system is standardization for product development, also suited for product declaration. On the other hand the inventory for LCA, including all emissions and byproducts, is even more detailed. Both systems reveal insight in process technology that is not desired by the producers. However, the TS generated for main applications can be reduced for communication purpose and enlarged for specific applications and requirements for process control. The even more detailed LCI data is not suited for communication purpose. However, LCI can be linked with TS and thereby opens a new combination for process control and cost calculation. Many companies so far are not able to calculate costs of individual products unless they have LCI data.

Existing, new or improved testing methods could be introduced in the TS system and set as a standard. Besides HVI also AFIS and NIR (Ethridge 1998) could be applied in sound cotton fiber testing. Established methods for yarn testing are proposed for yarn purchase (Faerber and Soell 1997). Although research for testing of fabrics is going on (Meier, Uhlmann and Leuenberger 1998) no instrument has been developed so far. The best situation concerning standardized testing is achieved in finishing.

The Textile Specifications (TS) do not predict a standard quality. It provides a structure, which can be filled individually and according to quality requirement. But once a quality is set, there are standardized measurements to approve it. Many practical experiences will flow into this structure and improve its value.

The advantages for companies using TS are: optimized product development and costs, adaptation of processing, a quantified information on quality and environmental impacts for customers and end consumers. All process control and improvements can be achieved on the individual company's level. The TS system allows specific definition of products and processes and therefore should be favored compared to "Best Available Technology" (BAT by Schaefer 2001) simply based on technology. Because European companies are highly specialized in products their process technology cannot be compared independent of the products.

For the LCA in general, data quality strongly influences the liability of the results. For the presented system, data quality of inventories can be defined on two levels: the completeness and the accuracy of the values. The completeness is given if all data within the system border is collected as measurement, calculation (based on chemical and physical laws) or estimation. Measurements are considered as most accurate, estimation as least accurate. In this study all data is based on measurements (except for the calculation of nylon production). Further validation of data is relevance and sensitivity: inventory data values are evaluated as to slight changes will cause considerable changes in an impact category's value.

The choice of the production site is essential for LCA, considering the magnitude of the impacts caused by transportation. If the fabrics shown in fig. 5 would be produced in the USA the impacts would be lowered by about 30%. But the reduction can only be made assuming a US consumer. If the manufactured apparel is transported later over sea there will be comparable impacts caused by this transport. The closer the raw material grows to the marked the lower the environmental impacts are. Consequently, for environmental reasons local fibers should be favored. For Europe this would mean wool, linen and hemp as natural fibers or any man made fiber based on European crude oil.

As shown in fig.5, 8 and 9 the selection of yarn construction and process technology play an important role. Fig 10 indicates the relevance of the energy source applied in production. Only if a company can prove the use of hydropower, e.g. by owning a hydro power plant, the accordingly lower impacts may be calculated. For all companies using Swiss energy even a European Mix has to be taken as a base, since electricity is bought and sold all over Europe. But any energy saving is beneficial for a reduction of environmental impacts. A further comparison between a doubled yarn without sizing and a sized single yarn of the same quality in terms of environmental impacts will be interesting, even if it will be influenced by the choice of the energy source.

However the results cannot be compared without considering the required quality of the individual fabric: Although OE spinning of a selected fineness is superior to ring spinning this cannot be generalized, since very fine yarns cannot be produced on the rotor spinning system or because a soft hand is required. On the other hand the choice of raw material (cotton or man made fibbers like PA) highly depends on fashion and the consumers preferences. Different fiber properties like water uptake, water retention, washing properties are not identical for the two T-shirt types (see fig.2). Therefore LCA results may be applied in product development only by giving a precise definition of the scope, namely of a desired quality. LCA may use different functional units or evaluate individual processes, which make it impossible to compare the results (Tobler 2000 b, Stockar 1996, Zwicker 1998). Standardization in of the functional unit and the inventory (LCI), based on textile specifications would allow to elaborating comparable LCAs for products and processes.

Costs for textile processing, mainly for energy, are so far quite stable and situated on a high level in Switzerland. The Swiss source for electricity is 60% hydro power and 40% nuclear power. However, the opening of the market for energy sources will change this situation. Cheaper energy will be available from all over Europe. On the other hand Switzerland will introduce a CO_2-tax in the next years. As a consequence, companies might search for cheaper energy to avoid increasing costs. Again such changes in energy sources will influence strongly environmental impacts.

Notes

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2. LCA of different growing systems of cotton is currently investigated by Simone Schaerer (master thesis ETH).

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Table 1.

PRODUCTS

jeans leisure

shirt fashion

product	spinning	fineness(tex)	fabric	weight
Jeans	Ring, combed	50 /74	w 24 / f 15	231g/m²
Jeans	Ring, combed	50 / 74	w 15 / f 24	231g/ m²
Jeans	OE, carded	50 /74	w 24 / f 15	231g/m²
T-Shirt	Ring, combed	20	single jersey	150g/m²
Nylon	DTY	2.3	single jersey	30g/m²
Nylon Shirt	DTY	20	single jersey	150g/m²

Table 2. Detailed inventory data bases on textile specicfications but requires information on individual processes.

INVENTORY: DATA QUALITY

- **measurments in site (spinning mill, weaving company and knitting company**
- **machinery (aproved settings)**
- **theoretical models, where measurments were not possible**
- **calculation for 1 m² fabric**

weaving:	5% waste	1.0526		
assembling			0.0007	[kWh]
sizing			0.0031	[kWh]
airjet weaving	Sulzer Airjet L5200		0.0351	[kWh]
air conditioning	Sulzer Airjet L5200		0.2491	[kWh]
air conditioning	assembling		0.0007	[kWh]
air conditioning	air jet weaving		0.0439	[kWh]
illumination	assembling		0.0003	[kWh]
illumination	sizing		0.0010	[kWh]
illumination	air jet weaving		0.0127	[kWh]

Table 3. Textile specifications for weaving. E = information for the end user, C = information for the client, functional unit = reference for LCA.

WEAVING		
functional unit		**weight of fabric /m^2 meter**
	quality parameters:	
E +C	width of fabric	cm
E +C	grammage	g/m^2, weight/fabric
E +C	warp density	Counts /cm
E +C	weft spacing	counts /cm
E +C	kind of weave	type
E +C	repeat of pattern	cm
		warp and weft ends down
K	failures	other failures
	process parameter:	
	number of warp threads	Number /cm
	warp length	m
	weaving preparation	
	process energy	kWh/meter
	type	warping, beaming, assembling
		knotting, threading (mechanical, manually)
	time	h / warp
	means of transport	process energy / ergonomics
C + E	sizing	energy/ meter
		type of size/sizing agent (CMC carboxymethyl cellulose, PVA, starch, acrylate)
		size per meter (according fineness)
	weaving technology	machine type
		weave
	tissue type	pile, double warp, etc.
	setting machines	warp tension
		velocity
		weft insertion
	Weaving	electrical energy /lm
		compressed -air/ lm,
		water /lm
		noise, vibration (db)
		aerosols, dust(PM)
		ends down per 100 000 weft
	Control	warp length, molecular weight
		warp thread cohort
		ends down in warp and weft
		weft threads
		tissue control, endcontrol
	productivity:	batch size
E		energy/ meter
		item exchange: min per batch or lot
	waste products	waste (yarn)
		air conditioning (kWh), change of air (x /h)
		water processing
E + C	recycling	sizing yarn

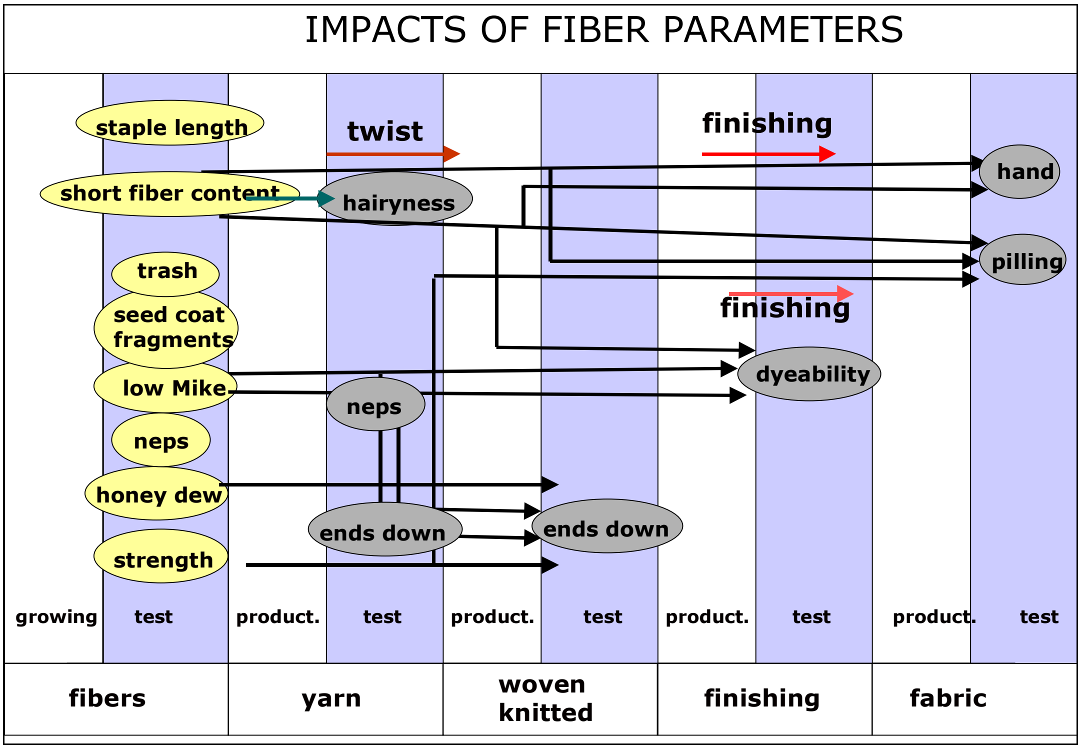

Figure 1. Impacts of fiber parameters upon fabric properties and textile processing.

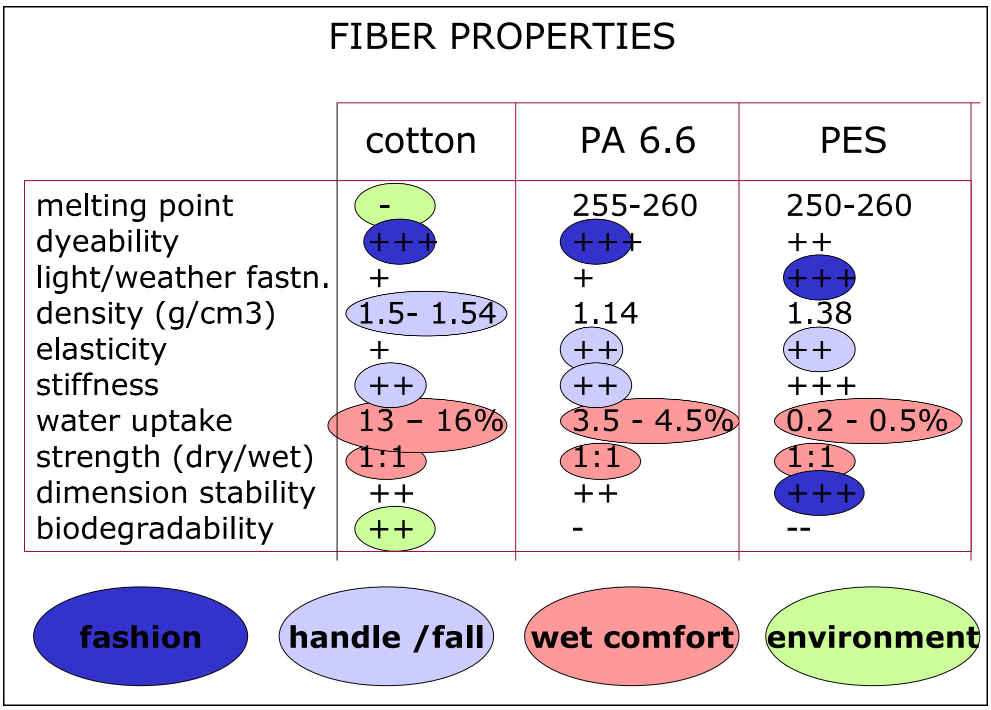

Figure 2. Selection of fiber properties which determine the required quality of a product.

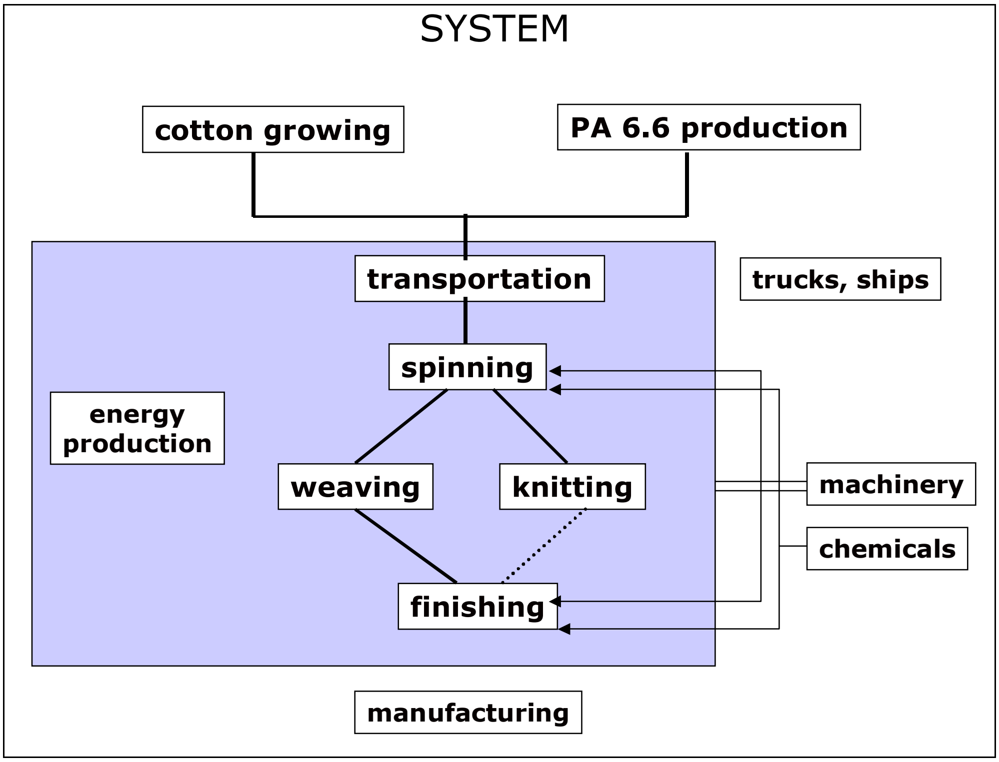

Figure 3. System of the presented LCA.

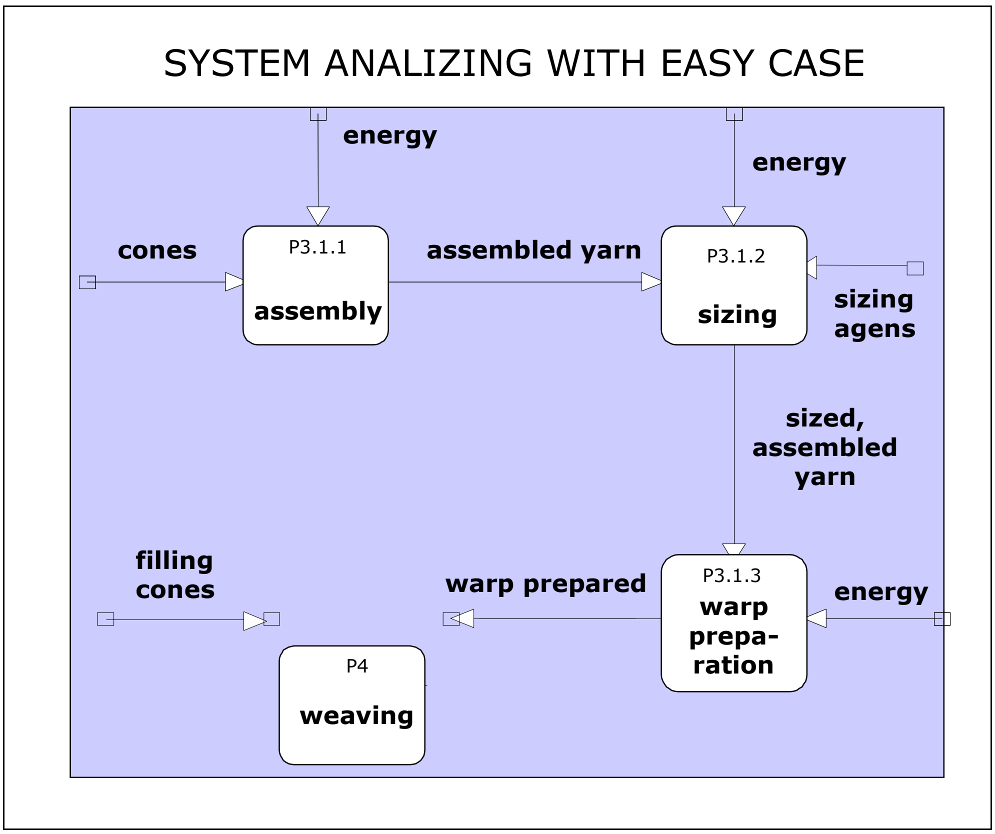

Figure 4. System for analizing processes. A rule check allows veryfying of all relations of flows.

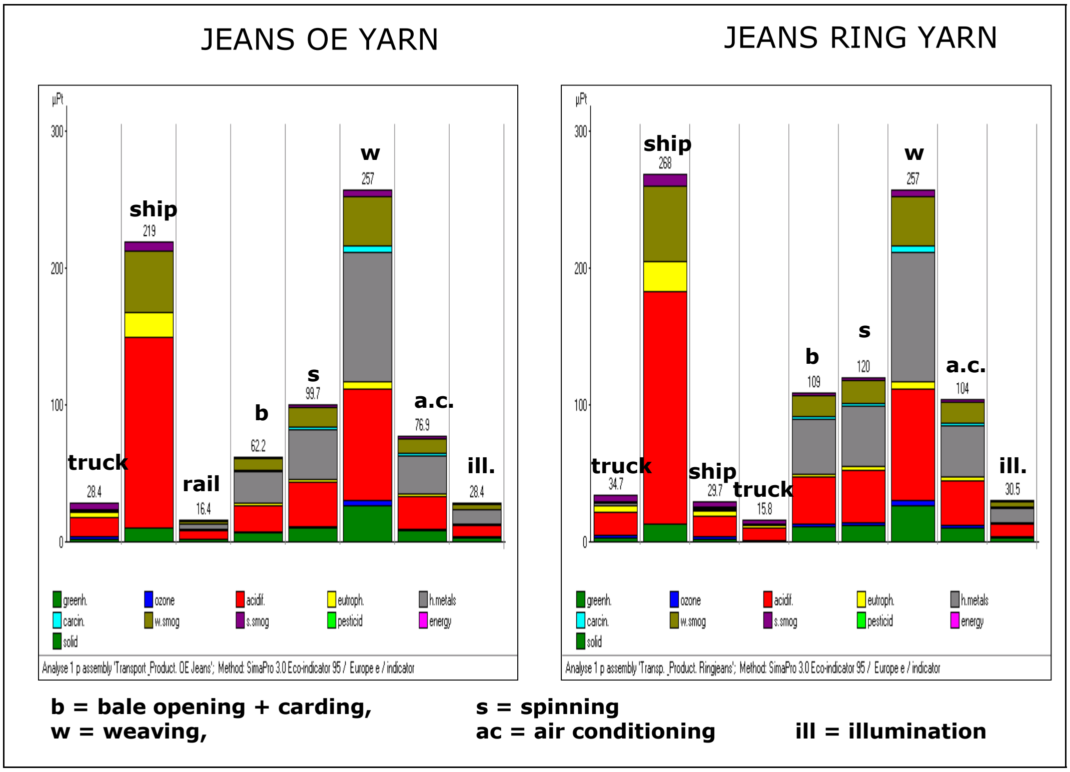

Figure 5. LCA of fabrics made of ring spun yarn and OE spun yarn including transportation with different vehicles.

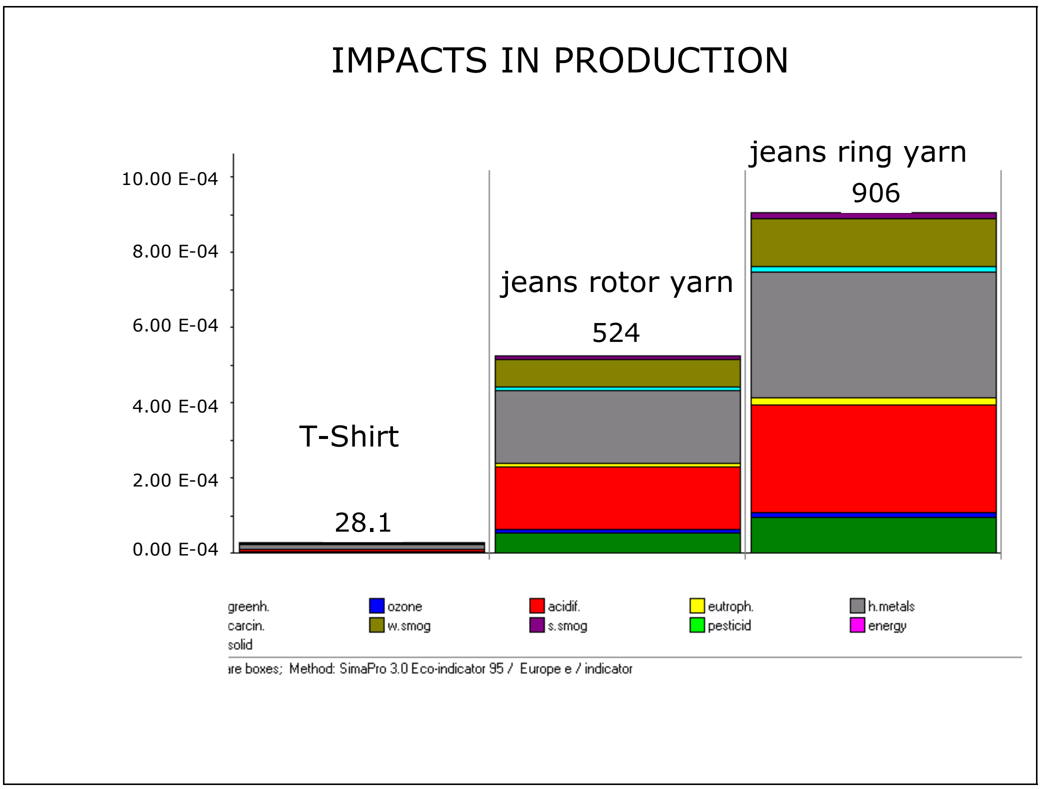

Figure 6. LCA of fabric production including different energy sources for production (without transportation).

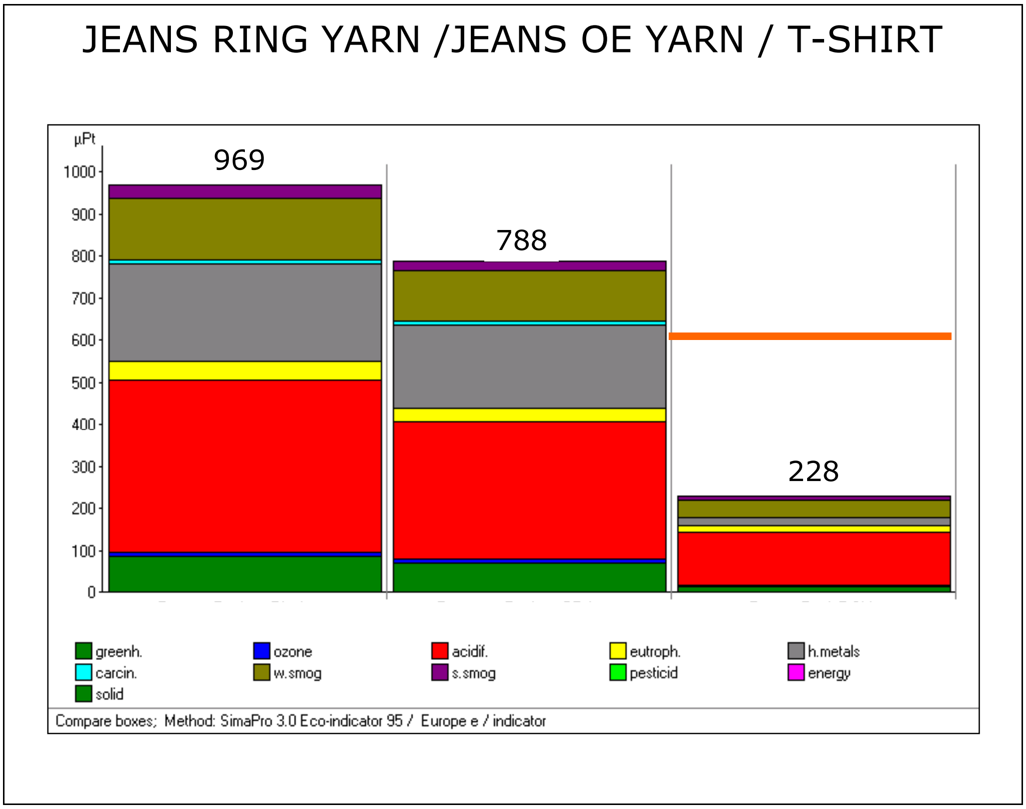

Figure 7. LCA of fabrics including transportation.

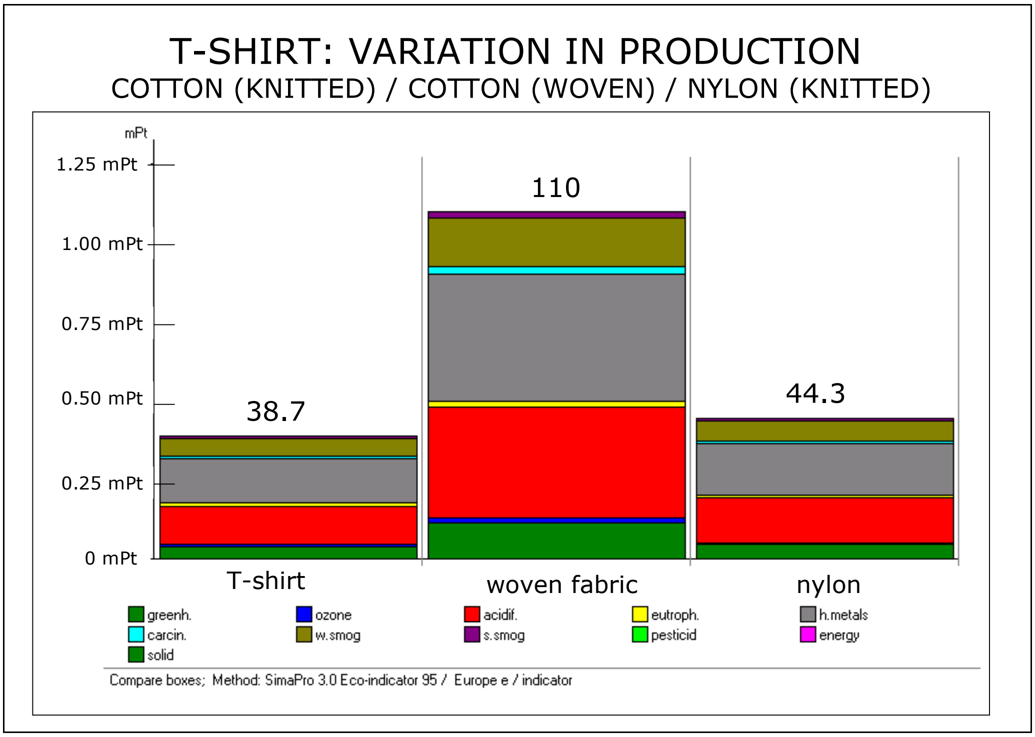

Figure 8. Variations of shirts (knitted, woven cotton shirts and knitted nylon shirt).

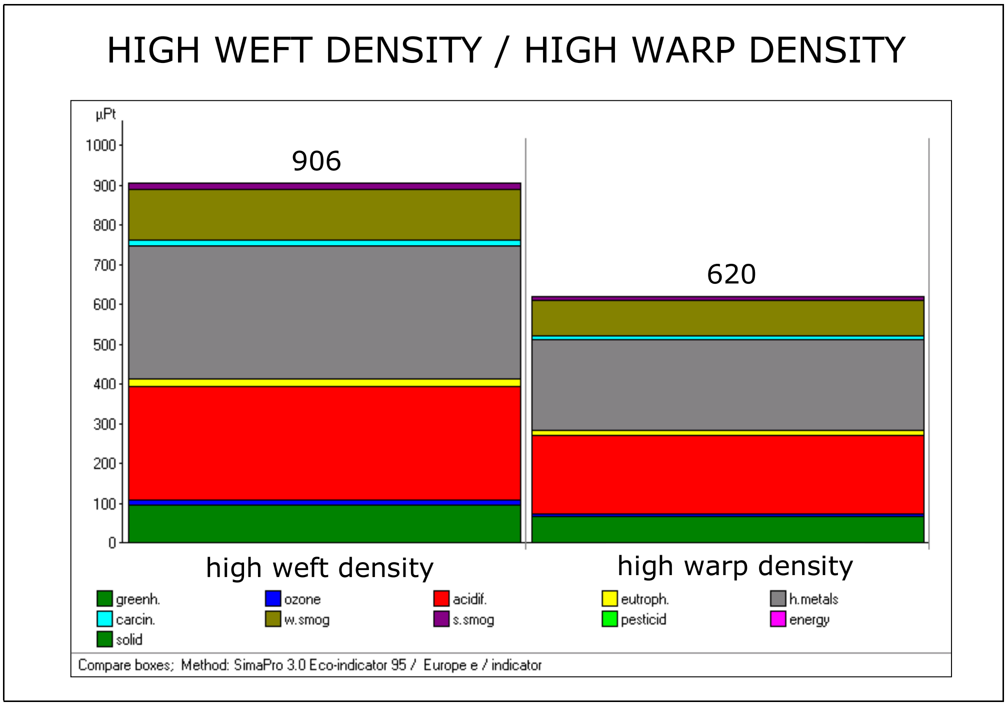

Figure 9. Differences in impacts caused by different warp and weft desity of the same weight.

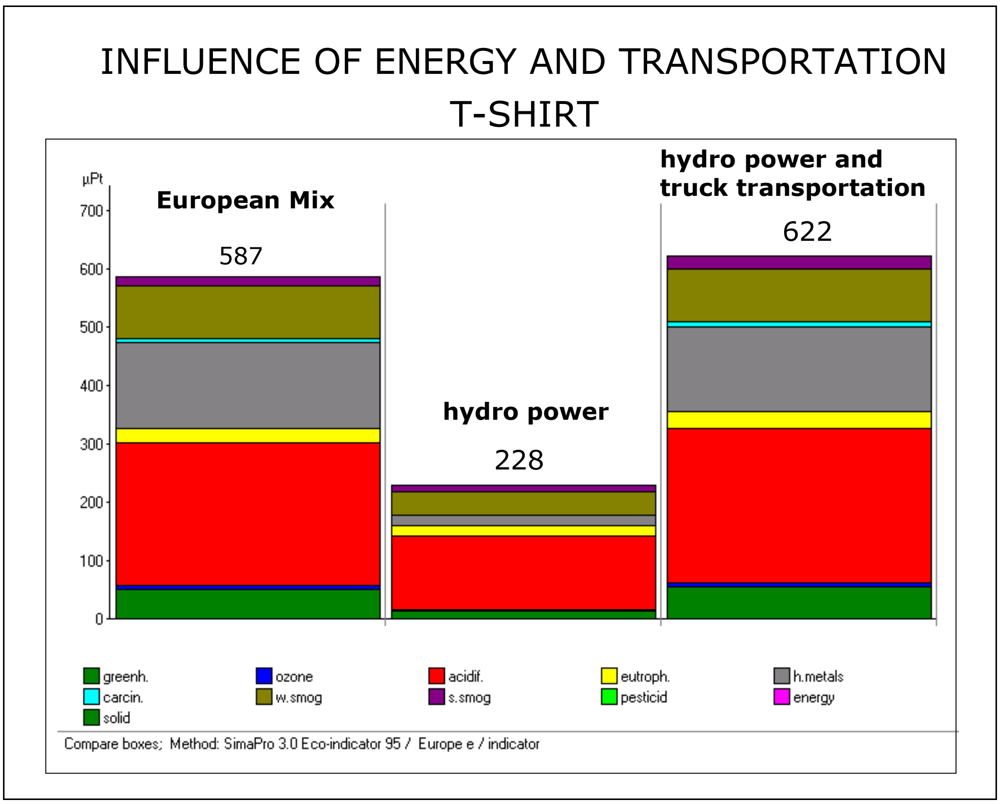

Figure 10. Influence of energy source and transportation vehicles on environmental impacts.

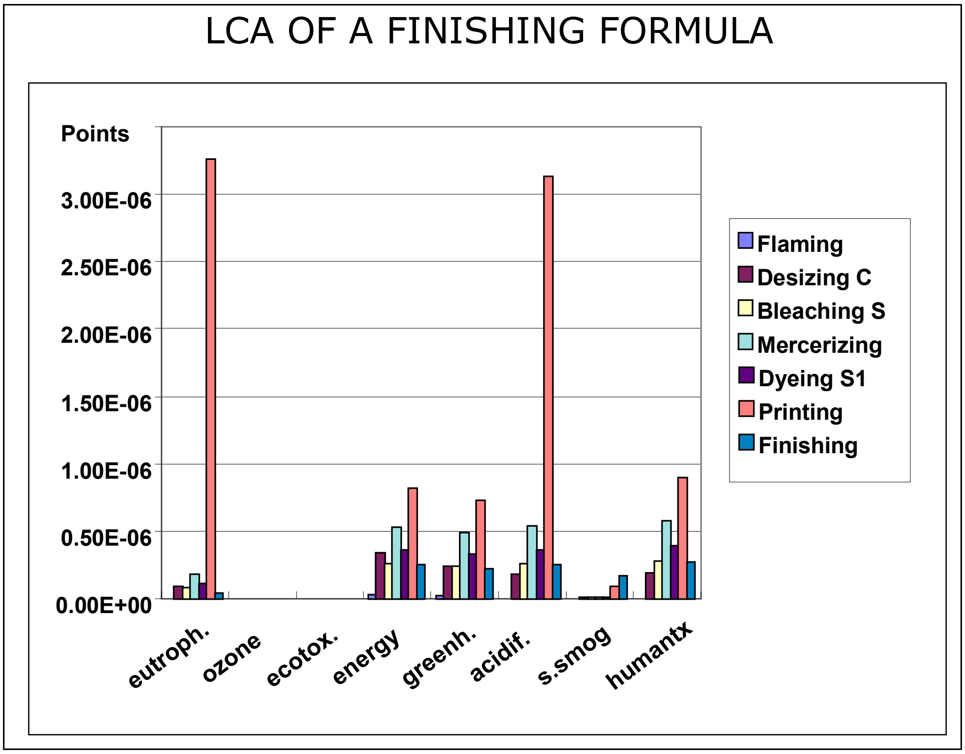

Figure 11. LCA of a finishing formula calculated for a m2 fabric by means of CML method, indicating the affected impact cazegories.

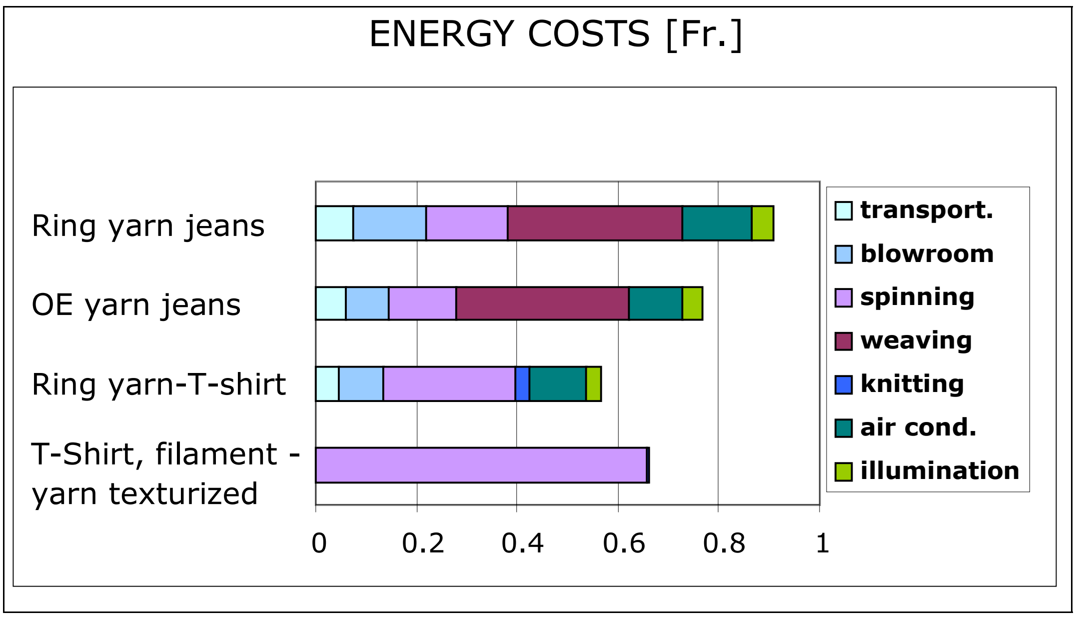

Figure 12. Costs of processing of different fabrics.

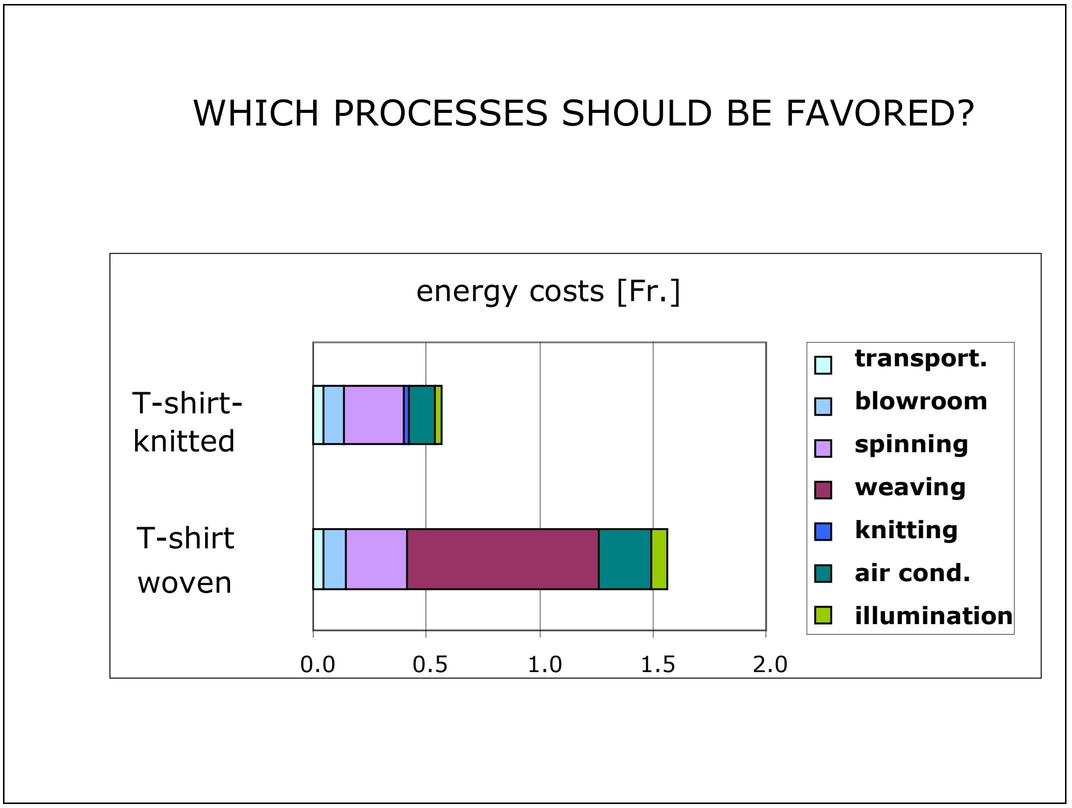

Figure 13. Comparison of costs for different process technology.