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Life Cycle Assessment of cotton fabric in B02 company

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Contents

1 Introduction

The work documented in this report is part of the project "Evaluation of the effect of the IPPC application on the sustainable waste water management in textile industries (Towef0)" funded by European Commission as a shared cost RTD project in the 5^{th} Framework Research program, Energy, Environment and Sustainable Development, Key action 1 Sustainable Management and Quality of Water, Treatment and purification technologies, Waste water treatment and reuse.
The project objective is to establish a multicriteria integrated and coherent implementation of Good Environmental Practices (GEP) and to promote the efficient use of resources within textile finishing industries characterised by large use of water, taking into account the treatment of industrial waste water effluent (Urban Waste Water Treatment Directive 91/271 EEC) and the impact of the final discharge to the water recipient bodies (Water Framework Directive COM (98)).
Within this framework ENEA-PROT-INN conducted detailed LCA studies on selected Italian and Belgian industries in order to estimate the potential impact on the environment of specific company processes, evaluate the environmental effects of alternatives scenarios of water management and develop a database of Life Cycle Inventories of textile production processes and chemicals.
Partners of the project were: ENEA, the Italian National Agency for New Technologies, Energy and the Environment, Vito, a Belgian research centre for the industry, Centexbel, a research centre for the Belgian textile federation, the Joint research Centres of Siviglia and Ispra, Lariana Depur S.p.A., a private Italian company, Ecobilan, a private French company and Lettinga Associates Foundation (LeAF), a Dutch foundation for environmental protection and resource conservation.
In this document LCA methodology has been applied to selected cotton fabric products within B02 company.

2 Goal and scope definition

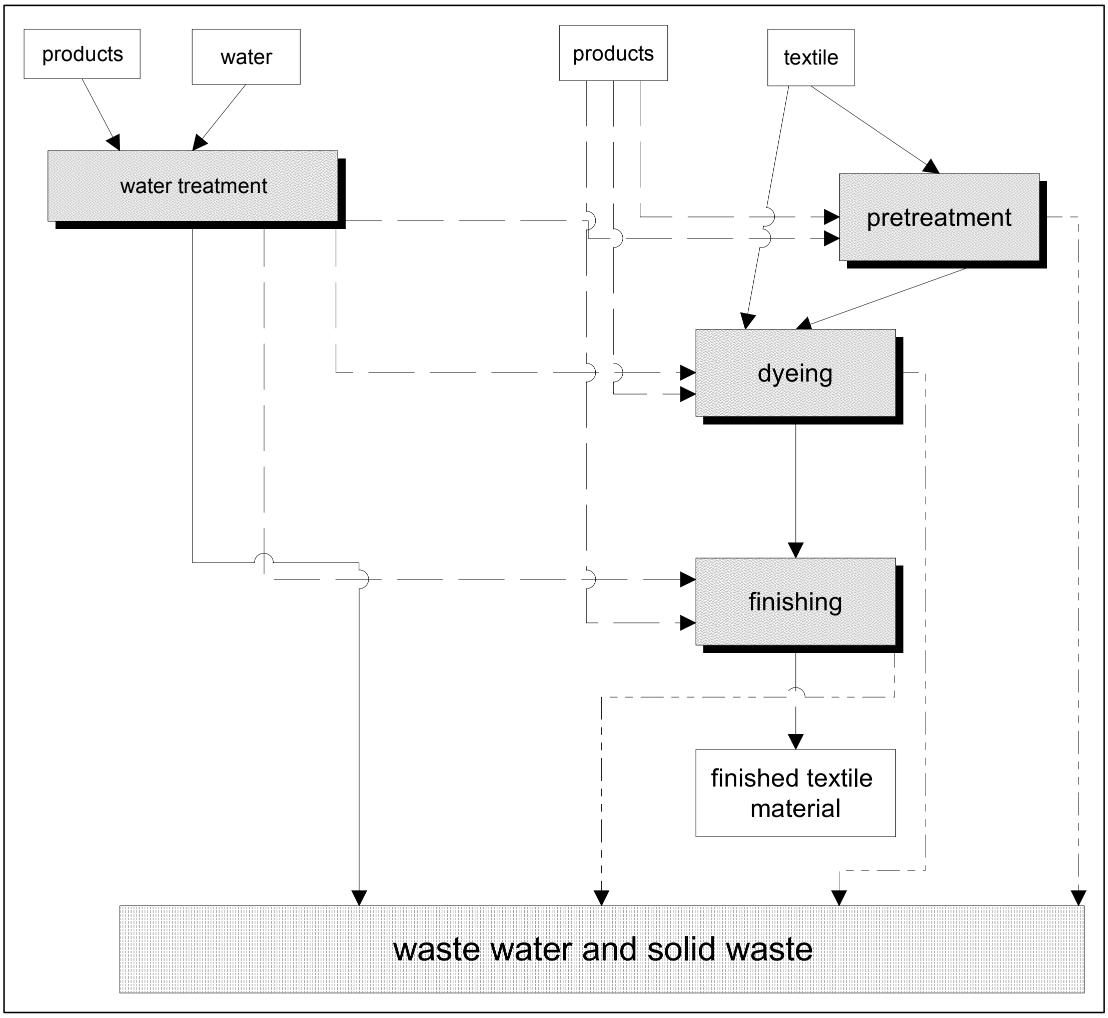
2.1 Goal of the study

The main goal of this LCA study is to quantify the environmental performance of selected textile production processes within B02 company identifying the potential environmental critical points.
The results achieved in this study will be used to support the identification of environmental favourable technologies/strategies in textile finishing industries, to evaluate different wastewater management scenarios and to develop a database of inventory data of textile processes and chemicals to be used with a industry specific, user friendly, environmental assessment software to be developed by Ecobilan within the project Towef0.
This study has been performed according to the requirements of ISO 14040 standards [1-4] by FEBE EcoLogic, an ENEA contractor. The study commissioner was the European Commission, which funded the Towef0 project. Researchers and technicians working in textile sector were the intended target of this study.

2.2 Scope of the study

2.2.1 General description of the systems

B02 is a Belgian company. Its annual production is over 16777 tons of textile products such as cotton yarn and fabric, PES/CO yarn, lycra woven in cotton and tencel. (There are no data available about annual production of different textile products.)
Concerning cotton textile production, a part of it is first dyed as a yarn, afterwards it is woven and part of that fabric is dyed again in another colour shade (this process is called: to top). B02 dyes predominantly jeans, which is a living fabric, i.e. the colour shade changes a bit after every household washing. This effect can be obtained when the same fabric is dyed different times and under different forms (as yarn and as fabric). The general organisation of the company production departments is highlighted in the following material flowchart.



A more detailed description of B02 company is available in Process Identification and data Collection Sheet (PIDACS) of B02 company.

In this study two cotton fabric product alternatives were analysed:

- cotton fabric pre-treated by desizing/bleaching and dyed with sulphur dyes (System A);
- cotton fabric pre-treated by desizing/boiling and dyed with vat dyes (System B).

The two production lines were selected on the basis of annual production of single processes as described in Table 2.1.

Table 2.1 Selection of production lines on the basis of contribution to annual production of cotton fabric

	Contribution	System A	System B
Pre-treatment			
Desizing/boiling	30%		x
Desizing/bleaching	70%	x	
Dyeing			
Sulphur dyeing	60%	x	
Vat dyeing	25%		x
Direct dyeing	15%		
Finishing			
Softening finishing	100%	x	x

For a better understanding of the report, a short description of the textile wet processes is presented hereafter. The description is extracted from the reference Document on Best Available Techniques for the Textile Industry [5].

Desizing

Desizing is used for removing from woven fabric sizing compounds previously applied to warp and is usually the first wet finishing operation performed on woven fabric.
Desizing techniques are different depending on the kind of sizing agent to be removed. Currently applied techniques can be categorised as follows:

- techniques for the removal of starch-based sizing agents (water-insoluble sizes)
- techniques for the removal of water-soluble sizes
- techniques for the removal of water soluble and insoluble sizes.

Bleaching

After scouring, cotton becomes more hydrophilic. However, the original colour stays unchanged due to coloured matter that cannot be completely removed by washing and alkaline extraction. When the material has to be dyed in dark colours it can be directly dyed without need of bleaching. On the contrary, bleaching is an obligatory step when the fibre has to be dyed in pastel colours or when it will need to be subsequently printed. In some cases, even with dark colours a pre-bleaching step may be needed, but this is not a full bleaching treatment.
Bleaching can be performed on all kinds of make-ups (yarn, woven and knitted fabric). The most frequently used for cellulosic fibres are oxidative bleaches, namely hydrogen peroxide (H_2O_2), sodium hypochlorite ($NaClO$) and sodium chlorite ($NaClO_2$).

Sulphur dyeing

Sulphur dyes are used in piece dyeing (cellulose and cellulose-polyester blends), yarn dyeing (sewing thread, warp yarn for denim fabric, yarn for coloured woven goods), dyeing of flock, card sliver (wool-man-made fibres blends).
Like vat dyes, sulphur dyes are insoluble in water, and, under alkaline conditions, are converted into the leuco-form, which is water-soluble and has a high affinity for the fibre. After adsorption into the fibre the colourant is oxidised and converted to the original insoluble state. The reducing agent, salts, alkali and unfixed dye are finally removed from the fibre by rinsing and washing.

Mostly continuous dyeing methods are applied, although batch dyeing (in jigger, jet, and winch beck) is also possible.
In continuous processes the material is impregnated with dye, reducing agent and wetting agent through a one-bath or a two-bath procedure. With the one-bath procedure (pad-steam process) the reducing agent and the dye are added at the same time. With the two-bath procedure (pad-dry/ pad-steam) the material is padded in the liquor containing the dye and the wetting agent, while the reducing agent is applied, if necessary, in a second step, after intermediate drying. The material is then submitted to air-free steaming. After that, rinsing, oxidation and re-rinsing are carried out.
Chemicals and auxiliaries applied to the substrate during the dyeing process are: reducing agents,: alkali (caustic soda), salt, dispersing agents (they are necessary in the process steps in which the pigment has not yet been reduced or has been re-formed by oxidation), complexing agents.

Vat dyeing
Vat dyes have excellent fastness properties when properly selected and are often used for fabrics that will be subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.).
Vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.
Continuous processes are used almost exclusively for dyeing woven fabrics and to only a small extent for knitwear. The most commonly applied continuous process is the pad-steam process.
The textile is padded with the aqueous dye dispersion in the presence of anti-migrant (polyacrylates, alginates, etc.) and dispersing/wetting agents, if required. After drying, the fabric is passed through a chemical padder, which contains the required amount of alkali and reducing agent and is fed immediately to a steamer. The material is finally rinsed, oxidised and soaped in an open-width washing machine.
The following chemicals and auxiliaries are applied in vat dyeing: reducing agents, oxidising agents, alkali (caustic soda), salt, dispersing agents, levelling agents.

Finishing processes
The term "finishing" covers all those treatments that serve to impart to the textile the desired end-use properties. These can include properties relating to visual effect, handle and special characteristics such as waterproofing and non-flammability.
Finishing may involve mechanical/physical and chemical treatments. Moreover, among chemical treatments one can further distinguish between treatments that involve a chemical reaction of the finishing agent with the fibre and chemical treatments where this is not necessary (e.g. softening treatments).
Some finishing treatments are more typical for certain types of fibre (for example, easy-care finishes for cotton, antistatic treatment for synthetic fibres and mothproofing and anti-felt treatments for wool). Other finishes have more general application (e.g. softening).

A detailed description of the studied systems is available in chapter 3.2.
A general description of the equipments used for all textile processes is given in the Reference Document on BAT for Textile processing [5].

2.2.2 Function

The main function of the studied systems is the pre-treatment, dyeing and finishing of cotton fabric, processed to reach the required commercial characteristics respecting the worker safety and the emission limits according to the law in air, water and soil.

2.2.3 Functional unit and reference flow

The chosen functional unit is the pre-treatment, dyeing and finishing of a weight unit of cotton fabric, processed to reach the required commercial characteristics, respecting the worker safety and the emission limits according to the law in air, water and soil.
The reference flow is 100 kg of cotton fabric.

2.2.4 System boundaries of product system

The system boundaries of the two studied product alternatives are shown in Fig. 2.2. The processes included in the analysis are included in the system bold line.

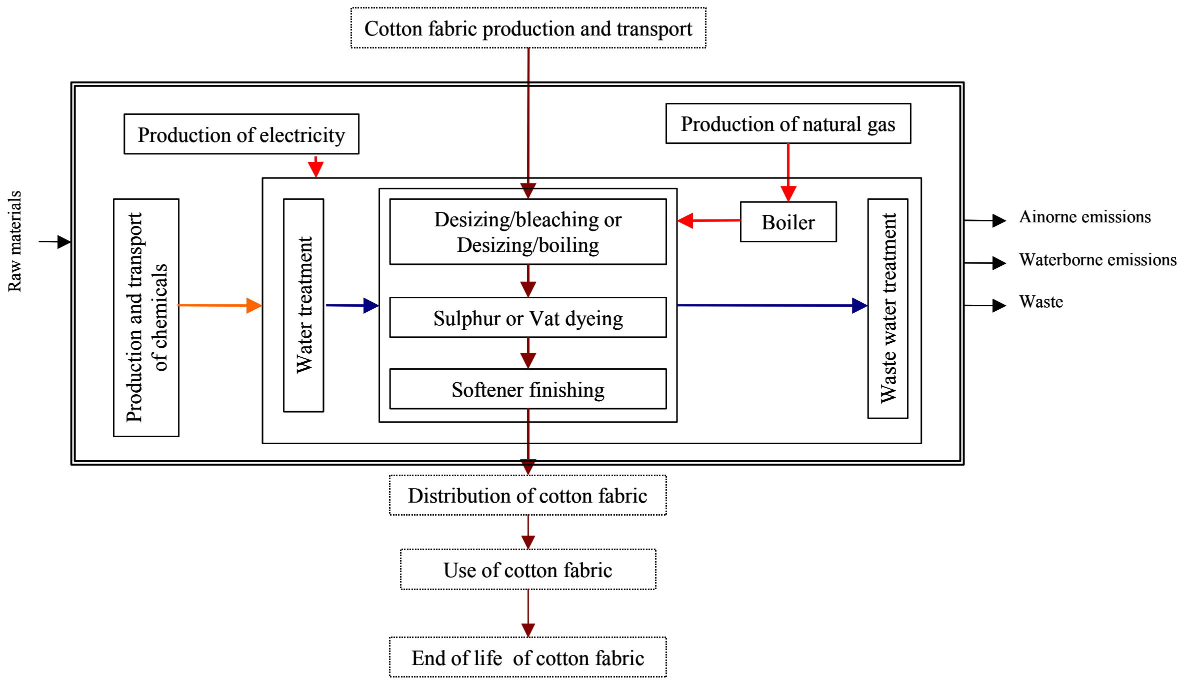


Fig 2.2 System boundaries of B02 product systems.

The processes excluded from the system boundaries are:

- cotton production processes, including the relative transports;
- all the product life cycle phases external to the company gate;
- the production and manufacturing of all equipment, machinery and capital goods used in the industrial processes, as commonly accepted in LCA.

2.2.5 Data categories

The choice of data categories has been made in relation to the impact categories and characterisation factors adopted. They include the macro categories of energy, raw materials, chemicals and emissions in air water and soil.
Different data sources were used in this study:

Company specific data:
- desizing and boiling
- desizing and bleaching
- sulphur dyeing of cotton fabric
- vat dyeing of cotton fabric
- softener finishing
- waste water treatment plant

TEAM 3.0/Ecobilan data:
- production of electricity;
- production of natural gas;
- transport processes;
- boiler: general model whose process parameters and efficiency are adjusted to B02 company.

Detailed hypotheses on the electricity production and on all the models used in this study are available in TEAM 3.0 modules database [6].

Lariana Depur data:
- All the centralised Waste Water Treatment Plant data.

Production of chemicals:
- TEAM 3.0/Ecobilan
- other LCA commercial databases and literature [7-11]
- data collection from manufacturers;
- surrogate data [12] for performing sensitivity analyses and check the influence of the missed data.

2.2.6 Criteria for initial inclusion of inputs and outputs

All the inputs and outputs available in PIDACS were included in the study.
Because of the large amount of base chemicals used for pre-treatment operation in textile wet processing, it was decided to include in the analysis the chemicals production. A comprehensive review of the chemicals Life Cycle Inventories (LCI) available in commercial databases has been performed and direct contacts with the main textile chemicals manufacturers have been started up. In case of lack of data, production of chemicals was excluded from the product system. In the Interpretation phase of the LCA study, a sensitivity check was made concerning the lack of data about production of chemicals. Surrogate inventory data about the production of inorganic chemicals [12] were used to evaluate the sensitivity of the product system to these data (see Chapter 5.2.2.3).

2.2.7 Data quality requirements

The on site data gathered in this study have the following characteristics:

- Time related coverage: All the B02 data are related to year 2000;
- Geographical related coverage: the data are company specific

To model the two product systems several assumptions were necessary:

Main assumptions within the company boundary:

- <u>Steam and electricity consumptions</u>

The annual company steam and electricity consumptions are measured and reported on the B02 PIDACS. Lacking process specific data on PIDACS, they were allocated to the reference flow on a mass basis.

- <u>Process specific wastewater effluent</u>

Due to data unavailability in the wastewater analyses the effluent from the company specific processes has been characterized only with measured COD and TSS concentration.

- <u>General facilities</u>

Due to data unavailability in B02 PIDACS general facilities are not included.

- <u>Solid waste</u>

Due to data unavailability in B02 PIDACS solid wastes are not included.

- <u>Airborne emissions</u>.

Due to data unavailability in B02 PIDACS airborne emissions are not included.

- <u>Transport of chemicals</u>

Due to data unavailability in B02 PIDACS transport processes are not included.

Main assumptions for production of chemicals:

The inventories available in the TEAM 3.0 database have been included in the study; the following databases were checked in addition to the TEAM 3.0 one:

- SimaPro [7];
- KCL Eco [8];
- IVAM [9];
- Boustead model [10];
- GaBi 3.2 [11]
- Specific industry data.

Main assumptions for waste water treatment plant (WWTP):

It was assumed that the potential environmental impacts of WWTP processes are mainly due to the production of the energy needed in the plant and to the emission of the treated effluent into the environment. The impact of chemicals production has been neglected. These hypotheses were based on the results of previous LCA studies of ENEA [13].

The potential environmental impacts for treating the waste water of the studied product systems have been considered proportional to effluent mass.

Direct greenhouse gas emissions to the environment from Lariana WWTP processes have not been considered (according to IPPC guidelines) [14].

Because it was not possible to have information on the specific contaminants contained in the effluents of the specific cotton treatment processes, the evaluation of the potential impact connected to the release to the environment of the treated water effluent has been calculated considering the effluent mass of the analysed processes and the contaminant concentration of the treated WWTP effluent. The Belgian electricity mix has been used to model the electricity production processes.

2.2.8 Impact assessment methods

The impact categories used for the analysis of the product systems are indicated in table.2.2

Tab. 2.2 Impact assessment categories

Category	Unit
CML 92-Air Acidification	g eq. H+
CML 92-Aquatic Eco-toxicity	1e3m3
CML 92-Depletion of non renewable resources	frac. of reserve
CML 92-Eutrophication	g eq. PO4
CML 92-Human Toxicity	g
CML 92-Terrestrial Eco-toxicity	t
IPCC-Greenhouse effect (direct, 100 years)	g eq. CO2
WMO-Photochemical oxidant formation (high)	g eq. ethylene
Reminders-Primary energy consumption	MJ

The chosen impact assessment categories are well know and accepted at international level: a short description can be found in TEAM software online documentation

2.2.9 Interpretation methods

In the interpretation phase of this study the significant issues have been identified and the contribution of the specific contaminant fluxes has been calculated. The sensitivity check has been focused on allocation rules (electricity and steam) and lack of inventory data for chemicals.
A comparison of the two product systems has been performed

2.2.10 Critical review

Being a pilot study performed in a research project, this report has not been submitted to a critical review.

3 Inventory analysis

3.1 Procedures for data collection

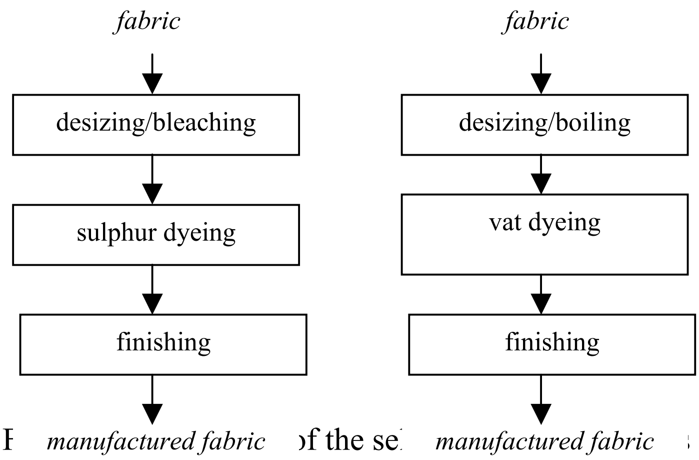
Data were collected from B02 company with the Process Identification and data Collection Sheet (PIDACS) defined and used by the Towef0 project. The PIDACS contains information for the entire Towef0 project and a part of the data was extracted for the LCA study.
Flow-charts of the most representative production lines were identified on the basis of the PIDACS data.
Data collection was performed by Centexbel. The elaboration of PIDACS data required further details concerning processes of B02 company. This information was obtained from Centexbel by e-mail contacts.
Data were implemented using predefined modules of the TEAM software. The modules were developed by Ecobilan and were specific for the textile finishing industrial sector.
The product system was completed using modules of the TEAM database and other bibliographical sources.

3.2 Qualitative and quantitative description of unit processes

The next paragraphs describe data collected for the inventory analysis. Data elaboration procedures are explained and assumptions and allocation procedures are documented.

3.2.1 Cotton wet processing

Annex 1 describes general structure and content of the PIDACS.
In collaboration with Centexbel, the most representative production lines were identified and their flow-charts were depicted. (see Figure 3.1)



Equipment capacities are:

- pretreatment line: 1500 kg/h
- dying by pad-steam: 1700 kg/h
- finishing by 2 sanfors: 1700 kg/h (on each of the sanfors)

The next paragraphs describe the data available in PIDACS, their elaboration and main assumptions of the LCA study. Data are always related to the above described capacities.

3.2.1.1 Water use

Table 3.1 shows the water consumption of the selected processes.

Table 3.1 Water consumption of processes

	Water consumption (l/kg)	**Uptake (%)**
Pre-treatment		
desizing	1	100
bleaching or boiling	0.6	60
rinsing	8	
TOTAL	9.6	
Sulphur dyeing		
dyed topped	0.7	70
reduction	0.6	60
rinsing	10	
oxidation	0.6	60
TOTAL	11.9	
Vat dyeing		
dyed topped	0.7	70
reduction	0.6	60
rinsing	10	
oxidation	0.6	60
total	11.9	
FINISHING		
preparation of finishing bath, cooling of the rubber band, sprinkling of the fabric and cleaning of the machinery	5 m^3/h	

3.2.1.2 Electricity consumption

PIDACS contains information about annual electricity consumption of B02 company. Because of the lack of process specific data, allocation of annual electricity to the reference flow was made on a mass basis:

39592851 kWh/yr [annual electricity] / 16777000 kg/yr [annual production] * 100 kg [reference flow] =
= 236 kWh

3.2.1.3 Methane consumption

Methane is consumed for steam production. 95% of methane is used for steam production necessary for heating water of industrial processes described in PIDACS. 5% is used for heating the factory shed (estimation of the company technicians).

There were no process specific data concerning steam consumption. PIDACS contains information about annual methane and steam consumptions. After consulting process experts

of Centelbex, allocation to the reference flow of annual steam and methane consumption was made on a mass basis.
Table 3.2 shows the annual consumption of methane and steam, and the factors used for allocation.

Table 3.2 Values and factors used for calculation of process specific methane and steam consumption

	Unit	Value	Comment
methane consumption of B02	GJ /yr	195494	
methane consumption for water heating	GJ /yr	185719	95% of methane consumption in B02
steam consumption of B02	m3/year	28468	
factor “steam/methane”	m^3 /GJ	0.153	
factor “steam/kg fabric”	m^3 /kg	0.0017	

3.2.1.4 Consumption of chemicals

Table 3.3 shows the concentration of chemicals used for each process. The mass of chemicals was calculated multiplying the concentration by the volume of consumed water (see Chapter 3.2.1.1) or the mass of treated fabric (when concentration is defined in ml of chemicals/kg fabric).

Table 3.3 Concentration of chemicals

	enzyme	Complex-binding agent	Wetting agent	Alkali	Dispersing agent	detergent	H2O2(50%)	NaOH(30%)	Stabilising agent	Reducing agent	Defoaming agent	NaCl	Complexing agent	Glucose monohydrate	Vat dyes	Anti-migration agent	Sodium hydrosulfite	Oxidising agent	Acid acetic	Finishing products
	ml/l	ml/l	ml/l	ml/l	ml/l	ml/l	ml/ kg	ml/ kg	ml/l	ml/l	ml/l	g/l	ml/l	ml/l	g/l	ml/l	g/l	g/l	ml/l	
Desizing/boiling																				
desizing	3	3	3																	
boiling				n.a.	n.a.	n.a.														
rinsing			2			2														
Desizing/bleaching																				
desizing	3	3	3																	
bleaching					3		35	45	6											
Sulphur dyeing																				
dyed topped			3							5										
reduction								30				50	5	40						
oxiding																		5	4	
Vat dyeing																				
Dyed/topped			3								0.25				0-50	10				
reduction								100					5				50			
oxidation																		5		
Softener finishing																				
																				n.a.

3.2.1.5 Discharged water

Table 3.4 shows the COD and TSS concentrations of discharged water. Mass of total COD and TSS were calculated by multiplying the concentration values and the consumed water at each process step (see Chapter 3.2.1.1). Discharged flow rates were calculated considering the uptake of water (see Table 3.2) and the assumption that 12% of the remaining flow rate is evaporated.
As Table 3.4 shows, there were several lack of data regarding COD and TSS concentrations.

Table 3.4 Discharged water

	COD (mg/l)	TSS (mg/l)
Desizing/ boiling		
mixed stream (concentrated streams and rinsing water)	19300	1590
Desizing/bleaching		
mixed stream (concentrated streams and rinsing water) (1)		
a)	15300	437
b)	11000	1410
c)	14300	1100
Sulphur dyeing		
dyed topped	122320	>2800
rinsing(light color)	4570	n.a.
oxidizing	n.a.	n.a.
Vat dyeing		
dyed topped	n.a.	n.a.
rinsing	1800	n.a.
oxidizing	n.a.	n.a.
Softener finishing (2)	n.a.	n.a.

(1) A medium value of a), b) and c) analyses was calculated.
(2) Discharge of concentrated solutions and rinsing of machinery: very low flow rate, very much varying in quantity and quality

3.2.2 Production of chemicals

Data on chemicals production were collected by a comprehensive review of the chemicals Life Cycle Inventories (LCI) available in commercial databases and software [6-11] and by direct contacts with the main textile chemicals manufacturers.

In case of lack of data, production of chemicals was excluded from the product system.
In the Interpretation phase of the LCA study, a sensitivity check was made to evaluate the impact of the lack of data related to chemicals production. Surrogate inventory data about the production of organic and inorganic chemicals [12] were used to evaluate the sensitivity of the product system (see Chapter 5.2.2.3).
Table 3.5 summarises the sources used for the production of each chemical of System A and B.

Table 3.5 Production of chemicals

Name	Source
Enzyme	-
Complex-binding agent	-
Wetting agent	-
Alkali	-
Dispersing agent	-
detergent	-
H2O2(50%)	TEAM
NaOH(30%)	TEAM
Stabilishing agent	-
Reducing agent	-
Defoaming agent	-
NaCl	TEAM
Complexing agent	-
Glucose monohydrate	-
Vat dyes	-
Anti-migration agent	-
Sodium hydrosulfite	KCL Eco
Oxidising agen	-
Acid acetic	TEAM
Finishing products	-

3.2.3 Energy production

Modules of TEAM 3.0 were used for the production processes of electrical and thermal energy.
To calculate the emissions of methane burning and the natural resources consumption of the boiler, the TEAM 3.0 model was calibrated according to the annual consumptions of methane (195494 gigajoule/yr) and steam (28468 m^3/yr).

3.2.4 Waste water treatment plant (WWTP)

Table 3.6 summarize the data used to model WWTP.

Table 3.6 Data used for WWTP

	Units	Value
INPUT		
Wastewater	litre	8.87E+09
Electricity (mix Belgium)	MJ	2.90E+07
Transport: Road (diesel oil, kg.km)	kg.km	8.99E+08
OUPUT		
(w) Ammonia (NH4+, NH3, as N)	g	6.00E+07
(w) COD (Chemical Oxygen Demand)	g	5.19E+08
(w) Nitrates (NO3-)	g	7.89E+07
(w) Nitrites (NO2-)	g	1.77E+06
(w) Nitrogenous Matter (unspecified, as N)	g	1.40E+08

3.3 Results of inventory analysis

Results of the inventory analysis were preliminary analysed with the impact assessment methods. Significant flows - whose summed contribution is more than 99% of an impact category- were selected. Table 3.7 shows the quantities of these main flows, as well as water consumption, COD and TSS emission of the textile industrial processes.

Table 3.7 Results of inventory analysis of System A and B of B02 company (only main flows are listed)

	Flow	Units	System A	System B
INPUTS	(r) Bauxite (Al2O3, ore)	kg	4.94E-02	4.17E-04
	(r) Coal (in ground)	kg	1.02E+01	9.65E+00
	(r) Iron (Fe, ore)	kg	2.01E-01	2.00E-01
	(r) Natural Gas (in ground)	kg	3.98E+01	3.89E+01
	(r) Oil (in ground)	kg	3.50E+00	3.21E+00
	(r) Potassium Chloride (KCl, as K2O, in ground)	kg	6.49E-02	3.59E-02
	(r) Uranium (U, ore)	kg	2.60E-04	1.10E-04
	Cotton fabric	kg	1.00E+02	1.00E+02
	Water: Treated	l	2.44E+03	2.44E+03
	Water: Unspecified Origin	l	7.73E+01	4.87E+01
	Water: Public Network	l	5.99E+00	3.31E+00
OUTPUTS	(a) Alkane (unspecified)	g	5.19E+00	5.15E+00
	(a) Aromatic Hydrocarbons (unspecified)	g	5.42E-01	1.64E-02
	(a) Arsenic (As)	g	6.32E-03	6.32E-03
	(a) Benzene (C6H6)	g	1.19E+00	1.19E+00
	(a) Butane (n-C4H10)	g	1.71E+00	1.71E+00
	(a) Carbon Dioxide (CO2, fossil)	g	1.41E+05	1.36E+05
	(a) Carbon Monoxide (CO)	g	4.02E+02	3.99E+02
	(a) Ethane (C2H6)	g	9.92E+00	9.92E+00
	(a) Ethylene (C2H4)	g	2.21E+01	2.21E+01
	(a) Hydrocarbons (except methane)	g	5.25E+01	6.36E+01
	(a) Hydrocarbons (unspecified)	g	4.23E+00	2.02E+00
	(a) Hydrogen Chloride (HCl)	g	1.16E+01	1.00E+01
	(a) Lead (Pb)	g	2.49E-02	2.43E-02
	(a) Methane (CH4)	g	3.06E+02	2.89E+02
	(a) Nickel (Ni)	g	8.12E-02	8.17E-02
	(a) Nitrogen Oxides (NOx as NO2)	g	1.68E+02	1.33E+02
	(a) Propane (C3H8)	g	3.34E+00	3.34E+00
	(a) Propylene (CH2CHCH3)	g	5.36E-01	5.34E-01
	(a) Sulphur Oxides (SOx as SO2)	g	2.86E+02	2.63E+02
	(a) Vanadium (V)	g	3.06E-01	3.08E-01
	(s) Arsenic (As)	g	3.20E-04	3.19E-04
	(s) Chromium (Cr III, Cr VI)	g	4.01E-03	4.00E-03
	(s) Zinc (Zn)	g	1.20E-02	1.20E-02
	(w) Ammonia (NH4+, NH3, as N)	g	1.32E+01	1.32E+01
	(w) Benzene (C6H6)	g	4.77E-02	4.64E-02
	(w) Cadmium (Cd++)	g	1.63E-04	1.55E-04
	(w) Chromium (Cr III)	g	8.41E-03	8.40E-03
	(w) Chromium (Cr III, Cr VI)	g	7.70E-04	7.44E-04
	(w) COD (Chemical Oxygen Demand)	g	1.24E+02	1.13E+02

	Flow	Units	System A	System B
	(w) Nitrate (NO3-)	g	1.85E+01	1.71E+01
	(w) Nitrogenous Matter (unspecified, as N)	g	3.05E+01	3.05E+01
	(w) Oils (unspecified)	g	1.85E+00	1.88E+00
	Cotton fabric	kg	1.00E+02	1.00E+02
REMINDERS	COD: to Waste Water Treatment Plant	kg	1.61E+01	1.56E+01
	TSS: to Waste Water Treatment Plant	kg	7.64E-01	1.15E+00
	E Feedstock Energy	MJ	8.73E+01	9.43E+01
	E Fuel Energy	MJ	2.71E+03	2.62E+03
	E Non Renewable Energy	MJ	2.05E+03	1.97E+03
	E Renewable Energy	MJ	7.49E+02	7.46E+02
	E Total Primary Energy	MJ	2.80E+03	2.72E+03
	Electricity	MJ elec	9.89E+02	9.42E+02

4 Life cycle impact assessment

Classification and characterisation were done on the basis of the impact assessment methods selected during scope definition of the study (see Chapter 2.2.8).

5 Life cycle interpretation

5.1 Identification of significant issues of System A

In the following paragraphs the graphs of the selected impact assessment categories and inventory data are presented for System A to highlight significant issues. Contributions of processes or electricity production, steam production and production of chemicals into impact assessment results are visualised, too. If production of chemicals has a significant contribution, more detailed information is given. The main contaminant flows which contribute to each category are specified.

5.1.1 Water consumption

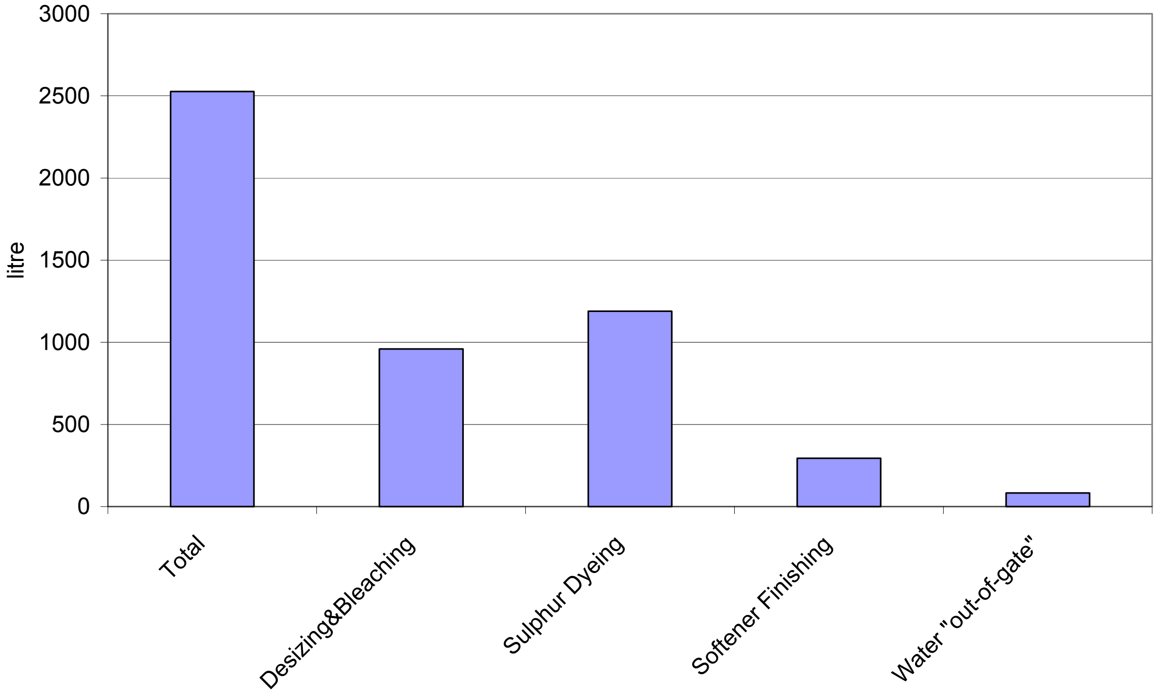


Figure 5.1 Water consumption

5.1.2 COD and TSS emissions

Table 5.1 shows COD and TSS emissions of the processes.

Table 5.1 COD and TSS emissions

	Desizing&Bleaching	**Sulphur Dyeing**	**Finishing**
COD	9.81	6.28	n.a.
TSS	0.71	2.62	n.a.

5.1.3 Energy indicators

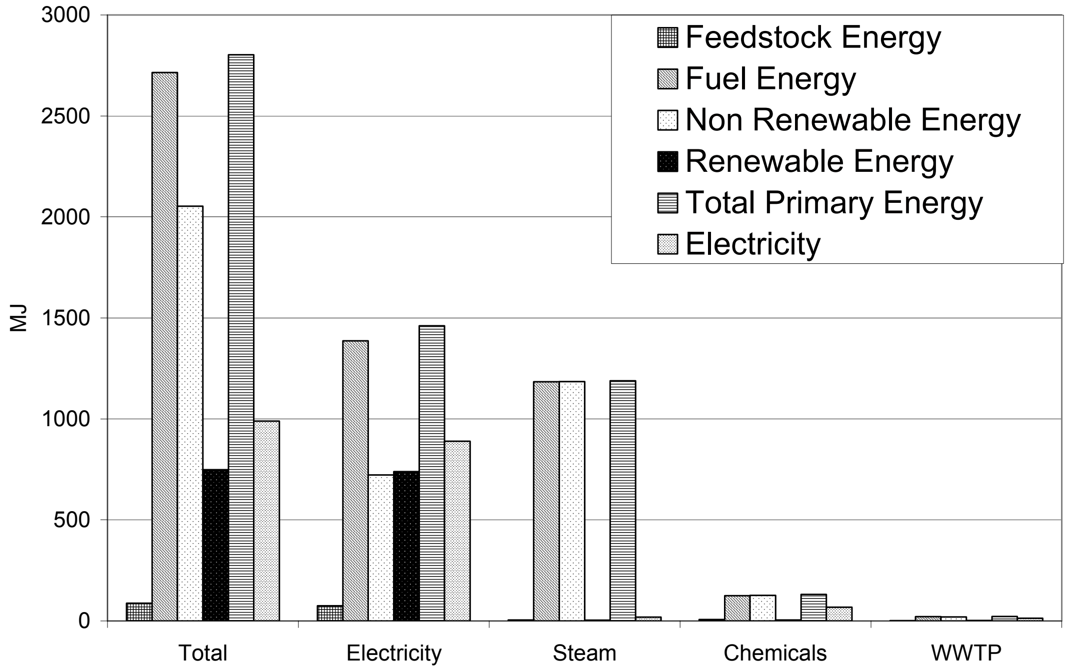


Figure 5.2 Energy indicators

5.1.4 Air Acidification

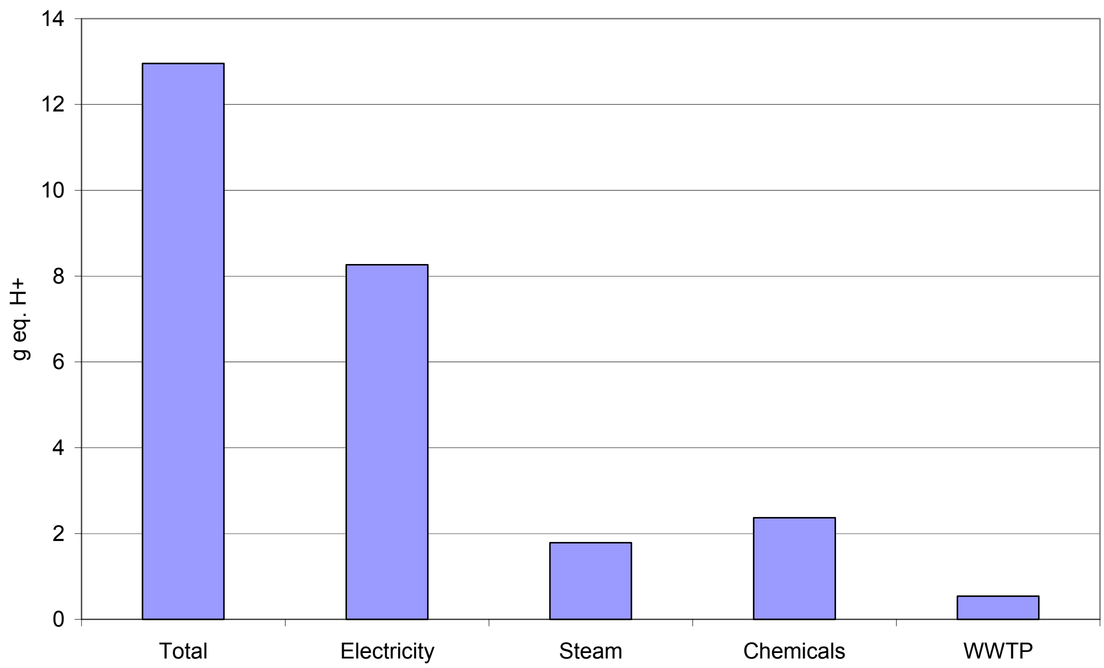


Figure 5.3 Air-Acidification

Chemicals have significant contribution because of the production of Hydrogen Peroxide (Desizing/Bleaching) and Sodium Hydroxide (Desizing/Bleaching and Sulphur Dyeing).
The main airborne emissions which contribute to total value are sulphur oxides (69%) and nitrogen oxides (28%).

5.1.5 Aquatic ecotoxicity

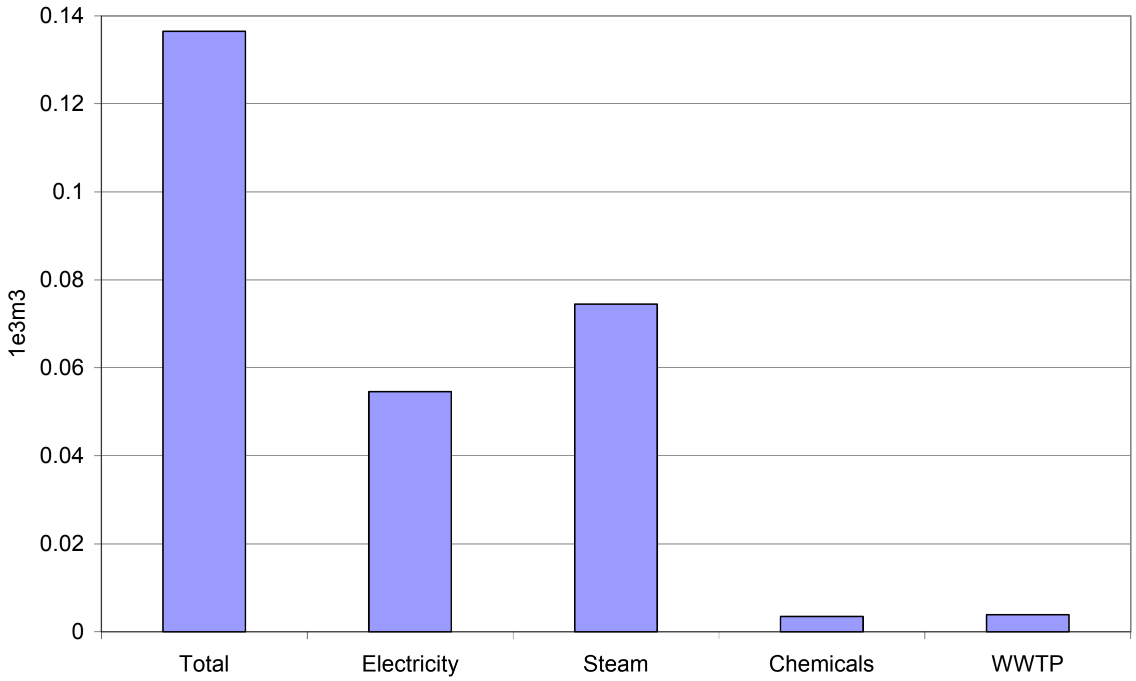


Figure 5.4 Aquatic ecotoxicity

The main waterborne emissions which contribute to total value are oils (68%) and cadmium (24%).

5.1.6 Depletion of non renewable resources

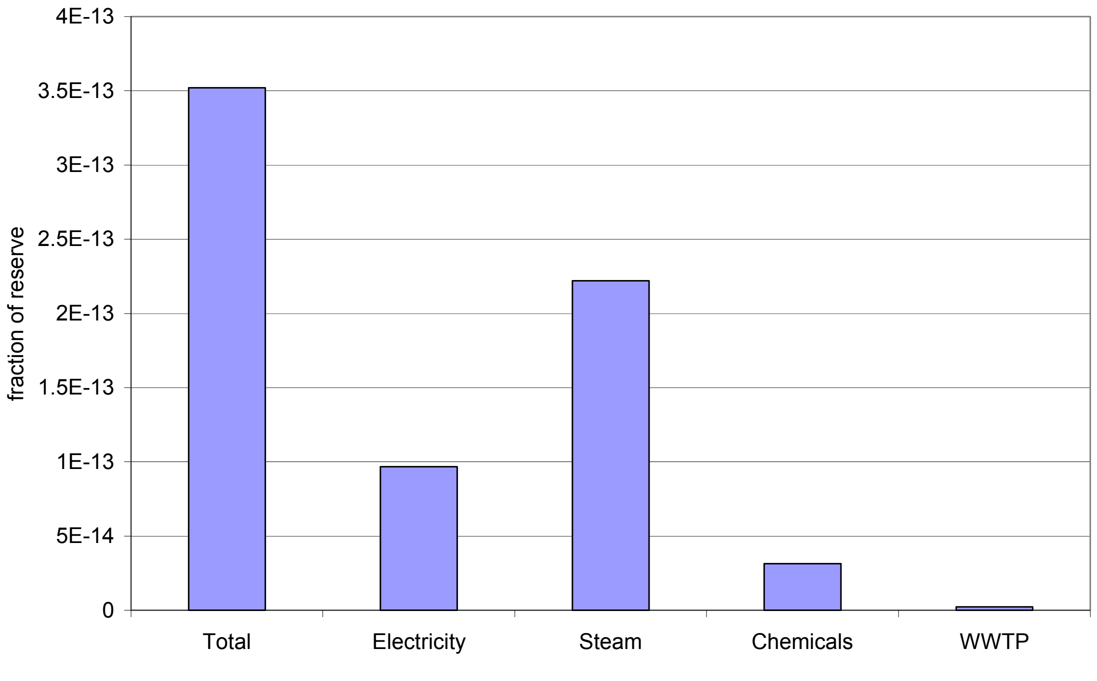


Figure 5.5 Depletion of non renewable resources

The main resource which contributes to total value is natural gas (87%).

5.1.7 Human toxicity

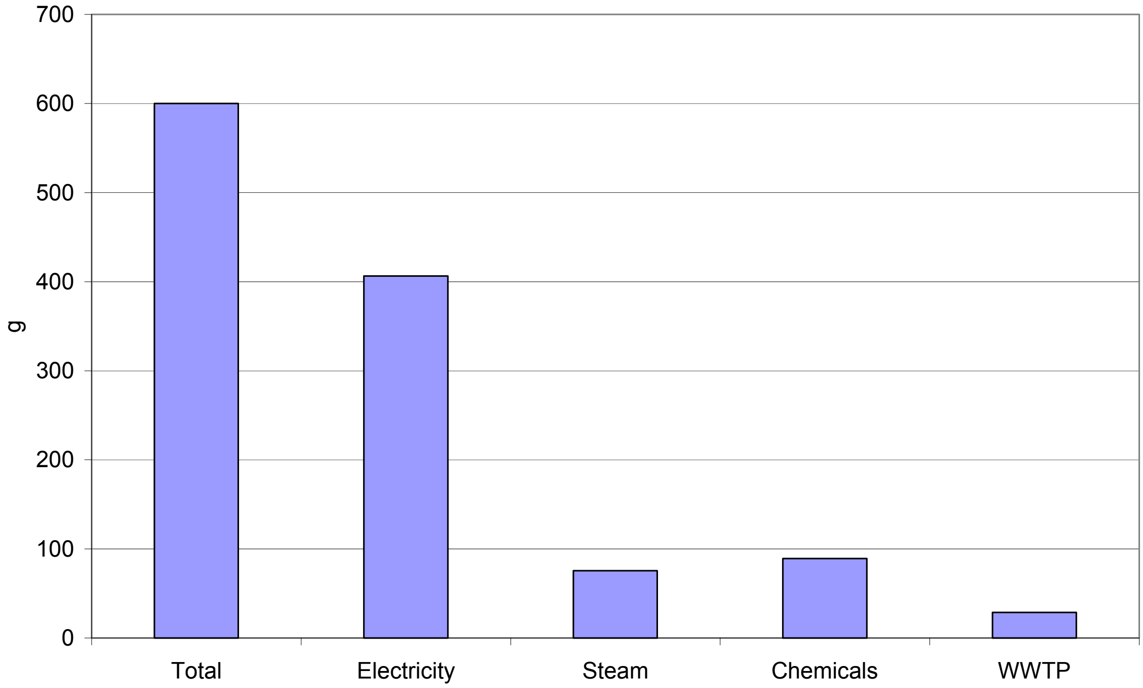


Figure 5.6 Human toxicity

Chemicals have significant contribution because of the production of Hydrogen Peroxide (Desizing/Bleaching) and Sodium Hydroxide (Desizing/Bleaching ans Sulphur Dyeing).
The main airborne emissions which contribute to total value are sulphur oxides (57%) and nitrogen oxides (22%).

5.1.8 Terrestrial ecotoxicity

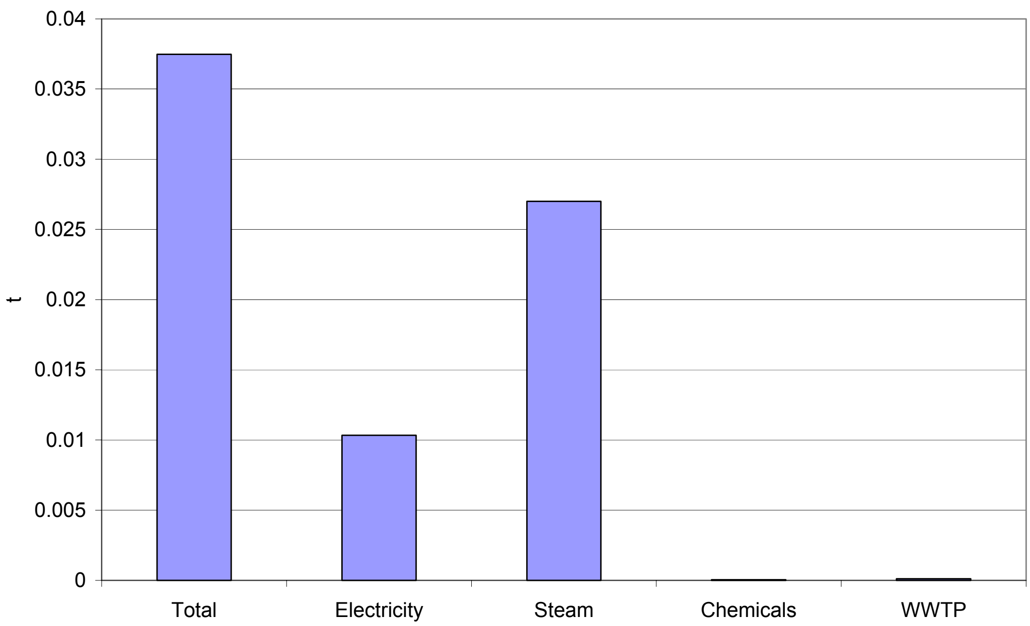


Figure 5.7 Terrestial ecotoxicity

The main soil emission which contribute to total value is zinc (83%).

5.1.9 Eutrophication

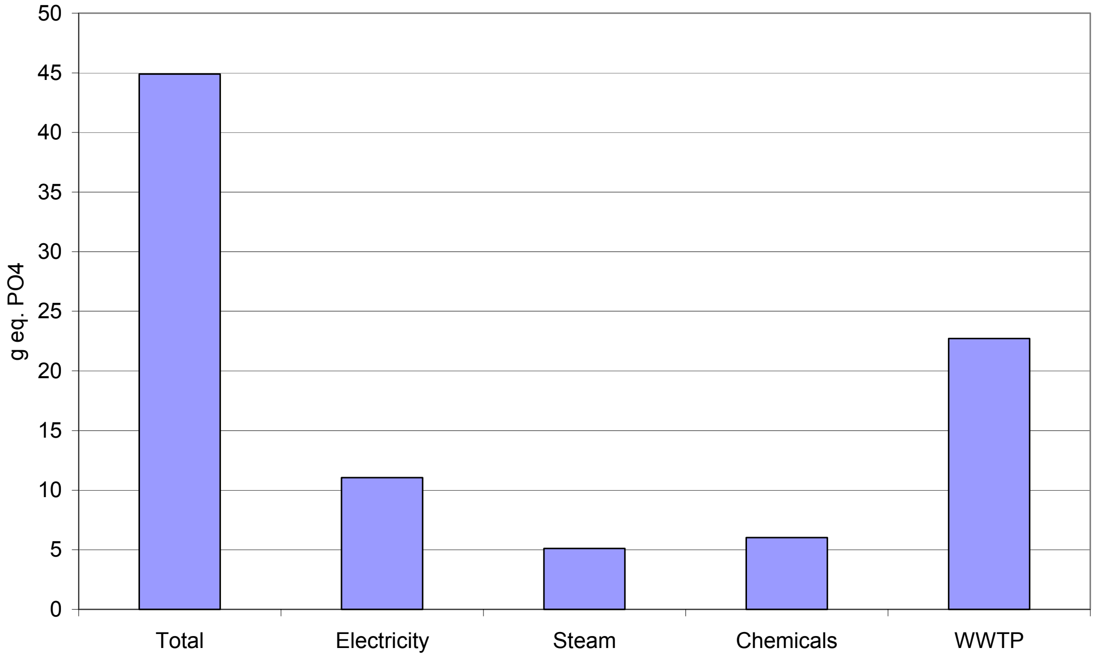


Figure 5.8 Eutrophication

Chemicals have significant contribution because of the production of Hydrogen Peroxide (Desizing/Bleaching). The main waterborne emissions which contribute to total value are nitrogen oxides (49%), nitrogenous matter (29%) and ammonia (12%).

5.1.10 Greenhouse effect

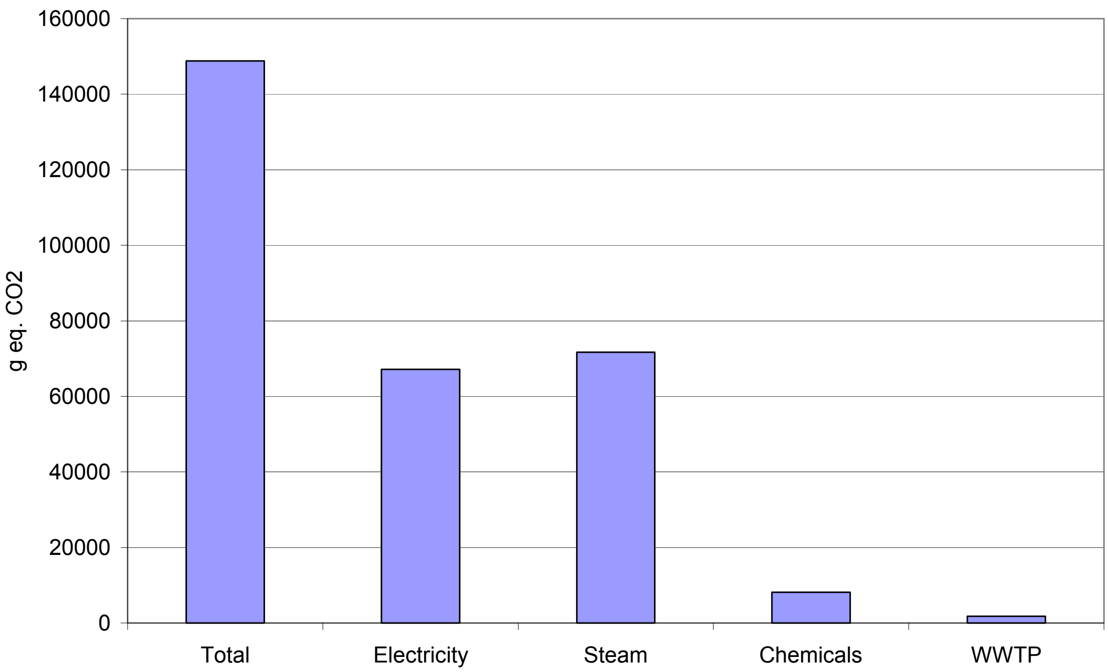


Figure 5.9 Greenhouse effect
The main airborne emission which contributes to total value is carbon dioxide (95%).

5.1.11 Photochemical smog

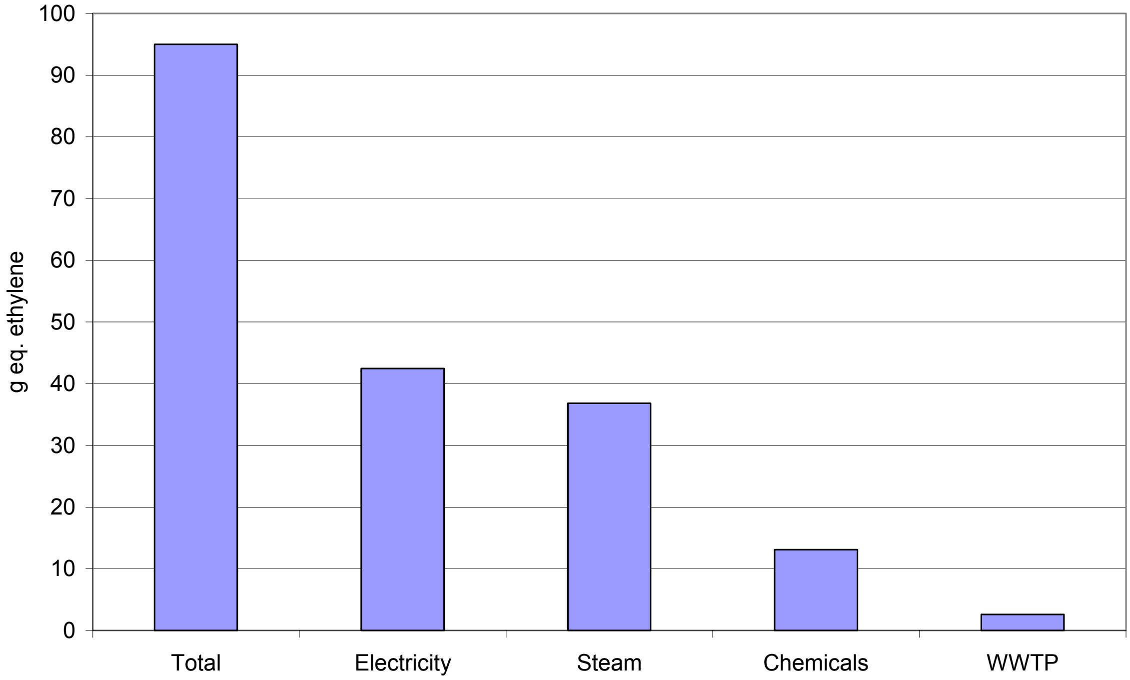


Figure 5.10 Photochemical oxidant formation

Chemicals have significant contribution because of the production of Hydrogen Peroxide (Desizing/Bleaching). The main airborne emissions which contribute to total value are hydrocarbons (48%), ethylene (23%) and methane (10%).

5.2 Comparison of System A and Sytem B

Inventory and impact assessment results of System B were compared to the results of System A. (see Figures 5.11-12)

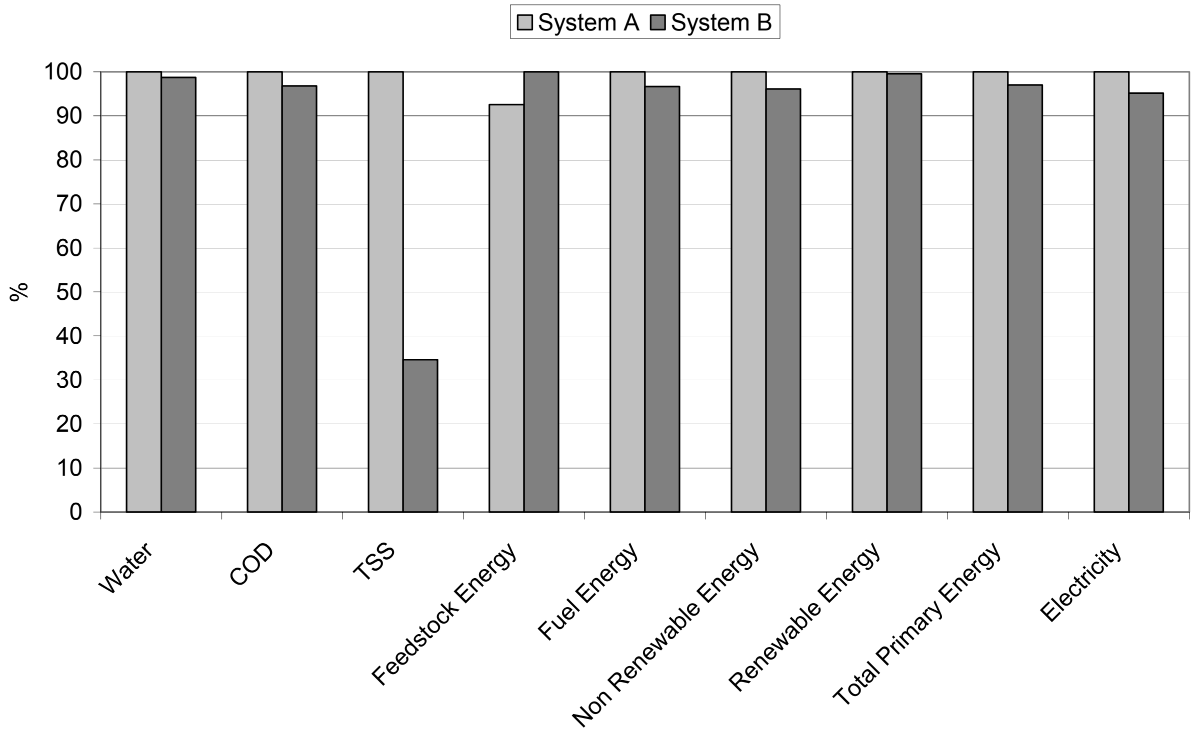


Figure 5.11 Comparison of water consumption, COD- and TSS emissions and energy indicators of System A and B

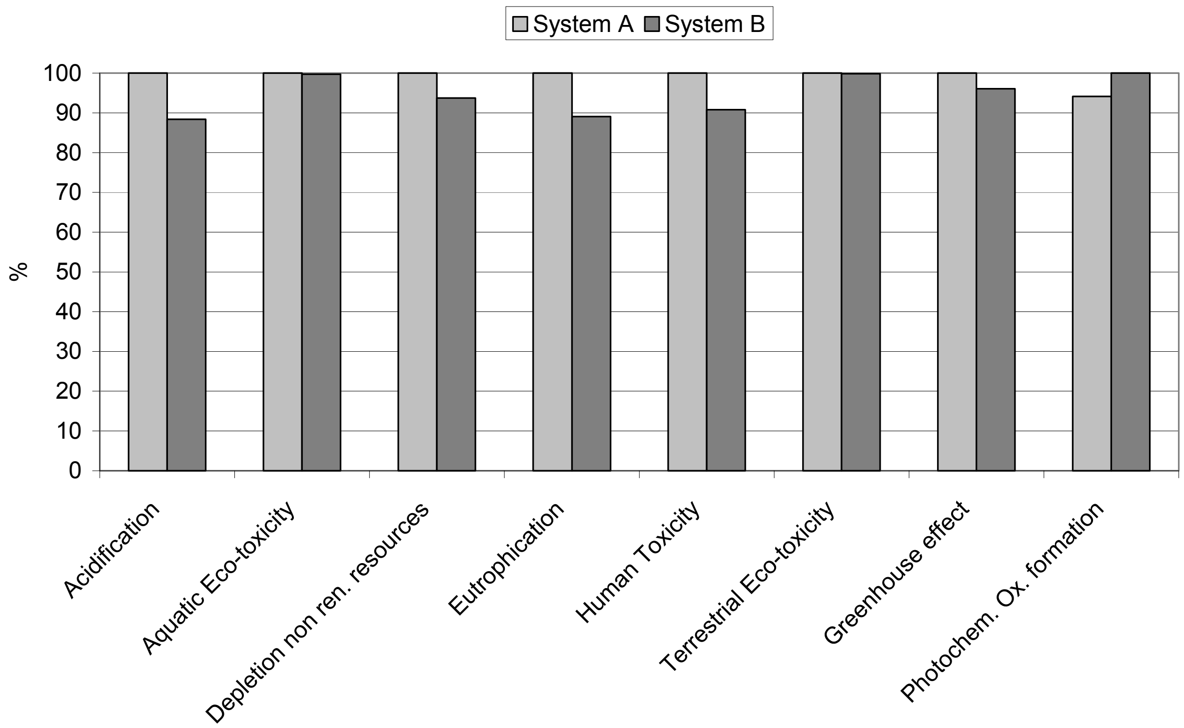


Figure 5.12 Comparison of impact assessment results of System A and B

System B has lower total values for most of the inventory and impact categories. Significant differences (more than 10%) were identified for acidification and eutrophication (because of the use of Hydrogen Peroxide in Bleaching of System A) and for TSS value (because of the lack of data in Vat Dyeing of System B).

5.3 Evaluation

5.3.1 Completeness check

The LCA study cannot be considered complete because of several lack of data regarding:

- concentration of some chemicals,
- COD and TSS emissions of some processes,
- solid waste,
- airborne emissions,
- transport of chemicals,
- production of numerous chemicals,
- general facilities.

5.3.2 Sensitivity check

5.2.2.1 Allocation of electricity

Annual electricity consumption was allocated to the reference flow on a mass basis. Electricity could be allocated to single processes on the basis of their working time. Sensitivity of final results to the allocation rule was checked.

Table 5.2 summarises the results of the allocation rule based on “working time”. Working times were calculated on the basis of yearly and hourly produced fabric amounts.

Table 5.2 Allocation of electricity consumption on a mass basis

Equipment	pretreatment line	pad-steam	sanfor	warp dyeing line
Item	PT1	PS1	SF1-2	WDL1-4
Processed fabric (kg/yr)	5 796 000	7 507 000	7 507 000 (SF1) + 9 270 000 (SF2)	9 480 000 (for all 4)
Processed fabric per hour (kg/h)	1500	1 700	1700 (on each of the sanfors)	350
Calculated working ours (h/yr)	3864	4416	4416 +5453	27086 (for all 4)
Allocated electricity (kWh/100 kg)	58.35	51.48	51.48	250.08

Table 5.3 shows the deviation of total values of impact assessment results change due to the application of the allocation rule based on working time.

Table 5.3 Deviation of total results of System A due to the applied allocation rule for electricity consumption

	Deviation of total results
Air Acidification	20%
Aquatic Eco-toxicity	13%
Depletion of non renewable resources	9%
Eutrophication	8%
Human Toxicity	22%
Terrestrial Eco-toxicity	9%
Greenhouse effect	14%
Photochemical oxidant formation (high)	14%
Feedstock Energy	27%
Fuel Energy	16%
Non Renewable Energy	11%
Renewable Energy	32%
Total Primary Energy	17%
Electricity	29%

Table 5.3 shows that results of System A of most of the impact categories are significantly sensitive to the allocation rule applied for electricity consumption (total values change more than 10%). This conclusion is also valid for System B because it has the same electricity consumptions and similar final results (see Figures 5-11 and 5-12).

5.2.2.2 Contribution analysis of steam and electricity

Steam and electricity consumptions are significant for several inventory and impact categories. The allocation rule applied for the definition of process specific steam and electricity consumptions (described in Chapters 3.2.1.2-3.2.1.3) is based on theoretic calculations and not direct measurements. A contribution check was necessary to analyse the uncertainty of these assumptions to the final results.

Table 5.4 shows the contribution of electricity and steam production into the impact categories. There are several categories where one (or both) of these issues has/have more than 40% of contribution. It means that a 25% of uncertainty of data can cause 10% of deviation of the final results.

Table 5.4 Contribution of electricity and steam production into total results of System A

	Contribution Electricity	Deviation (25% uncertainty of electricity)	Contribution Steam	Deviation (25% uncertainty of steam)
Air Acidification	64%	16%	14%	4%
Aquatic Eco-toxicity	40%	10%	55%	14%
Depletion of non renewable resources	28%	7%	63%	16%
Eutrophication	25%	6%	11%	3%
Human Toxicity	68%	17%	13%	3%
Terrestrial Eco-toxicity	28%	7%	72%	18%
Greenhouse effect (direct, 100 years)	45%	11%	48%	12%
Photochemical oxidant formation (high)	45%	11%	39%	10%
Feedstock Energy	86%	22%	6%	2%
Fuel Energy	51%	13%	44%	11%
Non Renewable Energy	35%	9%	58%	15%
Renewable Energy	99%	25%	0%	0%
Total Primary Energy	52%	13%	42%	11%
Electricity	90%	23%	2%	1%

System B has a similar sensitivity to these aspects because of its same electricity and steam consumptions and its similar final results (see Figures 5-11 and 5-12).

5.2.2.3 Lack of data about chemicals

The lack of data about the production of several chemicals of System A and B can influence final results. To analyse the sensitivity of systems, surrogate inventory data on the production of organic and inorganic chemicals were used [12]. Table 5.5 shows the deviation of final results due to the application of these surrogate data.

Table 5.5 Deviation of total results because of lack of data

	System A	System B
Acidification	11%	22%
Aquatic Eco-toxicity	8%	15%
Depletion non ren. resources	4%	9%
Eutrophication	3%	7%
Human Toxicity	12%	23%
Terrestrial Eco-toxicity	1%	2%
Greenhouse effect	5%	9%
Photochem. Ox. formation	8%	14%
Water	1%	1%
Feedstock Energy	26%	49%
Fuel Energy	4%	8%
Non Renewable Energy	6%	12%
Renewable Energy	1%	2%
Total Primary Energy	5%	9%
Electricity	4%	9%

5.3.3 Consistency check

The LCA study can be considered consistent. Most of the data are from PIDACS or from TEAM 3.0 modules which guarantee a good general consistency. Processes having a different origin are the waste water treatment plant (Lariana Depur) and the production of sodium hydrosulfite (KCL Eco) which influence on the overall system is limited.

6 Conclusions

For the Life Cycle Assessment of cotton products of the B02 company the following main conclusions can be drawn:

- The product system requires 25 litre of water for 1 kg of product. Only a negligible amount is consumed out of the company gates. Water consumptions of dyeing and pre-treatment processes are the highest (38-48%).
- Production of electricity has significant contribution (25-90%) to each impact category. The analysed systems are very sensitive to this issue: the application of different allocation principles (based on working time instead of mass) causes a 10-30% deviation of total values.
- Process specific steam consumption was calculated applying an allocation rule based on mass. A contribution check demonstrated that uncertainty of this calculation influences significantly inventory and impact assessment results.
- Significant contributions of Hydrogene Peroxide production (for bleaching in System A) causes significant differences between the two systems concerning acidification and eutrophication impact categories.
- COD and TSS emissions arise from pretreatment and dyeing processes but exact interpretation is not possible because of lack of data.
- It must be highlighted that the LCA study has a relevant lack of data on chemicals production. A sensitivity check, using surrogate data on organic and inorganic chemicals demonstrated the importance of this aspect: final results of acidification, human toxicity and feedstock energy indicator change 11-26% in System A; and System B shows a still higher sensitivity having a deviation of 12-49% for acidification, acquatic ecotoxicity, human toxicity, photochemical oxidant formation, feedstock and non renewable energy indicators.
- Eutrophication impact category hot-spot is the wastewater treatment plant because of its emissions to water (50% contribution to the total of category).

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[13] Ferri, F. and Tarantini, M., AQUASAVE project-Life cycle Assessment of drinking water and wastewater treatments of Bologna city (in Italian), ENEA OT-SCA-00024 Rev 2, 2001
[14] IPPC Guideline for National Greenhouse Gas Inventories: Reference Manual, 1996.

Annex 1 : Structure and content of PIDACS

Company:
Date:

a) Production:

Reference year:

Fiber	*Type*	*processed kg*
TOTAL:		

Notes:

b) Water use:

Reference year:

b.1) Supplied water:

Source	*Quantity [m^3/yr]*	*Cost [€/m^3]*
TOTAL:		

Notes:

b.2) Process water and treatment for internal use:

Water type	*Source*	*Treatment*	*Use*	*Quantity [m^3/yr]*	*Treatment specific cost [€/m^3]*

Notes:

b.3) Process water analytic features:

Source-Type		
T [°C]		
Conductivity [mS/cm]		
Hardness [°F]		
pH [-]		
COD [mg/l]		

TSS [mg/l]		
Fe (mg/l)		
Mn (mg/l)		
- - - - -		

Notes:

b.4) Steam production:

Source-Type	*Quantity [m³/yr]*	*T max [°C]*	*Use*

Notes:

b.5) Discharged water:

Type		
Quantity [m³/yr]		
Final destination		
Features:		
T [°C]		
Conductivity [mS/cm]		
Hardness [°F]		
pH [-]		
COD [mg/l]		
BOD5 [mg/l]		
SST [mg/l]		
Total N [mg/l]		
N-NH4 [mg/l]		
N-NO2 [mg/l]		
N-NO3 [mg/l]		
Ptot [mg/l]		
Absorbance 420 nm		
Absorbance 550 nm		
Absorbance 680 nm		
Anionic surf. [mgMBAS/l]		
Non-ionic surf. [mgBiAS/l]		
Cationic surf. [mg/ l]		
Chlorides [mg/l]		
Chlorine [mg/l]		
AOX [mg/l]		
Chrome [mg/l]		
Copper [mg/l]		
Endocrine activity		
Hydrocarbons [mg/l]		
Iron [mg/l]		
Manganese [mg/l]		

Nickel [mg/l]		
Zinc [mg/l]ì		
Toxic Units (for algae)		
Toxic Units (for fish)		
Toxic Units (for bacteria)		
Toxic Units (for invertebrates)		

Notes:

c) ENERGY CONSUMPTIONS:

Source	*Unit*	*Use*	*Quantity*	*Specific cost [€/]*

Notes:

d) DEPARTMENTS AND WORKING TIME:

Department.	*Operating days*	*Daily operating period*	*Weekly operating period*	*N° of shifts per days*

Notes:

e) EQUIPMENT:

Department.	*Equipment*	*Item*	*Quantity*	*Operating*	*Bath Volume [m^3]**

Notes:

ANNEXES (***<u>all sheets have to be considered as relevant part of the whole document</u>***):

- **An.1**: ***Material flow chart***;
- **An.2: *Energetic flow chart***;
- **An.3**: ***Water flow chart;***
- **An.4**: ***Production model;***
- **An.5**: ***Preparation, Dyeing, Finishing - Process scheme;***
- **An.6: *Water consumptions;***
- **An.7**: ***Water discharges;***