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TITLE:

Life Cycle Assessment of silk- and charged silk yarn in I09 company

KEY WORDS:

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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 5th 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 silk yarn products within I09 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 I09 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

I09 is an Italian company located in the Como area. Its annual production is over 1080 tons of textile product mainly made of silk yarn (69.5%) and silk fabric (24%). The general organisation of the company production departments is highlighted in the following material flowchart.

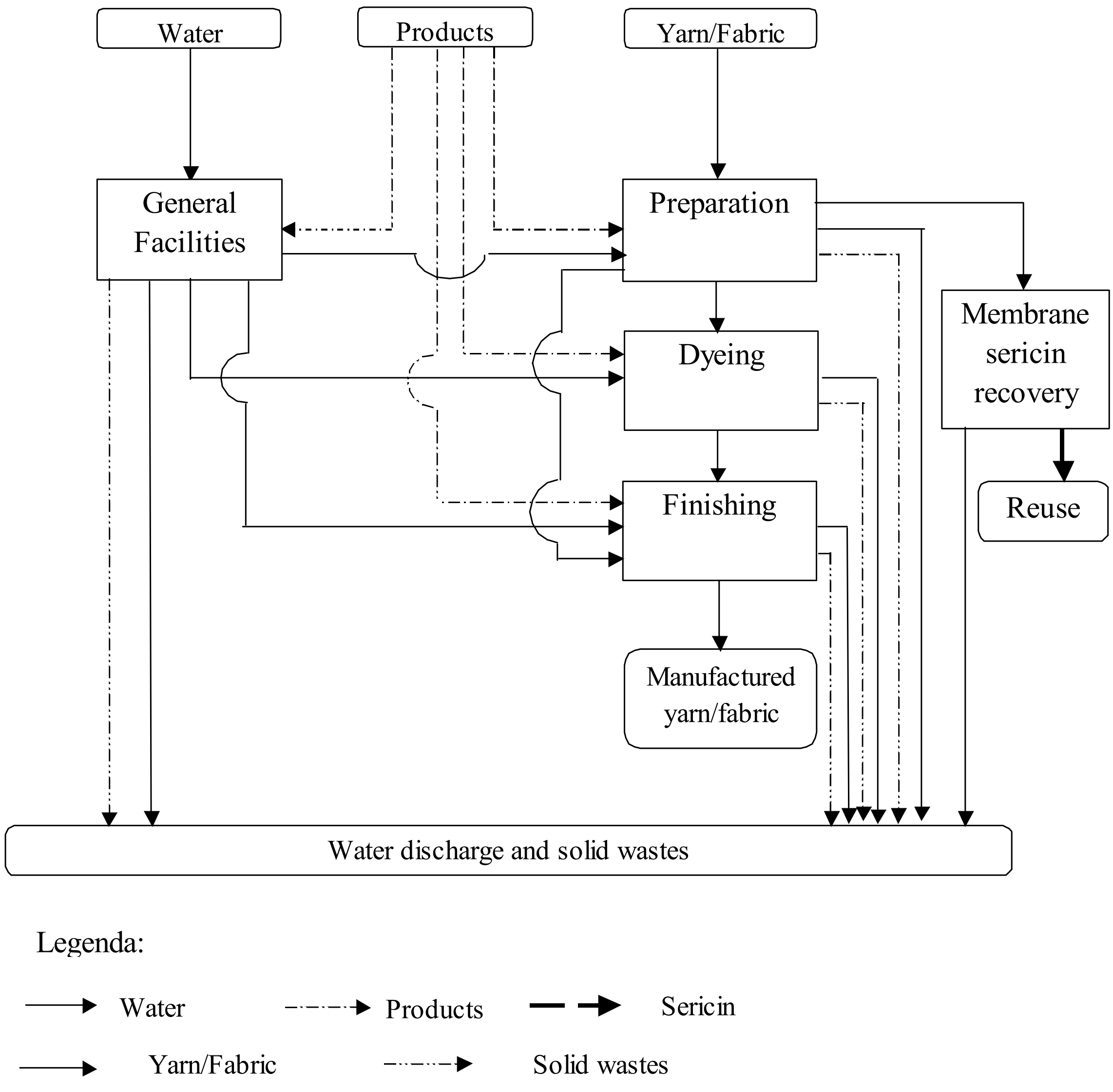

Fig. 2.1 Material flowchart of I09 company

A more detailed description of I09 company is available in the Process Identification and data Collection Sheet (PIDACS) of the company.

In this study two silk yarn product alternatives were analysed:

- Silk yarn dyed with dark colours (System A);
- Charged silk yarn dyed with dark colours (System B);

The general flow-chart of the two systems is shown in Fig 2.2. Pre-treatment processes depend on the entering silk yarn characteristics: scouring or charging of the yarn is necessary. In case of scouring, the waste water has to be treated in membrane ultra-filtration process for the recovery of sericin.

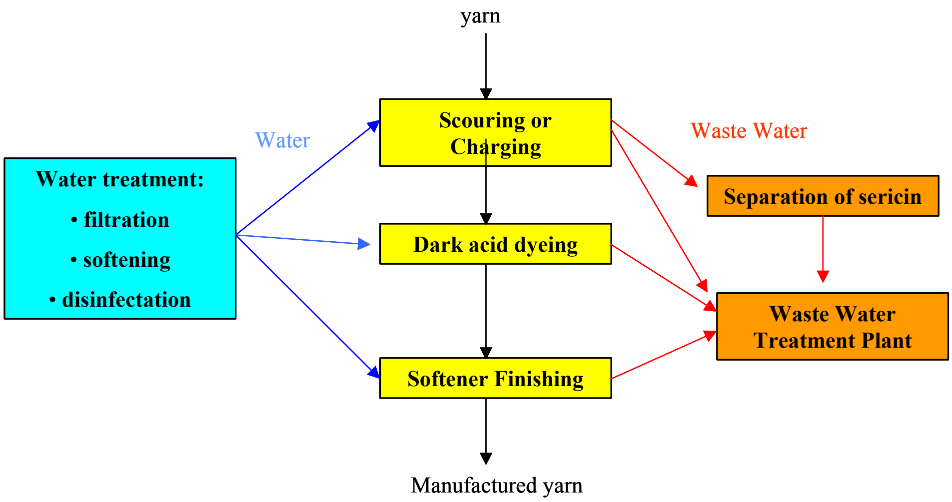

Fig.2.2 Schematic flowchart of analysed silk yarn products
(Separation of sericin is missing in case of charging pre-treatment)

Table 2.1 shows the textile wet processes of the two product systems; the process numbers refer to I09 PIDACS classification.

Product systems	System A	System B
HT Scouring	F.1.3	-
Polymer charge	-	F.2
Silk dark acid dyeing	G.6.2	-
Charged silk dark acid dyeing	-	G.6.3
Softener finishing	H.1.1	H.1.1

Table 2.1 Textile wet processes of the product systems

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].

HT Scouring

To prepare a silk yarn for dyeing, it is necessary to partially or completely remove sericin, as well as natural oils and organic impurities. Depending on the percentage of sericin removed during scouring, the end-product is defined as unscoured (use only for shirts and suits), "souple" or degummed.

The scouring treatment can be carried out in a neutral, acid or alkaline solution, depending on the desired results. At the industrial level, treatment in alkaline conditions is by far the most common. It is extremely important to control the temperature.

Polymer charge

The weighting operation is carried out mostly on yarns to promote recovery of the weight loss after the removal of the sericin. The treatment consists in the deposition of tin salts or in grafting polymer chains to the functional groups of the fibroin protein chain.
Grafting vinyl monomers onto silk represents an alternative to the traditional mineral weighting. Such a method not only allows the desired weight increase to be achieved, but also improves silk characteristics and performance. Co-polymerisation with vinyl monomers is carried out using radical activation methods (redox systems, UV, γ rays etc).
Methacrylamide (MAA) is one of the most frequently applied monomers at the industrial level. MAA weighting is a simple application. Radical activation is obtained through ammonia or potassium persulphate.

Acid dyeing
Silk is dyed with the same dyes as wool. In addition, direct dyes can be used. The dyeing pH is slightly higher than with wool.
Acid dyes are typically applied in acidic conditions, but the used pH range depends on the type of acid dye. The greater the affinity of the dyestuff for the fibre, the more the hydrophobic interaction must be repressed by applying the dye at higher pH:

- level-dyeing colorants are applied under strongly acidic conditions in the presence of sulphate ions to assist migration and levelling;
- fast acid dyes exhibit superior fastness properties, while retaining some of the migration properties;
- acid milling dyes have good affinity for the fibre and do not migrate well at the boil.

Levelling agents play an important role in acid dyeing. A number of non-ionic, cationic, anionic and amphoteric surfactants belong to this category.

Softener finishing
The term “finishing” covers all those treatments that serve to impart to the textile the desired end-use properties. These can include properties related to the visual effect, handling 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).The application of softening agents does not involve curing processes.
All processes use sand filtered, softened (by means of ion exchange resins) and disinfected (by means of UV lamp) water.
The wastewater treatment for all the analysed Italian companies is performed in a centralised WWTP which treats also municipal effluents.
A detailed description of the studied systems is available in chapter 3.2.
A general description of the equipment 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 silk yarn, 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 silk yarn, 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 silk yarn.

2.2.4 System boundaries of product system

The system boundaries of the two studied product alternatives are shown in Fig. 2.3. The processes included in the analysis are included in the system bold line.

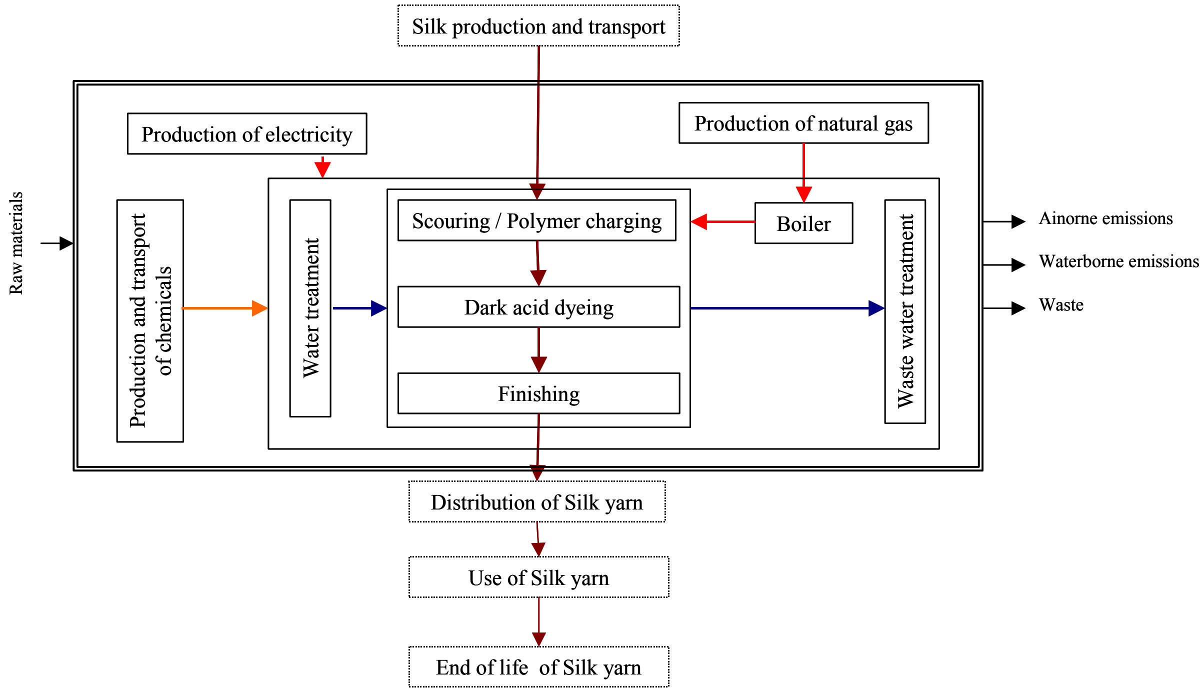

Fig 2.3 System boundaries of I09 product systems.

The processes excluded from the system boundaries are:

- silk 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:

- HT Scouring

- polymer charge
- silk dark acid dyeing
- charged silk dark acid dyeing
- softener finishing
- water treatment (sand filtration, ion-exchange softening, disinfection)
- membrane ultra-filtration for recovery of sericin.

TEAM 3.0/Ecobilan data:
- production of electricity;
- production of methane;
- transport processes;
- boiler: general model whose process parameters and efficiency are adjusted to I09 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. Chemicals were treated as flows and characterised in the impact assessment (see Chapter 2.2.8). 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 5.2.2.2).

2.2.7 Data quality requirements

The on site data gathered in this study have the following characteristics:
- Time related coverage: All the I09 data are related to year 2000;
- Geographical related coverage: the data are company specific and reflect the Como area situation.

To model the two product systems several assumptions were necessary:

Main assumptions within the company boundary:

- Steam production

The annual company methane consumption as well as the annual steam consumption are measured and reported on the I09 PIDACS. The 95% of the methane is used for industrial processes described in the PIDACS, the remaining part is used for heating the factory shed (estimation of the company technicians). To evaluate the specific methane consumption for processes, the specific consumption of steam has been calculated (m^3 of steam/kcal of required heating energy). The calculation of "required heating energy" took in account the volume of water to be heated, the bath temperature and the inlet water temperature. To calculate the emissions of methane burning and the natural resources consumption, the TEAM 3.0 model developed by Ecobilan was used, adjusting the water inlet and the steam outlet temperatures on the actual company data and calibrating the steam generator efficiency.

- Process specific wastewater effluent

The wastewater effluent from the company specific processes has been characterised only with measured COD and TSS concentration, due to unavailability of specific contaminant concentration.

- Electricity consumption

The electricity consumption of specific processes has been calculated as absorbed power * run time. The electricity consumption for lighting and general services has been neglected as generally accepted in LCA studies because it is not relevant for the specific objectives of this study.

- Water pre-treatment (filtration, softening, disinfection)

Water is consumed and discharged in bed-expansion, backwashing and regeneration of sand filter and ion exchange softener. These consumptions and emissions were neglected because of their low value compared to water treatment capacities (less then 3%). The potential impact of the production of the ionic exchange resins was neglected, due to the very small quantities used.

- Solid waste

The annual solid waste production of the company is specified in the PIDACS. The waste has been classified in three main fluxes: recycled waste (divided in packaging, iron and steel, plastic waste), special waste and special dangerous waste. The total waste quantity has been allocated to the analysed product systems on a mass basis. The solid waste treatment has not been included in the systems, because of lack of specific data and the difficulty to identify reference treatment scenarios.

- Airborne emissions.

PIDACS specifies for each emission source, typically a specific equipment, the chimney flow rate and the contaminant concentration. For LCA purposes the contaminant emissions in the environment have been calculated as: [emission source flow rate]x[equipment run time]x [contaminant concentration]. If the concentration has been indicated as < limit value, the specific limit value has been assumed.

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 Lariana 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 silk 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.

2.2.8 Impact assessment methods

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

Table 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	fraction. 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
Because of project limits (detailed analyses of process wastewaters were not available) and methodological limits (characterisation factors are available only for a small part of the manufactured chemicals), the EDIP (Environmental Design of Industrial Products method proposed by Wenzel and Haushild has been adopted for screening the potential impact of chemicals on ecotoxicity. A short description of the method is reported hereafter.
This EDIP screening method is based on the existing EU hazard classification of substances, available in the list of hazardous substances published by the EEC (1994). A semi-quantitative scoring of the substance in the inventory is obtained by calculating a score for exposure and a score for ecotoxicity, which are multiplied to give a final ecotoxicological impact score.

The idea behind multiplication of separate scores for exposure and ecotoxicity is that if emission of a substances is expected or if undesirable long term effects are possible, and the substance has some form of ecotoxicity, the score for environmental hazardousness will be increased significantly more than by simple addition. This is in agreement with a toxic property being assessed as having a greater environmental significance if the substance is emitted often, is not easily degradable or can undergo bioaccumulation.

Exposure score

The score for the exposure is a combination of expectation concerning emission (yes/no) and the possibility of undesirable long term effects on the environment (R53 or R58).
The two scores are added and their sum is multiplied by the score for ecotoxicity.
R53 is a classification assigned to substances which are not easily biodegradable or which are potential bioaccumulators, and where the following values are found for acute toxicity:
96-hour LC_{50} (fish)≤ 10 mg/l, or
48-hour EC_{50} (Daphnia))≤ 10 mg/l, or
72-hour IC_{50} (algae) 10 mg/l.
There are no criteria for assignment of an R58 classification, which refers to undesirable long term effects in environments other than the aquatic environment.

Ecotoxicity score

The score of ecotoxic effects is a combination of ecotoxicity to aquatic organisms(?) (R50-R51-R52 alone or in combination with other R phrases) and ecotoxicity to soil-dwelling organisms(?) (R54-R55-R54 R56-R57 alone or in combination with other R phrases). The two scores are added to give a total score for the substance's ecotoxicity (see table 2.3)

Tab. 2.3 Ecotoxicity scores

Aquatic ecotoxicity		Terrestrial ecotoxicity	
(**R50**….) $LC_{50} \leq 1$ mg/l	4	**R54** Toxic to flora or	4
(**R51**….) 1mg/l< $LC_{50} \leq 10$ mg/l	2	**R55** Toxic to fauna or	
(**R52**….) 10 mg/l< $LC_{50} \leq 100$ mg/l	1	**R56** Toxic to soil organisms or **R57** Toxic to bees	

If no ecotoxicity data are available for the substance, it is assigned an ecotoxicity score of 8 (4 for water compartment and 4 for the soil compartment); if the substance is, however, well know and considered to have no significant hazardous effects, it is assigned a score of 0.

Ecotoxicological impact score

The total ecotoxicological impact score for the emissions is calculated by multiplying the score for exposure and the score for ecotoxicity as shown in table 2.4.

Tab. 2.4 Impact assessment categories

	Ecotoxicity score 0	Ecotoxicity score 1	Ecotoxicity score 4	Ecotoxicity score 8
No emission and not classified as R53 or R58 (score 1)	0	1	4	8
Emission expected or R53 or R58 (score 4)	0	4	16	32
Emission expected and R53 or R58 (score 8)	0	8	32	64

2.2.9 Interpretation methods

In the interpretation phase of this study the potential environmental impact of the different processes has been evaluated, 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 (thermal energy) and lack of inventory data for chemicals.
A comparison of the different 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 I09 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 Lariana Depur.
The elaboration of PIDACS data required further details concerning processes of I09 company. This information was obtained from Lariana Depur by phone and 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 has been 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 Silk wet processing and general facilities

Annex 1 describes the general structure and content of the PIDACS.
In cooperation with Lariana Depur, the most representative production lines were identified and depicted in flow-charts of Figure 3.1.

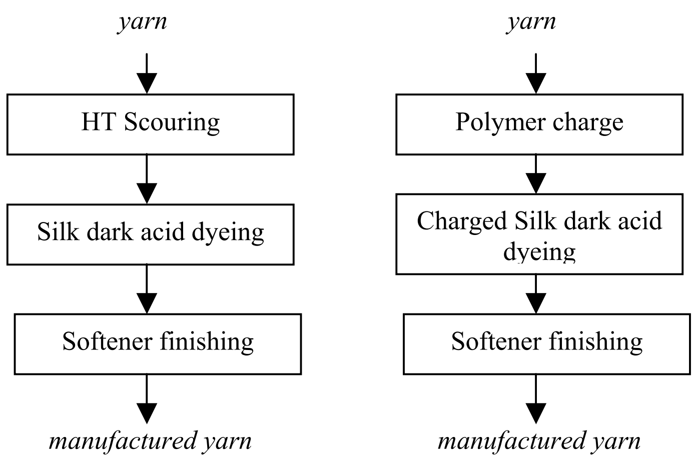

Figure 3.1 Flow-charts of the selected production lines

The most productive equipment was identified for each process of the selected production lines. Table 3.1 summarises the annual production of each process and the percentage contribution of autoclaves in I09 company. Three types of autoclave were selected for the inventory analysis based on their significant contribution to the annual production:

- BT352 for HT Scouring and Softener finishing: **200 kg yarn/run** capacity;
- BT600 for Polymer charge: **300 kg yarn/run** capacity;
- BT112 for Dark acid dyeing and for Charged silk dark acid dyeing: **40 kg yarn/run** capacity;

Table 3.1: Selection of equipment on the basis of annual production

	HT Scouring	**Polymer charge**	**Silk dark acid dyeing**	**Charged silk dark acid dyeing**	**Softener Finishing**
annual production (ton)	258,045	110,765	60,717	17,981	137,555
Equipment					
BT176	4%	3%	7%	7%	6%
BT176	4%	3%	7%	7%	6%
BT352	**43%**	22%	22%	22%	**24%**
BT600	32%	**45%**	9%	11%	12%
BT1040	16%	27%	15%	11%	16%
BT16			6%	7%	6%
BT64			7%	6%	5%
BT112			**27%**	**28%**	24%

Specific data of the selected equipment and related processes were extracted from the PIDACS.

Processes of general facilities were analysed, too. Data were collected and elaborated for the next facilities:

- Sand filtration of water: **291568 m^3 water/year** capacity;
- Ion exchange softening of water: **205300 m^3 water/year** capacity;
- Disinfection of water by UV lamp: **198800 m^3 water/year** capacity;
- Membrane ultra-filtration for sericin recovery: **562.5 m^3 water/year** capacity (calculated form 1500 l/run * 375 run/year);
- Steam production: **14890 ton steam/year** capacity.

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 of the selected equipment.

3.2.1.1 Water use

Table 3.2 shows the water consumption of the selected processes and equipment .

Table 3.2 Water consumption of processes

	Water consumption (l/run)	**Water consumption (m^3/year)**
HT Scouring		
1st bath	2000	-
2nd bath	2000	-
warm washing	2000	-
washing	2000	-
total	8000	-
Polymer charge		
bath	4000	-
1st warm washing	4000	-
2nd warm washing	4000	-
total	12000	-
Silk dark acid dyeing		
1st bath	650	-
1st washing	650	-
2nd washing	650	-
2nd bath	650	-
total	2600	-
Charged silk dark acid dyeing		
1st bath	650	-
1st washing	650	-
2nd washing	650	-
2nd bath	650	-
total	2600	-
Softener finishing		-
bath	2000	-
total	2000	-
Sand filtration of water		
bad expansion		298
rinsing		122
total		420
Ion exchange softening of water		
bad expansion		2940
regeneration		1206
washing		2352
total		6498
Membrane ultra-filtration		
backwashing		63
total		63

Water consumption of general facilities (except Membrane ultra-filtration) was neglected because it represents less then 3% of the treated water used in I09 company.

3.2.1.2 Electricity consumption

Table 3.3 describes the electricity consumption of each process.

Table 3.3 Consumption of electricity

	absorbed power (kW)	run time (h)	electricity (kWh/run)	number of run /year	working hours/year	electricity (kWh/year)
HT Scouring	4	1,1	4,4	-	-	-
Polymer charge	20	2,25	45	-	-	-
Silk dark acid dyeing	5	1,1	5,5	-	-	-
Charged silk dark acid dyeing	5	1,1	5,5	-	-	-
Softener finishing	4	0,75	3	-	-	-
Sand filtration of water (1)	6	1.75	-	15	-	315
Disinfection of water	1,14		-	-	5280	6019,2
Membrane ultra-filtration (2)	5	14,05	-	375	-	26343.7
Steam production (3)	45		-0-	-	2640	237600

(1) Sand filter consumes electricity during backwashing. Run-time and run/year are related to backwashing process. There are 2 sand filters, so electricity consumption is multiplied by 2.
(2) Membrane ultra-filtration consumes electricity during its filtration and backwashing. Run time was calculated by the estimation of 220 working ours.
(3) There are 2 boilers, so electricity consumption is multiplied by 2.

Electricity consumption of boilers for steam production has not been considered because these values are included in the TEAM steam generator model.

3.2.1.3 Methane consumption

Methane is consumed for steam production. 95% of methane is used 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 consumption. Allocation to specific processes of the annual consumption of steam and methane was made by calculating the energy needed for each process with the next formula:

"required heating energy"[kcal] = volume of heated water [m^3] * (bath temperature – initial water temperature)[°C] * density of water [kg/ m^3] * specific heat of water [kcal/kg*°C]

where:

- initial water temperature = 25 °C
- density of water = 1 kg/ m^3
- specific heat of water = 1 kcal/kg*°C

The value of "required heating energy" was calculated for each equipment of the I09 company and total methane consumption was allocated on the basis of the factor "total methane/ total "required heating energy".

Table 3.4 shows the annual consumption of methane and steam, and the factors used for allocation. Table 3.4 Values and factors used for calculation of process specific methane and steam consumption

	Unit	Value	Comment
methane consumption of I09	m^3 /yr	1320000	
methane consumption for water heating	m^3 /yr	1254000	95% of total methane consumption in I09
total “required heating energy”	kcal/yr	3802628	
factor “total methane/ total “required heating energy”	m^3 /kcal	0,32	
steam consumption	kg/year	14890000	
factor “steam/methane”	kg/ m^3	11,874	

Table 3.5 describes the calculation procedure for methane and steam consumption of processes of the selected production lines.

Table 3.5 Calculation of process specific steam consumption

	Heated water	Water temperature	Required heating energy	Specific consumption of methane	Specific consumption of steam	Total specific consumption of steam /year	Number of run	Specific consumption of steam
	(m^3/year)	(°C)	(kcal/bath)	(m^3/yr)	(kg/yr)	(kg/yr)	(run/year)	(kg/run)
HT Scouring								
1st bath	1104	130	115916	36315	431200			
2nd bath	1104	98	80589	25247	299787			
warm washing	1104	50	27599	8646	102667			
total						833654	552	**1510**
Polymer charge								
bath	331	70	11159	3496	41511			
1st warm washing	331	80	13639	4272	50736			
2nd warm washing	331	60	8679	2719	32287			
total						124535	124	**1004**
Silk dark acid dyeing								
1st bath	269	80	14776	4629	54967			
total						54967	413	**133**
Charged silk dark acid dyeing								
1st bath	81	90	5275	1653	19624			
total						19624	125	**157**
Softener finishing								
bath	335	30	1676	525	6234			
total						6234	168	**37**

3.2.1.4 Consumption of chemicals

Table 3.6 shows the concentration of chemicals used for each process. The mass of chemicals was calculated based on the volume of consumed water (see Chapter 3.2.1.1) or treated yarn (when concentration is defined in kg of chemicals/100 kg yarn [%]).

Table 3.6 Concentration of chemicals

	Solubilizing agent (10389)	Sequestering agent (10433)	Sequestering -dispersant agent (10299)	Metacrylamide (10073)	Ammonium sulphate (10012)	Formic acid (10005)	Acid buffer (10178)	Equalizing agent (10029)	Antifoaming agent (10404)	Sequestering agent (10263)	Acid dyestuffs	Acetic acid (10002)	Softener (10344)	Sodium chloride	Deoxygenating agent (S01)	Deoxygenating agent (S02)	Cationic detergent	Caustic soda (10016)
	g/l	g/l	g/l	%	%	g/l	g/l	%	g/l	g/l	%	g/l	%	g/l	g/l	g/l	% vol	g/l
HT Scouring																		
1st bath	5	2																
2nd bath			2															
Polymer charge																		
bath				80	8	5												
Silk dark acid dyeing																		
1st bath							1,5	0,17	0,5	0,8	1,5							
2nd bath												1						
Charged silk dark acid dyeing																		
1st bath							1,5	0,17	0,5	0,8	1,5							
2nd bath												1						
Softener finishing																		
bath												2	0,3					
Ion exchange softening of water																		
regeneration														199				
Membrane ultra-filtration																	0,5	2
Steam production (1)															0,117	0,04		

(1) Chemicals for steam production are used in evaporated water (14890 ton water/year).

Chemicals used for steam production have not been considered because general data on chemicals and materials consumption are included in the TEAM 3.0 model developed by Ecobilan.

3.2.1.5 Discharged water

Table 3.7 shows the COD and TSS concentrations of discharged waters. Masses of total COD and TSS were calculated by multiplying the concentration values and the consumed water at each process step (see Chapter 3.1.1.

Table 3.7 Discharged water

	COD (mg/l)	TSS (mg/l)
HT Scouring		
1st bath (1)	18785	1500
2nd bath	2900	25
warm washing	720	15
washing	220	25
Polymer charge		
bath	20384	100
1st warm washing	4782	46
2nd warm washing	850	15
Silk dark acid dyeing		
1st bath	2067	35
1st washing	426	15
2nd washing	131	10
2nd bath	1636	28
Charged silk dark acid dyeing		
1st bath	2067	35
1st washing	426	15
2nd washing	131	10
2nd bath	1636	28
Softener finishing		
bath	1200	30
Sand filtration of water		
bad expansion	10	10
rinsing	10	
Ion exchange softening of water		
bad expansion	10	
regeneration	10	
washing	10	
Membrane ultra-filtration		
ultra-filtration (2)	8227	
backwashing	500	150

(1) Discharged water of 1th bath of HT Scouring goes into membrane ultra-filtration process for sericin recovery.
(2) Membrane ultra-filtration produces 13125 l/run discharged water and 1875 l/run sericin. (375 run/year).

COD and TSS of general facilities (except Membrane ultra-filtration) were neglected because of their low values.

3.2.1.6 Airborne emission

Concerning processes of the selected production lines in I09 company, there were no emission sources related to the used equipment. Airborne emissions were therefore not allocated to the analysed processes.

3.2.1.7 Solid waste

The annual solid waste production of the company is specified in the PIDACS. The total waste quantity has been allocated to the reference flow of the analysed product systems on a mass basis. Table 3.8 describes annual and calculated values.

Table 3.8 Production of waste

	annual production (kg)	**normalised to ref. flow (kg)**	**destination of waste**
silk yarn	1079773	100	
150106 Packaging	71800	6,65	Incinerator
150101 Paper	44200	4,09	Recovery
120102 Iron-materials	4900	0,45	Recovery
160117 Iron	3300	0,31	Recovery

3.2.2 Production and transport 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. Chemicals were treated as flows and characterised in the impact assessment (see Chapter 2.2.8).

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 applied to evaluate the sensitivity of the product system (see Chapter 5.2.2.2).

Table 3.9 summarises the sources used for the production of each chemical of System A and B.

Transport of chemicals was considered on the basis of PIDACS data. Transport modules of the TEAM database were selected on the basis of type of freight. “Ton*km” values were calculated by the multiplying transported mass and distance values. (see Table 3.10)

Table 3.9 Chemicals

Code	Commercial Name	Composition	Chemical class	CAS number	Supplier	Source
10012	Ammonium Persulphate	Ammonium Persulphate	Ammonium sulphate	57727-54-0	Allchital spa	-
10016	Sodium Hydroxide	Sodium Hydroxide	Caustic soda Sodium hydroxide NaOH	1310-73-2	Allchital spa	TEAM
10029	Avolan UL 75	Alkil-amine-polyglycolic ether sulphate	Equalising agent	67-63-0	Bayer	-
10073	Metacrilamide	Metacrylamide	Metacrylamide	79-39-0	Rohm GmbH	-
10178	Sandacid VS liq.	Carboxylic acid ester	Acid buffer	107-21-1	Clariant Italia spa	-
10181	Sodium cloride (sale iperturo)	Salt	Sodium chloride		Allchital spa	TEAM
10263	Sandopur RSK liq.	Organic acid based compound	Sequestering agent		Clariant Italia spa	-
10299	Datexal P 2S	Sequestering -dispersant agents mixture	Sequestering-dispersant agent	1310-73-2	Datt Chimica srl	-
10344	Morbidol WE/N	35% polyxiloxane emulsion	Softener		Datt Chimica srl	-
10389	Solvodatt HT	Glycolic derivatives and surfactant mixture	Solubilizing agent	111-46-6	Datt Chimica srl	-
10404	Sancowad NSK liq.	Alcohol polyglycolether	Antifoaming agent	68439-46-3	Clariant Italia spa	-
10433	Conalan NO	Polycarboxilic polymer	Sequestering agent		Galbusera	-
10002	Acetic acid		Acetic acid	64-19-7	Allchital spa	TEAM
10005	Formic acid		Formic acid		Allchital spa	-
AD01	yellow Nylosan E-2RL SGR	Azoic dyestuff	Acid dyestuff		Clariant Italia spa	-
AD02	Red Lanasyn 2GLN 250	Chrome complex	Acid dyestuff		Clariant Italia spa	-
AD03	Blue marine Infanyl CRD	Azoic dyestuff	Acid dyestuff	6262-07-3	Infa srl	-
n.d.	n.d.	n.d.	Cationic detergent	n.d.	n.d.	-

Table 3.10 Types and distances of transport of chemicals

Code	Chemical class	Supplier	Type of freight	Distance from delivery [km]
10012	Ammonium sulphate	Allchital spa	3,5 tons< Lorry< 12 tons	< 10
10016	Caustic soda Sodium hydroxide NaOH	Allchital spa	3,5 tons< Lorry< 12 tons	< 10
10029	Equalising agent	Bayer	3,5 tons< Lorry< 12 tons	< 10
10073	Metacrylamide	Rohm GmbH	3,5 tons< Lorry< 12 tons	> 100
10178	Acid buffer	Clariant Italia spa	3,5 tons< Lorry< 12 tons	< 50
10181	Sodium chloride	Allchital spa	3,5 tons< Lorry< 12 tons	< 10
10263	Sequestering agent	Clariant Italia spa	3,5 tons< Lorry< 12 tons	< 50
10299	Sequestering-dispersant agent	Datt Chimica srl	3,5 tons< Lorry< 12 tons	< 10
10344	Softener	Datt Chimica srl	3,5 tons< Lorry< 12 tons	< 10
10389	Solubilizing agent	Datt Chimica srl	3,5 tons< Lorry< 12 tons	< 10
10404	Antifoaming agent	Clariant Italia spa	3,5 tons< Lorry< 12 tons	< 50
10433	Sequestering agent	Galbusera	3,5 tons< Lorry< 12 tons	< 50
10002	Acetic acid	Allchital spa	3,5 tons< Lorry< 12 tons	< 10
10005	Formic acid	Allchital spa	3,5 tons< Lorry< 12 tons	< 10
AD01	Acid dyestuff	Clariant Italia spa	Lorry < 3,5 tons	< 50
AD02	Acid dyestuff	Clariant Italia spa	Lorry < 3,5 tons	< 50
AD03	Acid dyestuff	Infa srl	Lorry < 3,5 tons	< 50
n.d.	Cationic detergent	n.d.	3,5 tons< Lorry< 12 tons (assumption)	< 10 (estimation)

3.2.3 Energy production

Modules of TEAM 3.0 were used for the production processes of electrical, thermal and mechanical energy.

To calculate the emissions of methane burning and the natural resources consumption of the boiler, the TEAM 3.0 model was calibrated.

As Chapter 3.2.1.3 describes, the boiler of I09 consumes 0,0842 m^3 of methane for the production of 1 kg steam. This amount of consumed methane corresponds to 2,74 MJ of energy input calculating with the next values:

- 0,72 kg/ m^3 is the density of the consumed methane,
- 1,13 kg methane extracted from the environment for supplying 1 kg combustible gas,
- 0,025 kg methane extracted from the environment for supplying 1 MJ consumable energy by combustion [6].

The model predefines some technical variables that influence methane consumption. Concerning I09 company, the following variables were modified:

- Initial temperature of water: 18 ^oC
- Final temperature of steam: 140 ^oC
- Boiler yield: 0.982

These variables result the consumption of 2,74 MJ of energy / 1 kg of steam.

3.2.4 Waste water treatment plant (WWTP)

Table 3.11 summarizes the data used to model the WWTP.

Table 3.11 Data use for the WWTP

	Units	Value
INPUT		
Wastewater	litre/year	8.87E+09
Electricity	MJ/year	2.90E+07
Transport: Road (diesel oil, kg.km)	kg.km/year	8.99E+08
OUPUT		
(w) Ammonia (NH4+, NH3, as N)	g/year	6.00E+07
(w) COD (Chemical Oxygen Demand)	g/year	5.19E+08
(w) Nitrates (NO3-)	g/year	7.89E+07
(w) Nitrites (NO2-)	g/year	1.77E+06
(w) Nitrogenous Matter (unspecified, as N)	g/year	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% for an impact category- were selected. In table 3.12 and 3.13 the quantities of these main flows are presented.

The tables show water consumption and COD and TSS emission of the textile industrial processes, too.

Table 3.12 Results of inventory analysis of I09 silk yarn-System A (only main flows are listed)

Flow	Units	Total	HT Scouring	Dark acid dyeing	Softener Finishing	Water Sand Filtration	Water Softening	Water Disinfection	Membrane ultra-filtration	Waste water treatment
INPUT										
(r) Coal (in ground)	kg	4.744853	1.5473	1.60029	0.386131	0.000793022	0.22746	0.0222247	0.301416	0.659239
(r) Iron (Fe, ore)	kg	0.389216	0.252746	0.118724	0.00824597	0.00000675	0.00114589	0.000189036	0.00254231	0.00561581
(r) Natural Gas (in ground)	kg	78.81013	52.1761	23.9012	1.5451	0.00083775	0.146709	0.0234783	0.31806	0.698664
(r) Oil (in ground)	kg	9.71374	0.833885	3.49005	2.51422	0.00213062	0.141617	0.0597115	0.803586	1.86849
(r) Uranium (U, ore)	kg	0.000171	0.000101282	0.0000495	0.0000144	7.45E-11	0.00000472	2.09E-09	0.000000925	6.21E-08
Water (gate to gate)	l	11511.2	4000	6500	1000				11.2	
Water (out of gate)	l	231.1083	108.505	63.1514	14.8422	0.010552	31.0992	0.295731	4.03378	9.17076
OUTPUT										
(a) Alkane (unspecified)	g	10.48942	6.06012	3.21678	0.844398	0.000270885	0.0309883	0.00759166	0.102013	0.227213
(a) Arsenic (As)	g	0.005095	0.00100736	0.00189878	0.000389625	0.00000133	0.000149203	0.0000373	0.000501847	0.00110923
(a) Benzene (C6H6)	g	1.460116	0.902478	0.447728	0.0536743	0.0000382	0.00822082	0.00106921	0.0143678	0.0325353
(a) Butane (n-C4H10)	g	3.577363	1.80591	1.17612	0.125806	0.000353264	0.0253669	0.00990038	0.133039	0.300863
(a) Cadmium (Cd)	g	0.008472	0.000982691	0.0033395	0.000607926	0.00000272	0.000170343	0.0000763	0.0010248	0.00226818
(a) Carbon Dioxide (CO2, fossil)	g	222268.9	132113	69551.6	6435.89	10.2202	1186.05	286.424	3873.61	8812.4
(a) Carbon Monoxide (CO)	g	137.8363	79.6132	41.7336	7.86482	0.00415864	2.51289	0.116548	1.57637	4.41484
(a) Ethane (C2H6)	g	18.55123	7.16842	6.39837	1.20161	0.00287636	0.200637	0.080611	1.08321	2.41549
(a) Ethylene (C2H4)	g	39.12946	25.7741	11.8723	0.8131	0.000459982	0.0998204	0.0128912	0.173223	0.383607
(a) Hydrocarbons (except methane)	g	106.9983	32.7806	35.9999	17.7031	0.0147437	1.11951	0.413198	5.55305	13.4141
(a) Hydrocarbons (unspecified)	g	27.24887	0.0165835	7.86672	19.3259	0.0000086	0.00213325	0.000240941	0.0301176	0.00720666
(a) Hydrogen Chloride (HCl)	g	4.168249	1.23021	1.42124	0.347443	0.000765578	0.196034	0.0214556	0.314513	0.63658
(a) Lead (Pb)	g	0.023393	0.00532926	0.00862966	0.00164935	0.00000578	0.000613969	0.00016185	0.00218604	0.00481748
(a) Manganese (Mn)	g	0.019765	0.0124744	0.00604517	0.000531213	0.000000471	0.000131724	0.0000132	0.000177246	0.000391662
(a) Methane (CH4)	g	453.31	164.109	158.059	29.3043	0.0769293	6.12344	2.15597	29.0424	64.4379
(a) Nickel (Ni)	g	0.167252	0.0195891	0.0659032	0.0120249	0.0000536	0.00334519	0.0015026	0.020191	0.0446418
(a) Nitrogen Oxides (NOx as NO2)	g	168.9923	76.009	55.3328	8.05096	0.0189474	2.39281	0.531008	7.24307	19.4138
(a) Nitrous Oxide (N2O)	g	0.962393	0.346729	0.324341	0.0458715	0.000150777	0.0180333	0.00422558	0.0568193	0.166221
(a) Propane (C3H8)	g	5.075934	2.16385	1.73235	0.220543	0.000724125	0.0560086	0.0202939	0.2727	0.60947
(a) Sulphur Oxides (SOx as SO2)	g	381.375	72.8146	144.796	25.0015	0.105273	8.01759	2.95031	39.8012	87.8887

Flow	Units	Total	HT Scouring	Dark acid dyeing	Softener Finishing	Water Sand Filtration	Water Softening	Water Disinfection	Membrane ultra-filtration	Waste water treatment
(a) Toluene (C6H5CH3)	g	0.769275	0.439753	0.240092	0.0423784	0.0000341	0.00381366	0.000955149	0.0128353	0.0294131
(a) Vanadium (V)	g	0.65463	0.0700121	0.259159	0.0475306	0.000213818	0.0131705	0.00599234	0.080521	0.178031
(s) Arsenic (As)	g	0.000652	0.000431922	0.000197516	0.0000126	6.65E-09	0.00000118	0.000000186	0.0000025	0.00000554
(s) Chromium (Cr III, Cr VI)	g	0.008156	0.00540735	0.00247276	0.000158297	8.32E-08	0.0000148	0.00000233	0.0000313	0.0000694
(s) Zinc (Zn)	g	0.024485	0.0162324	0.007423	0.000475194	0.00000025	0.0000445	0.000007	0.0000941	0.00020824
(w) Ammonia (NH4+, NH3, as N)	g	77.48817	0.0629222	0.200267	0.198711	0.0000925	0.00863179	0.00259333	0.0348615	76.9801
(w) Benzene (C6H6)	g	0.139243	0.0206537	0.0491917	0.0324296	0.0000274	0.00183299	0.000767857	0.0103187	0.0240211
(w) Cadmium (Cd++)	g	0.00054	0.0000972	0.000179983	0.0001598	7.32E-08	0.00000575	0.00000205	0.0000276	0.0000676
(w) Chromium (Cr III)	g	0.017123	0.0113518	0.00519112	0.000332317	0.000000175	0.0000311	0.0000049	0.0000658	0.000145628
(w) Chromium (Cr III, Cr VI)	g	0.002399	0.000248708	0.000854951	0.000608833	0.000000506	0.0000377	0.0000142	0.000190387	0.000443352
(w) COD (Chemical Oxygen Demand)	g	692.3075	0.807065	7.7408	17.9438	0.000102813	0.00946656	0.00288138	0.0388621	665.765
(w) Nitrate (NO3-)	g	101.6411	0.0202233	0.155253	0.318481	0.0000175	0.00136966	0.000490665	0.00660441	101.138
(w) Nitrogenous Matter (unspecified, as N)	g	180.135	0.0536824	0.255438	0.287236	0.0001175	0.00739576	0.00329299	0.044295	179.483
(w) Oils (unspecified)	g	4.028804	2.24019	1.26092	0.267875	0.00019011	0.0165498	0.00532791	0.0716093	0.166142
REMINDERS										
COD (to WWTP)	kg	30.754.7	22.625	6.922.5	1.200				7.20	
TSS (to WWTP)	kg	1.7384	1.565	0.143	0.030				0.00168	
E Feedstock Energy	MJ	164.776	10.5716	49.9834	95.0486	0.00694014	0.51407	0.1945	2.6136	5.84303
E Fuel Energy	MJ	3655.881	2237.11	1136.41	85.7662	0.140804	17.9314	3.94609	53.4566	121.113
E Non Renewable Energy	MJ	3777.441	2238.86	1169.76	178.379	0.135667	18.078	3.80211	51.5007	116.916
E Renewable Energy	MJ	43.03885	8.81079	16.588	2.39505	0.0120581	0.309091	0.337932	4.56217	10.0237
E Total Primary Energy	MJ	3820.597	2247.68	1186.37	180.812	0.147725	18.4445	4.14004	56.0629	126.94
Electricity	MJ elec	309.6141	51.8154	121.967	16.6015	0.0947681	1.71278	2.65591	35.9877	78.7795

Table 3.13 Results of inventory analysis of I09 charged silk yarn-System B (only main flows are listed)

Flow	Units	Total	Polymer charge	Charged silk dark acid dyeing	Softener Finishing	Water Sand Filtration	Water Softening	Water Disinfection	Waste water treatment
INPUT									
(r) Coal (in ground)	kg	0.000016963	0.0000075	0.00000875	0.000000477	2.5E-10	4.46E-08	7.02E-09	0.000000211
(r) Iron (Fe, ore)	kg	0	0	0	0	0	0	0	0
(r) Natural Gas (in ground)	kg	0.1190897	0.0511002	0.0597975	0.00478333	0.00000292	0.00084518	0.0000819	0.00247895
(r) Oil (in ground)	kg	54.56674	24.075	28.0695	1.5451	0.000836935	0.146566	0.0234554	0.706342
(r) Uranium (U, ore)	kg	13.46736319	0.00190313	0.00222082	0.000798197	0.00000086	13.4617	0.0000241	0.000736473
Water (gate to gate)	l	11500	4000	6500	1000				
Water (out of gate)	l	187.489	60.3094	71.6907	14.8422	0.010542	31.069	0.295443	9.27154
OUTPUT									
(a) Alkane (unspecified)	g	7.80474	2.99338	3.69843	0.844398	0.000270621	0.0309581	0.00758427	0.22971
(a) Arsenic (As)	g	0.00561	0.00195071	0.00196058	0.000389625	0.00000133	0.000149058	0.0000373	0.00112142
(a) Benzene (C6H6)	g	1.059067	0.443703	0.519482	0.0536743	0.0000381	0.00821282	0.00106817	0.0328928
(a) Butane (n-C4H10)	g	2.98574	1.20446	1.31572	0.125806	0.000352921	0.0253422	0.00989074	0.304169
(a) Cadmium (Cd)	g	0.0100393	0.00350956	0.00337959	0.000607926	0.00000272	0.000170177	0.0000762	0.00229311
(a) Carbon Dioxide (CO2, fossil)	g	167145.9	70331.2	79987.9	6435.89	10.2102	1184.89	286.145	8909.24
(a) Carbon Monoxide (CO)	g	103.714	40.7123	48.043	7.86482	0.0041546	2.51044	0.116434	4.46335
(a) Ethane (C2H6)	g	17.2996	6.44048	6.93165	1.20161	0.00287356	0.200442	0.0805326	2.44203
(a) Ethylene (C2H4)	g	27.18944	11.9447	13.9307	0.8131	0.000459535	0.0997233	0.0128786	0.387822
(a) Hydrocarbons (except methane)	g	103.26	32.0443	38.4051	17.7031	0.0147294	1.11842	0.412796	13.5615
(a) Hydrocarbons (unspecified)	g	27.220617	0.0170937	7.86793	19.3259	0.00000859	0.00213117	0.000240707	0.00728586
(a) Hydrogen Chloride (HCl)	g	4.12696	1.40895	1.50895	0.347443	0.000764834	0.195844	0.0214348	0.643575
(a) Lead (Pb)	g	0.0251641	0.00888889	0.00897458	0.00164935	0.00000577	0.000613372	0.000161693	0.00487042
(a) Manganese (Mn)	g	0.01417111	0.00606075	0.0070379	0.000531213	0.00000047	0.000131596	0.0000132	0.000395966
(a) Methane (CH4)	g	432.801	159.887	170.111	29.3043	0.0768545	6.11748	2.15388	65.146
(a) Nickel (Ni)	g	0.197978	0.0692119	0.0667119	0.0120249	0.0000536	0.00334193	0.00150114	0.0451324
(a) Nitrogen Oxides (NOx as NO2)	g	149.594	57.8603	61.1156	8.05096	0.0189289	2.39048	0.530491	19.6271
(a) Nitrous Oxide (N2O)	g	0.94083	0.35497	0.349556	0.0458715	0.00015063	0.0180157	0.00422147	0.168048
(a) Propane (C3H8)	g	4.59066	1.78166	1.89536	0.220543	0.00072342	0.0559541	0.0202741	0.616167
(a) Sulphur Oxides (SOx as SO2)	g	425.356	151.303	149.133	25.0015	0.10517	8.00979	2.94744	88.8545

Flow	Units	Total	Polymer charge	Charged silk dark acid dyeing	Softener Finishing	Water Sand Filtration	Water Softening	Water Disinfection	Waste water treatment
(a) Toluene (C6H5CH3)	g	0.58594	0.234198	0.274829	0.0423784	0.000034	0.00380995	0.00095422	0.0297363
(a) Vanadium (V)	g	0.78103	0.272421	0.261734	0.0475306	0.00021361	0.0131577	0.00598651	0.179987
(s) Arsenic (As)	g	0.000450617	0.000198969	0.000232025	0.0000126	6.64E-09	0.00000118	0.000000186	0.0000056
(s) Chromium (Cr III, Cr VI)	g	0.005641406	0.00249095	0.00290479	0.000158297	8.31E-08	0.0000148	0.00000233	0.0000701
(s) Zinc (Zn)	g	0.016935052	0.00747762	0.00871994	0.000475194	0.00000025	0.0000445	0.00000699	0.000210529
(w) Ammonia (NH4+, NH3, as N)	g	78.378483	0.138494	0.203911	0.198711	0.0000924	0.00862339	0.0025908	77.826
(w) Benzene (C6H6)	g	0.150794	0.0410089	0.050445	0.0324296	0.0000274	0.0018312	0.000767109	0.0242851
(w) Cadmium (Cd++)	g	0.00055349	0.000130817	0.000186661	0.0001598	7.32E-08	0.00000574	0.00000205	0.0000683
(w) Chromium (Cr III)	g	0.011843182	0.00522932	0.0060981	0.000332317	0.000000175	0.0000311	0.00000489	0.000147229
(w) Chromium (Cr III, Cr VI)	g	0.00267496	0.000698077	0.000867469	0.000608833	0.000000505	0.0000377	0.0000142	0.000448224
(w) COD (Chemical Oxygen Demand)	g	699.326055	0.484698	7.80385	17.9438	0.000102713	0.00945735	0.00287858	673.081
(w) Nitrate (NO3-)	g	0.16337	0.0287118	0.156625	0.318481	0.0000175	0.00136833	0.000490188	102.25
(w) Nitrogenous Matter (unspecified, as N)	g	182.16939	0.157884	0.258052	0.287236	0.000117386	0.00738857	0.00328978	181.456
(w) Oils (unspecified)	g	3.10914	1.21364	1.43762	0.267875	0.000189925	0.0165337	0.00532273	0.167968
REMINDERS									
COD (to WWTP)	kg	42.810.5	34.688	6.922.5	1.200				
TSS (to WWTP)	kg	0.387.667	0.214.667	0.143	0.030				
E Feedstock Energy	MJ	164.9717	12.5703	50.7312	95.0486	0.00693338	0.513569	0.194311	5.90724
E Fuel Energy	MJ	2697.38	1153.57	1313.6	85.7662	0.140667	17.914	3.94225	122.444
E Non Renewable Energy	MJ	2814.35	1148.61	1347.17	178.379	0.135535	18.0604	3.79841	118.201
E Renewable Energy	MJ	47.8164	17.506	17.123	2.39505	0.0120463	0.308791	0.337604	10.1339
E Total Primary Energy	MJ	2862.29	1166.12	1364.31	180.812	0.147581	18.4265	4.13601	128.335
Electricity	MJ elec	355.3389	129.858	124.775	16.6015	0.0946759	1.71112	2.65333	79.6452

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 (silk yarn) to highlight significant issues. Contributions of electricity production, steam production and other issues (such as production and transport of chemicals, gate-to-gate flows etc.) into impact assessment results are visualised, too. If the issue “Others” 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

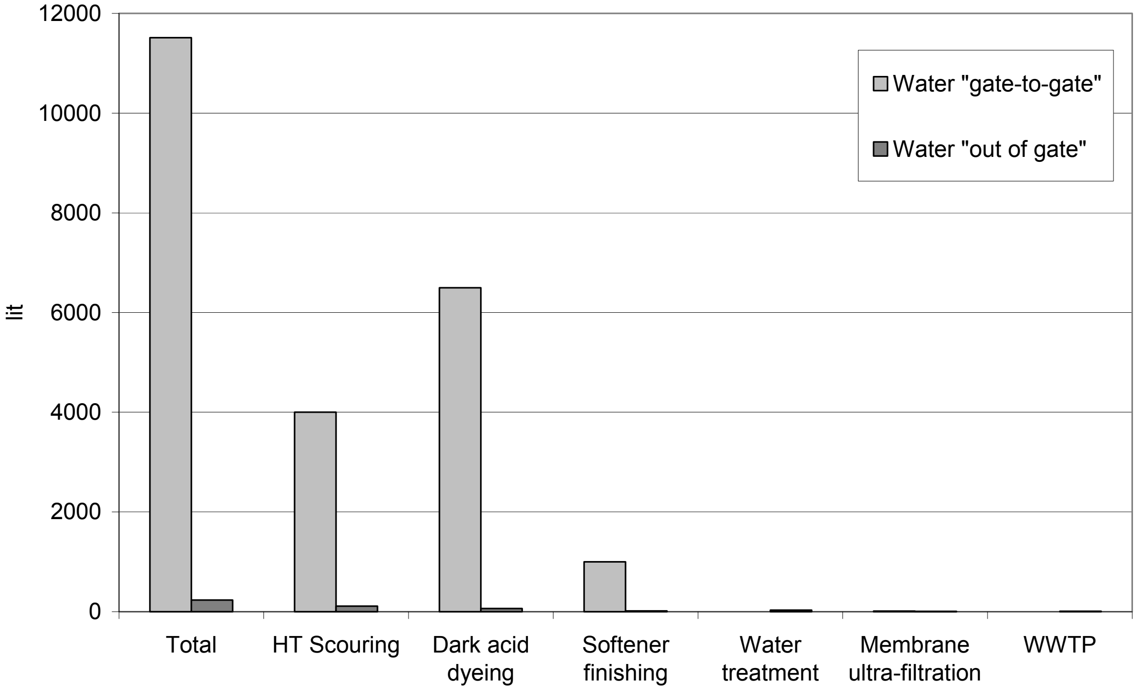

Figure 5.1 Water consumption

5.1.2 COD and TSS emissions

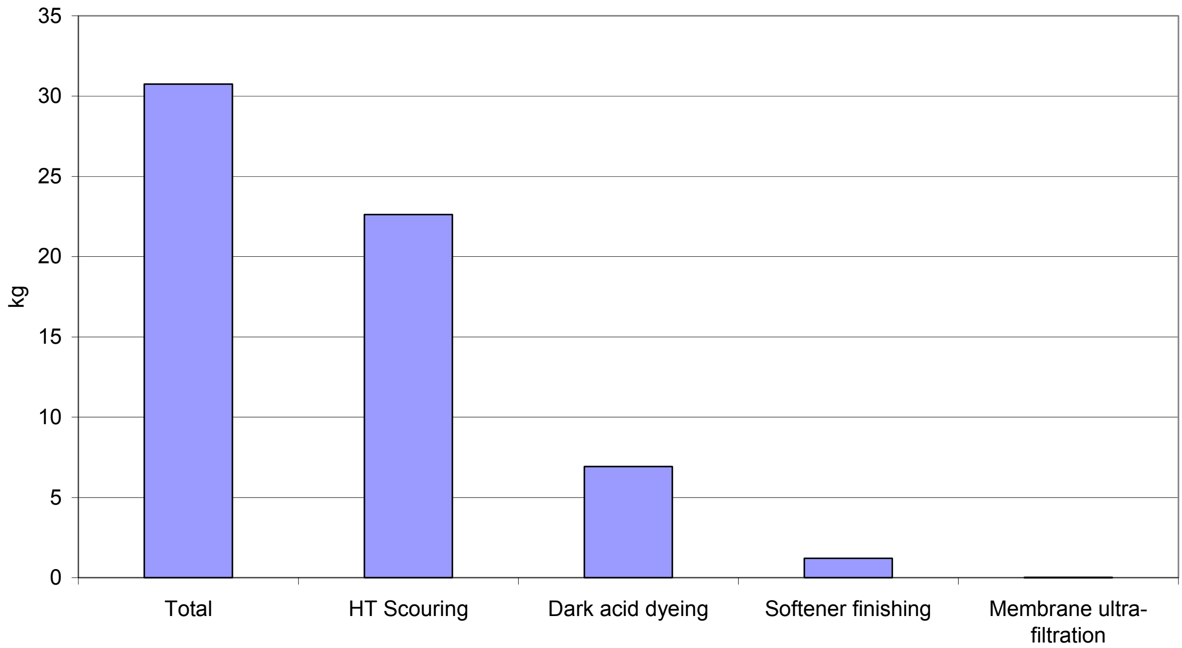

Figure 5.2 COD emission (to WWTP)

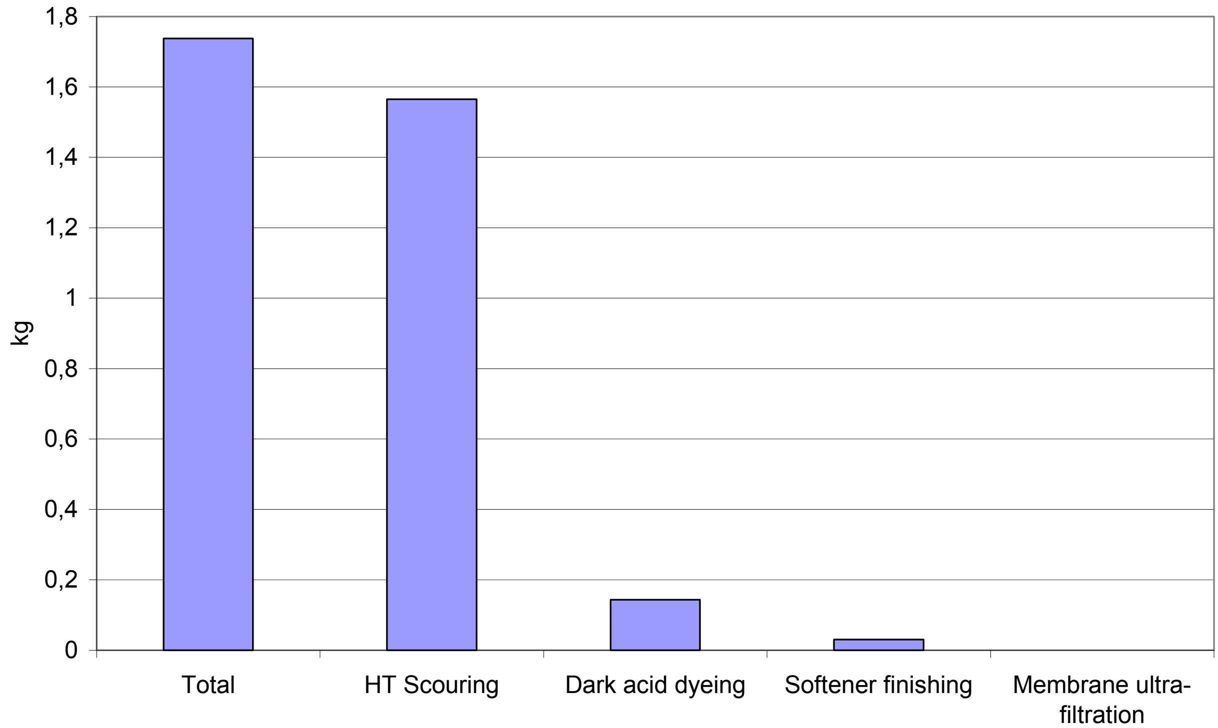

Figure 5.3 TSS emission (to WWTP)

5.1.3 Energy indicators

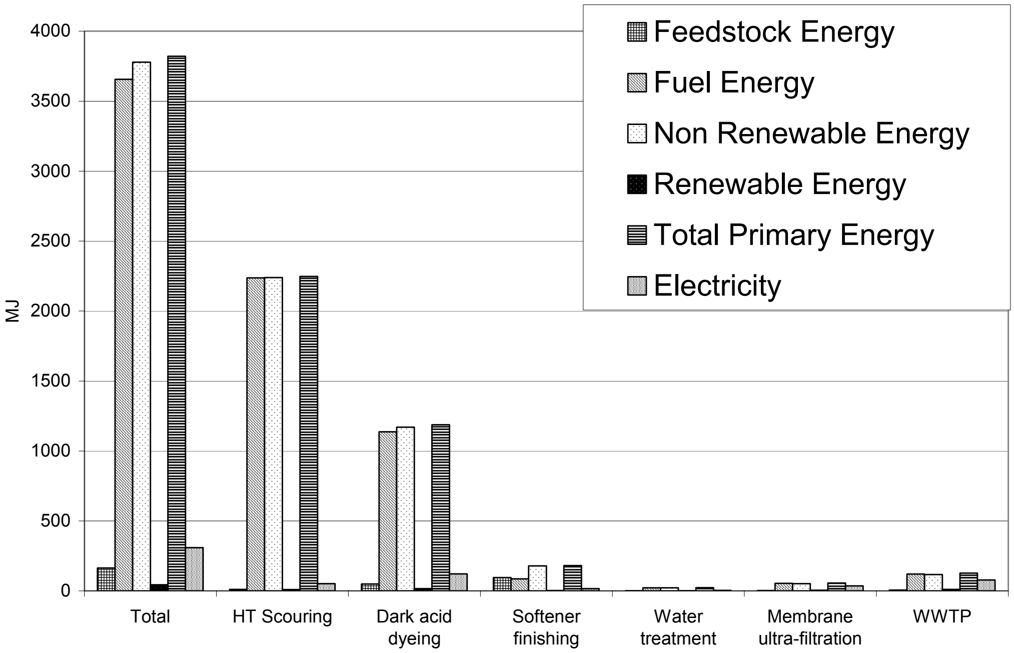

Figure 5.4 Energy indicators

5.1.4 Air Acidification

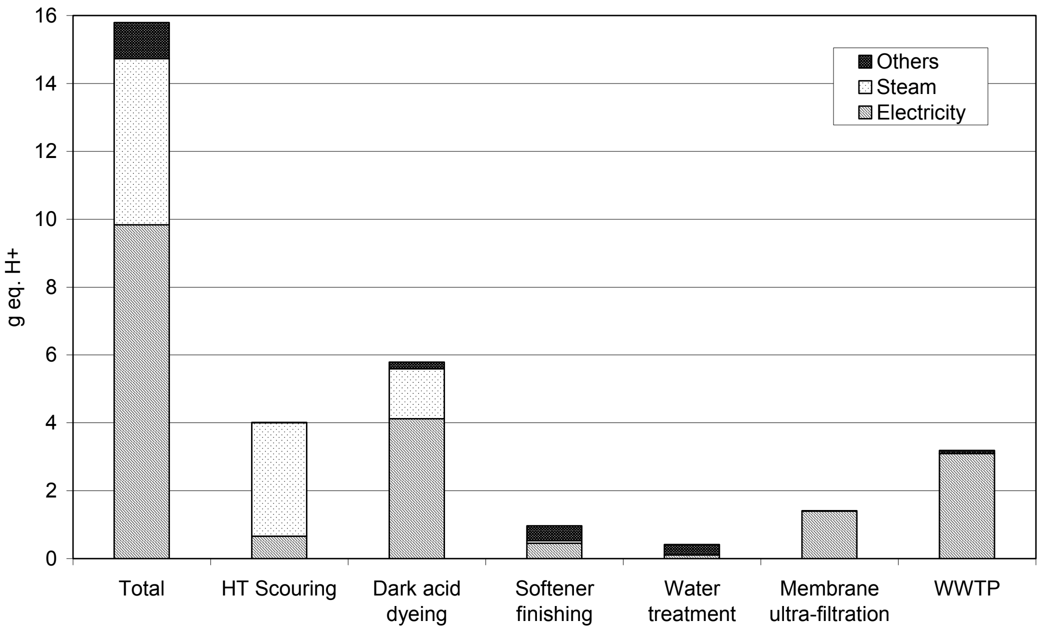

Figure 5.5 Air-Acidification

The issue "Others" has significant contribution because of the production of chemicals such as Acetic acid (Dark acid dyeing and Softener Finishing) and Sodium chloride (Water treatment). The main airborne emissions which contribute to total value are sulphur oxides (75%) and nitrogen oxides (23%).

5.1.5 Aquatic ecotoxicity

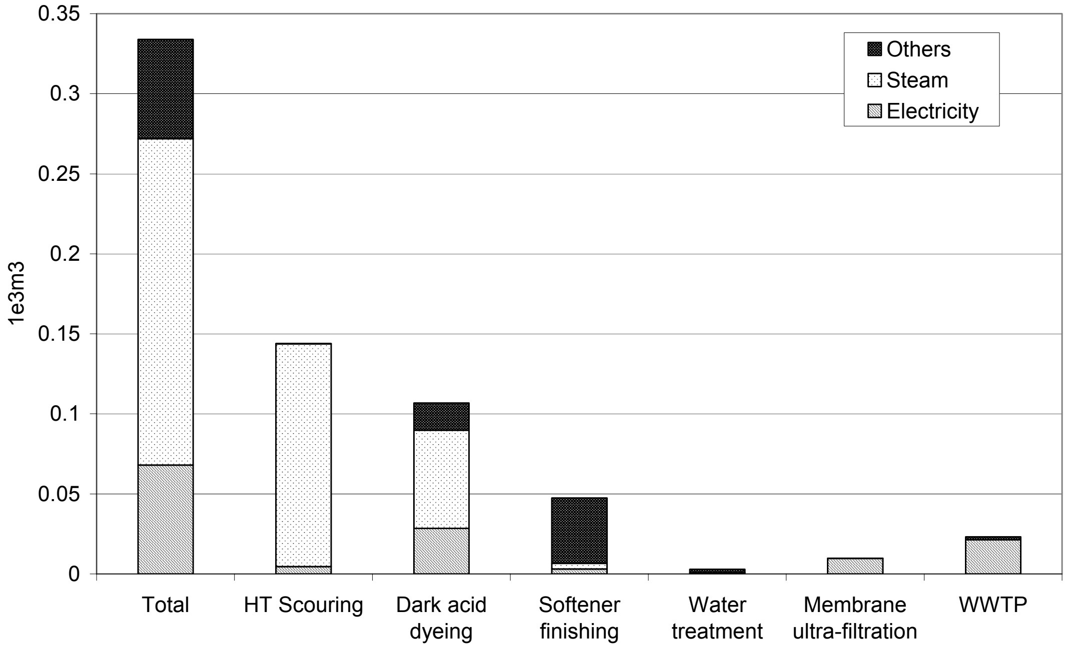

Figure 5.6 Aquatic ecotoxicity

The issue "Others" has significant contribution because of the production of Acetic acid (Dark acid dyeing and Softener Finishing). The main waterborne emissions which contribute to total value are oils (60%) and cadmium (32%).

5.1.6 Depletion of non renewable resources

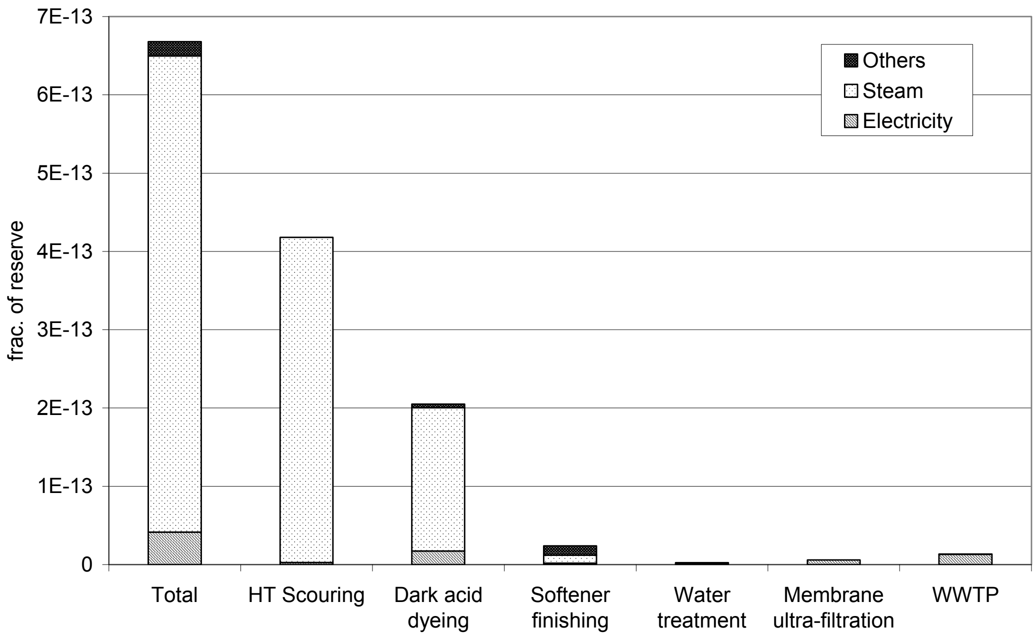

Figure 5.7 Depletion of non renewable resources

The main resource which contributes to total value is natural gas (91%).

5.1.7 Human ecotoxicity

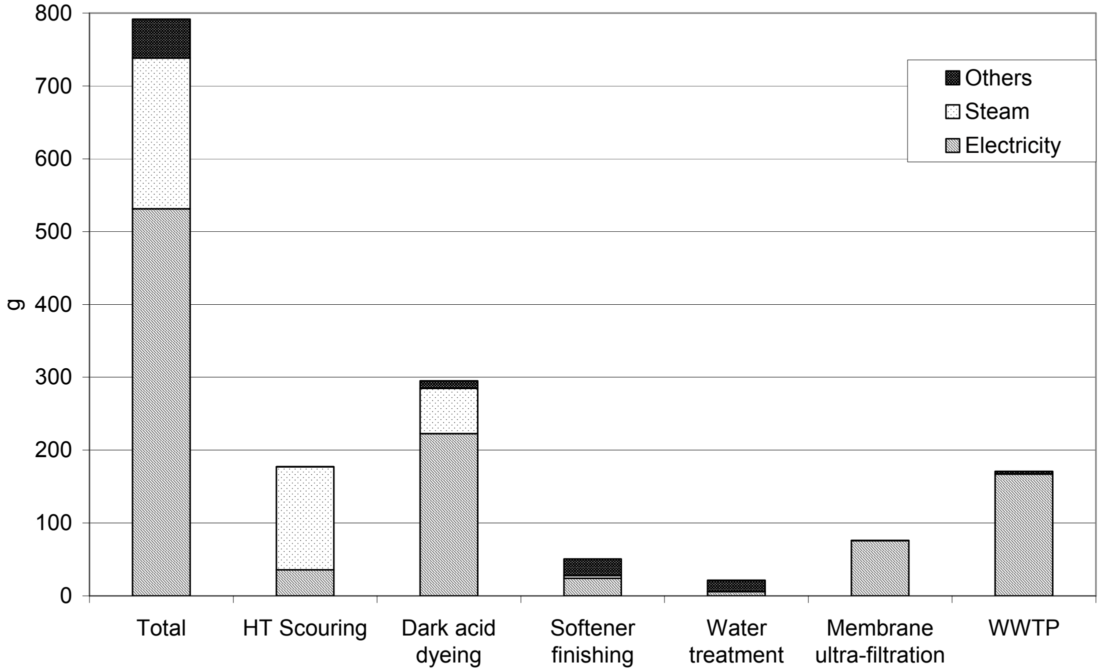

Figure 5.8 Human ecotoxicity

The main airborne emissions which contribute to total value are sulphur oxides (58%), nitrogen oxides (18%), nickel (10%) and vanadium (10%).

5.1.8 Terrestrial ecotoxicity

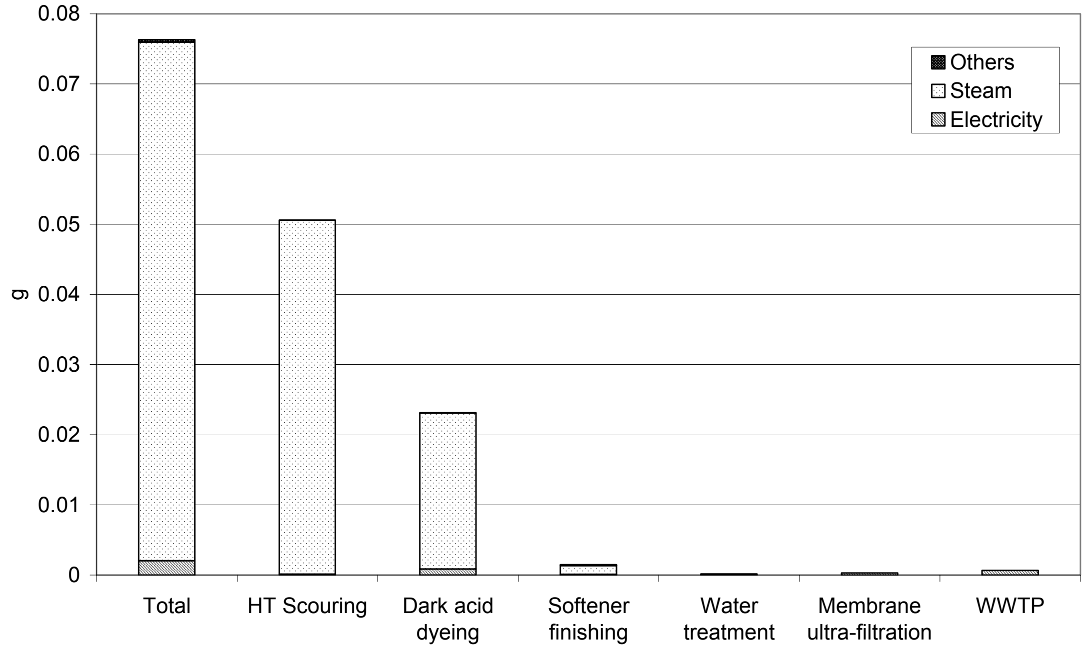

Figure 5.9 Terrestrial ecotoxicity

The main soil emissions which contribute to total value are zinc (83%) and chromium (16%).

5.1.9 Eutrophication

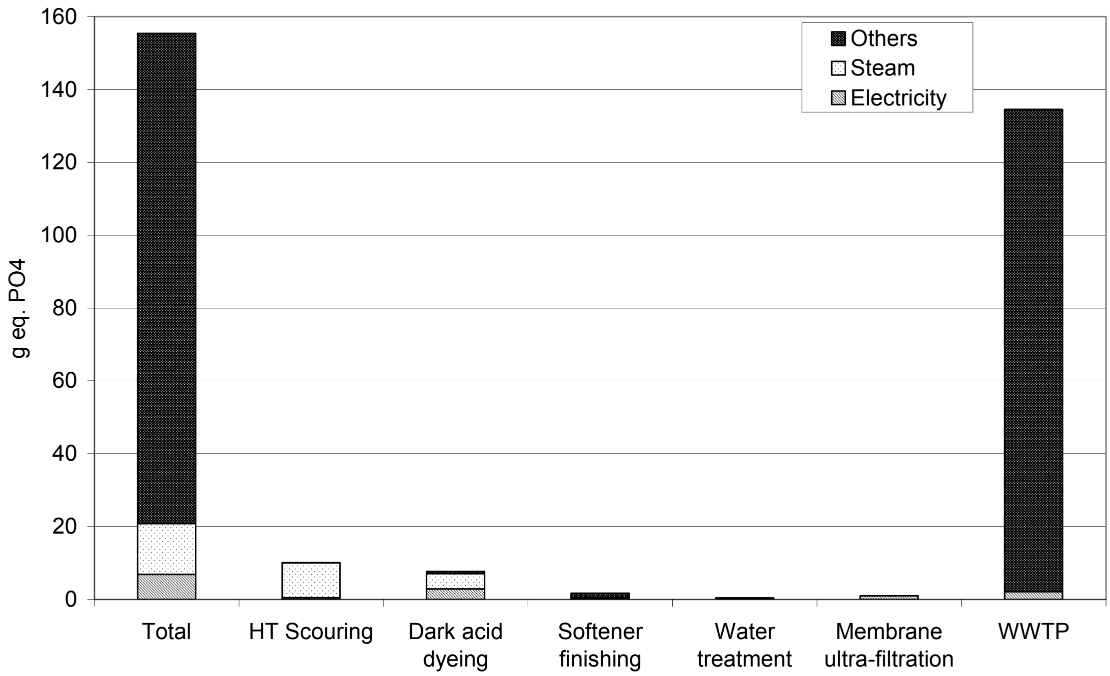

Figure 5.10 Eutrophication

The issue “Others” has significant contribution because of the emissions to water from the waste water treatment plant. The main waterborne emissions which contribute to total value are nitrogenous matter (49%), ammonia (21%), nitrogen oxides (14%) and COD (10%).

5.1.10 Greenhouse effect

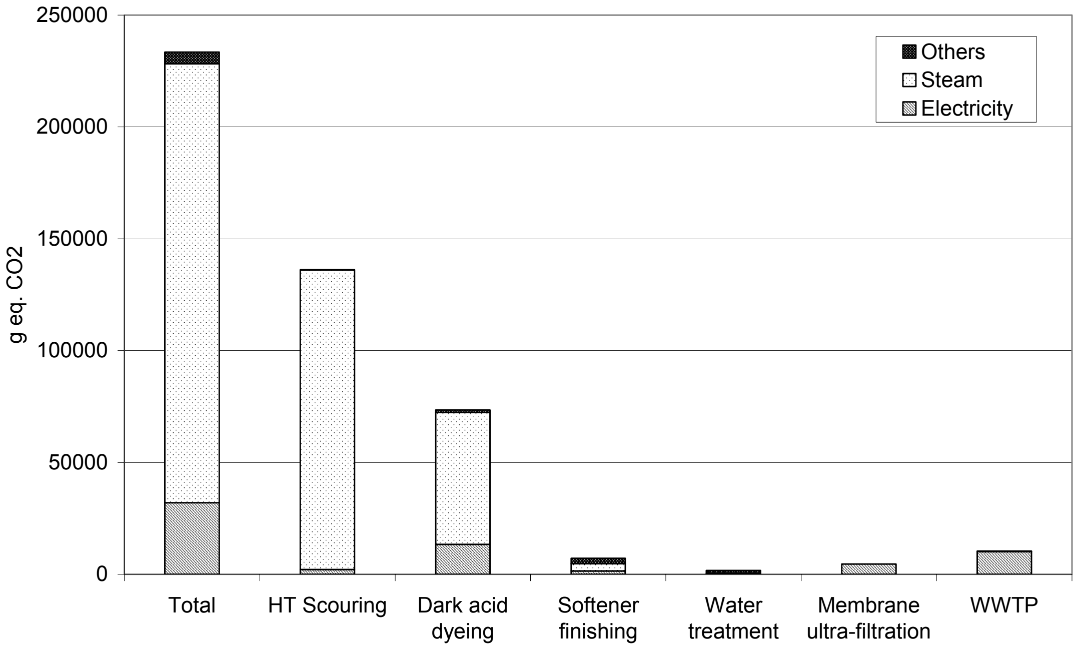

Figure 5.11 Greenhouse effect

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

5.1.11 Photochemical smog

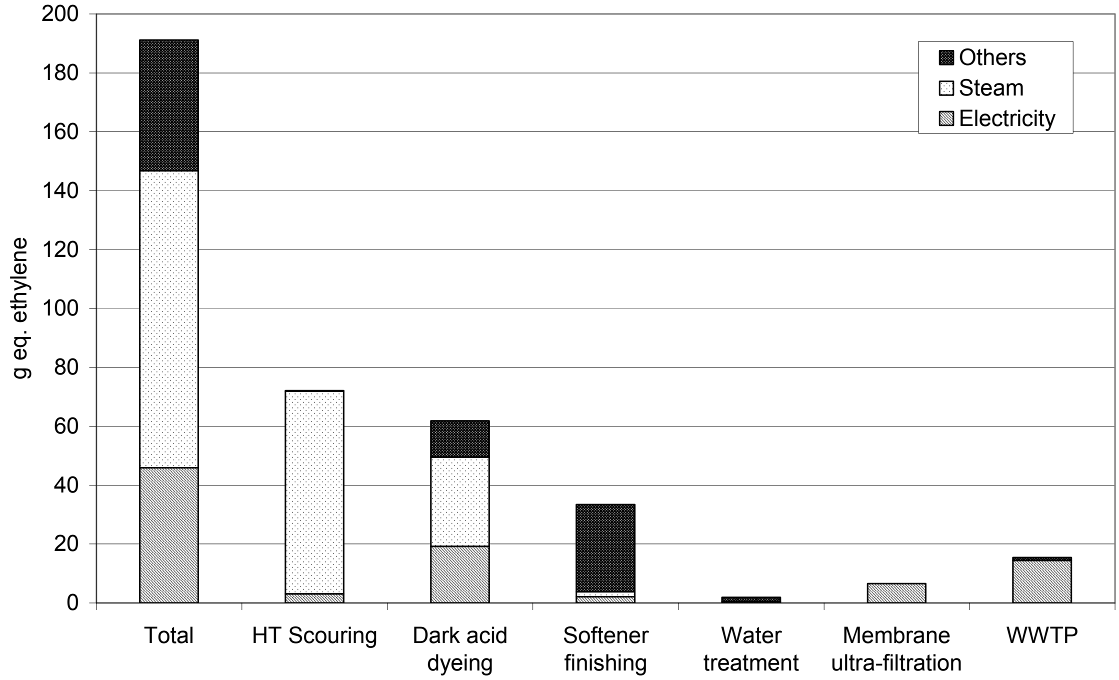

Figure 5.12 Photochemical oxidant formation

The issue "Others" has significant contribution because of the production of Acetic acid (Dark acid dyeing and Softener Finishing). The main airborne emissions which contribute to total value are hydrocarbons (57%) and ethylene (20%).

5.1.12 Exotoxicity of chemicals (screening)

Processes in systems A and B do not use chemicals classified with risk phrases R50, R51, R52, R53, R54, R55, R56, R57, R58 and so the total score for both systems is 0.

5.2 Comparison of System A and System B

Inventory and impact assessment results of System B (charged silk yarn) were compared to the results of System A. (see Figures 5.13-14)

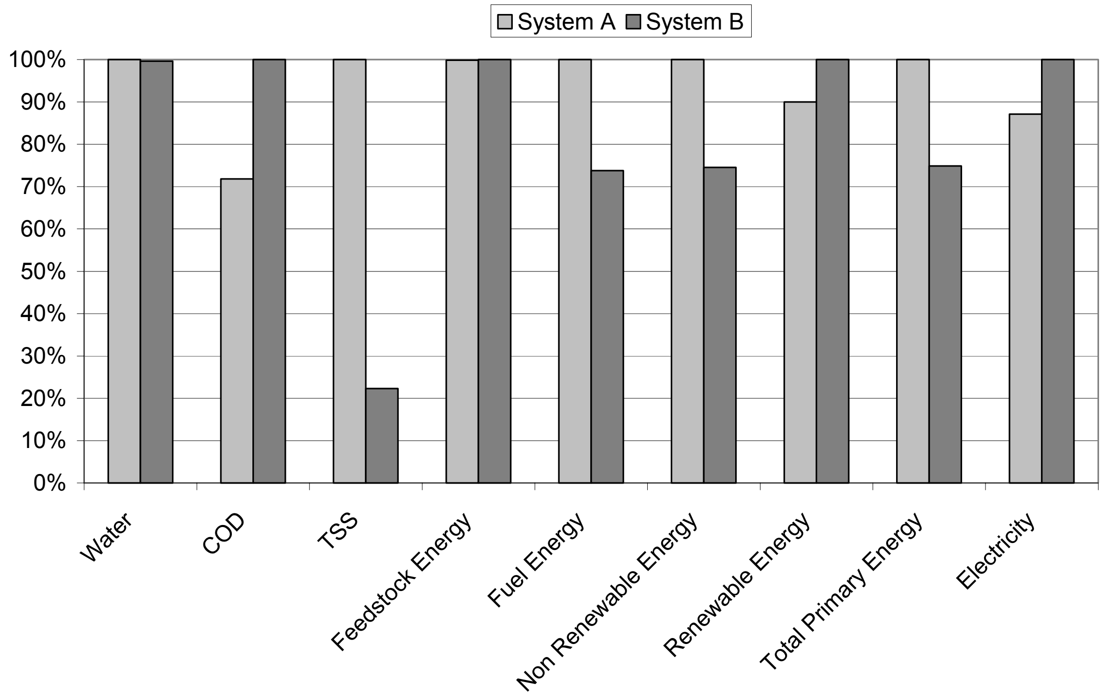

Figure 5.13 Comparison of water consumption, COD- and TSS emissions and energy indicators of System A and B

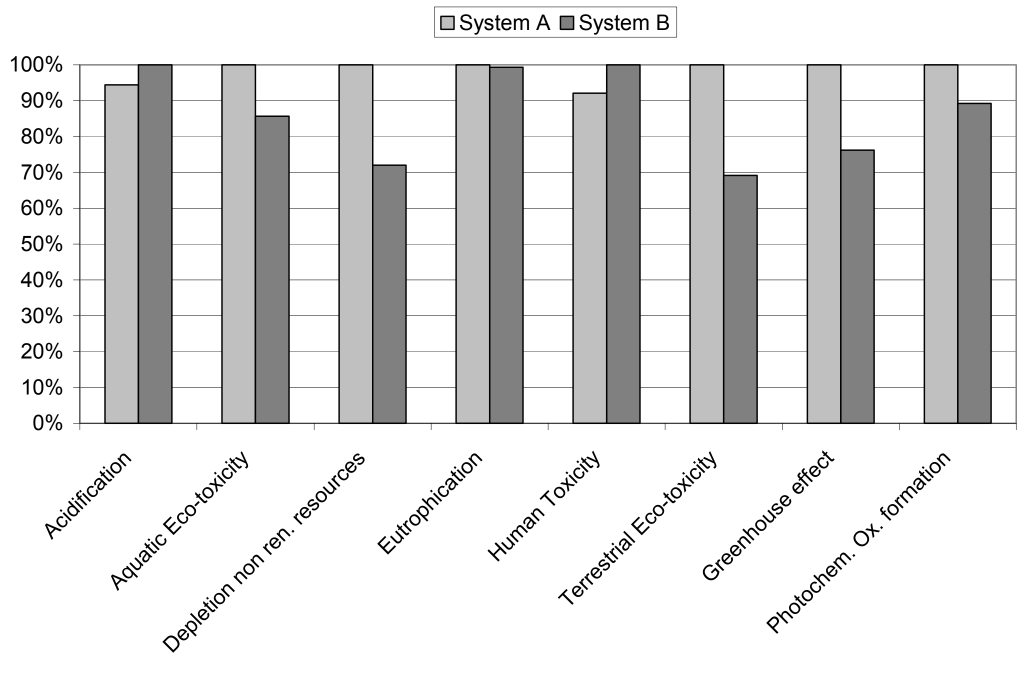

Figure 5.14 Comparison of impact assessment results of System A and B

System B has significantly (more than 10%) lower total values for several inventory and impact categories (such as fuel energy, non renewable energy, total primary energy, aquatic eco-toxicity, depletion of non renewable resources, terrestrial eco-toxicity, greenhouse effect, photochemical oxidant formation). The main reason is that Polymer charge pre-treatment process requires less thermal energy (production of steam) than HT Scouring.

On the contrary, COD emission is higher in Polymer charge than in HT Scouring but TSS emission is again higher for System A because of the scouring process.

5.3 Evaluation

5.3.1 Completeness check

The LCA study cannot be considered complete because of the lack of data about production of numerous chemicals used in System A and B. It was decided to check the sensitivity of results to this aspect.

5.3.2 Sensitivity check

5.3.2.1 Allocation of thermal energy

The allocation rule applied for the definition of process specific steam and methane consumption (described in Chapter 3.2.1.3) is based on theoretic calculations and not on direct measurements. The final results of the study identified steam consumption as a significant issue for several inventory and impact categories. A sensitivity check was necessary to analyse the effect of the uncertainty of this aspect to the final results. Figures 5.14-17 show comparison of final results if steam consumption is increased by 10%.

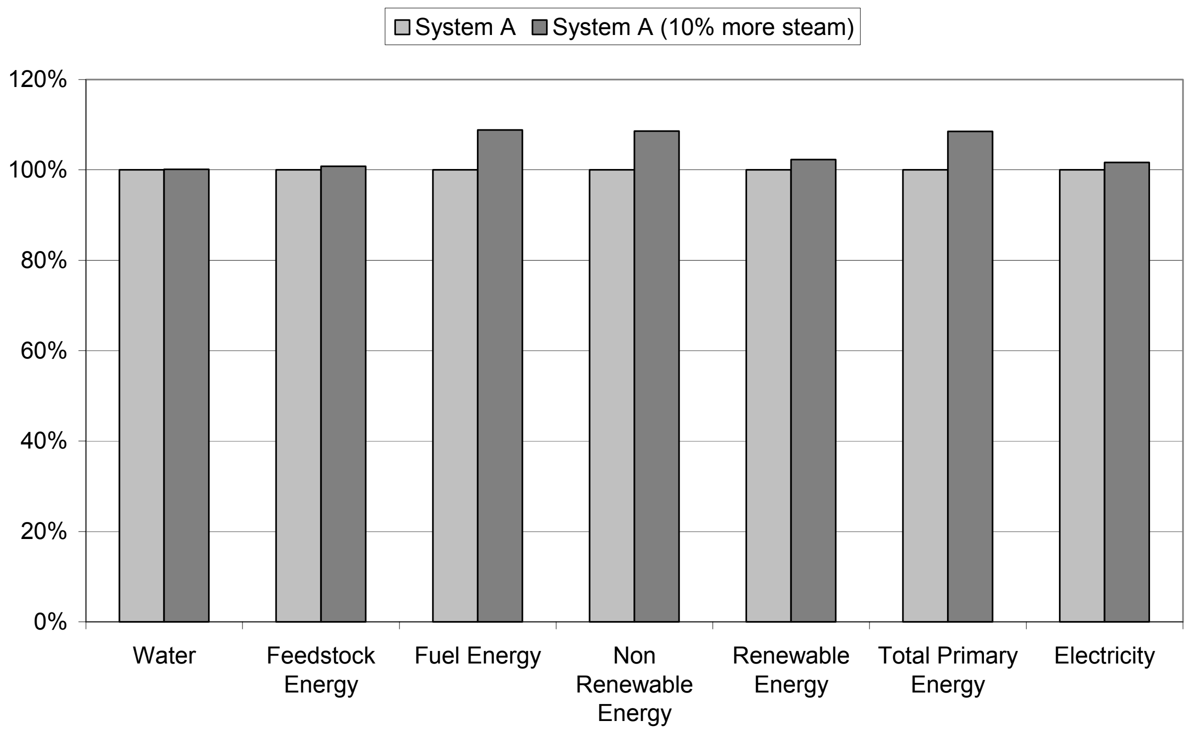

Figure 5.14 Sensitivity check of System A to the uncertainty of steam consumption

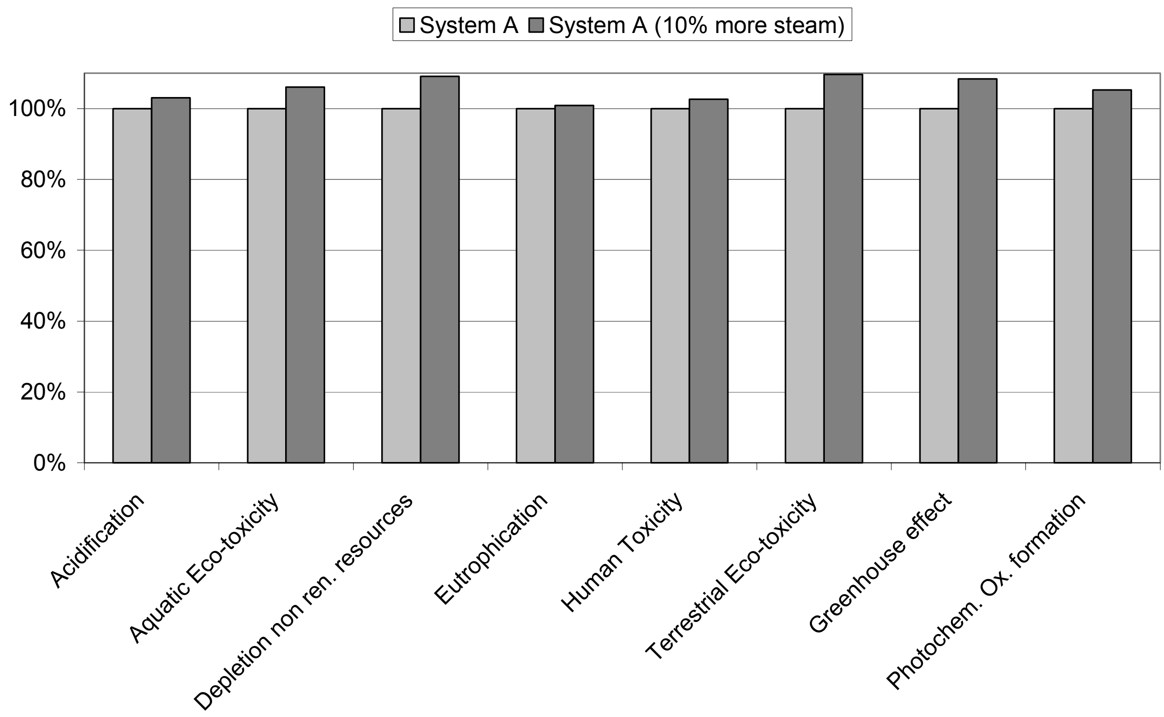

Figure 5.15 Sensitivity check of System A to the uncertainty of steam consumption

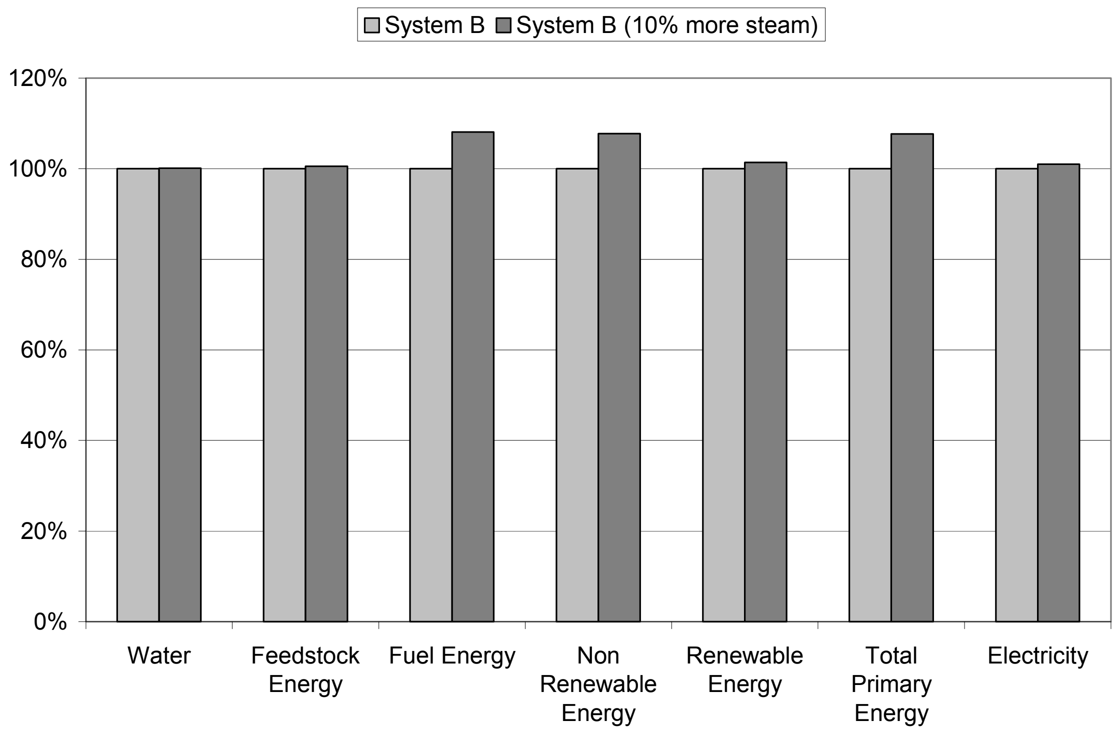

Figure 5.16 Sensitivity check of System B to the uncertainty of steam consumption

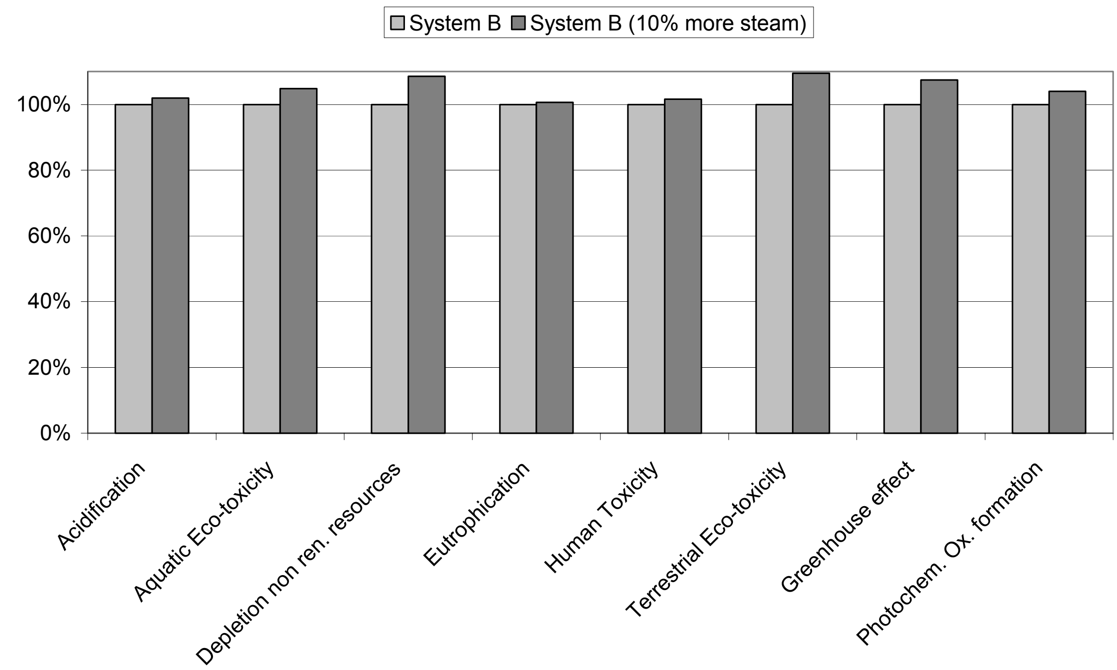

Figure 5.17 Sensitivity check of System B to the uncertainty of steam consumption

It can be concluded that a 10% uncertainty of steam consumption does not significantly influence inventory and impact assessment results. On the other hand, there are some categories (fuel energy, non renewable energy, total primary energy, depletion of non renewable resources, terrestrial ecotoxicity and greenhouse effect) where total results can be modified nearly by 10%.

5.3.2.2 Lack of data on 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 chemicals were used [2]. Figures 5.18-5.21 show how the final results are influenced by the application of these generic data.

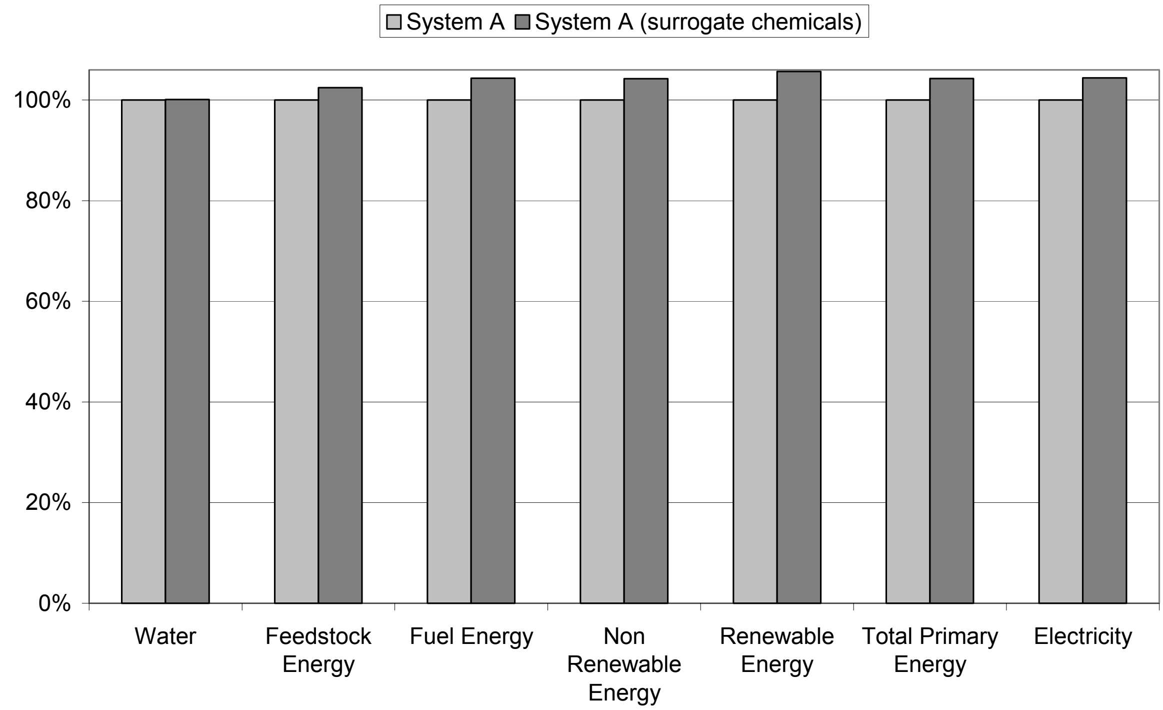

Figure 5.18 Sensitivity check of System A to lack of data about chemicals

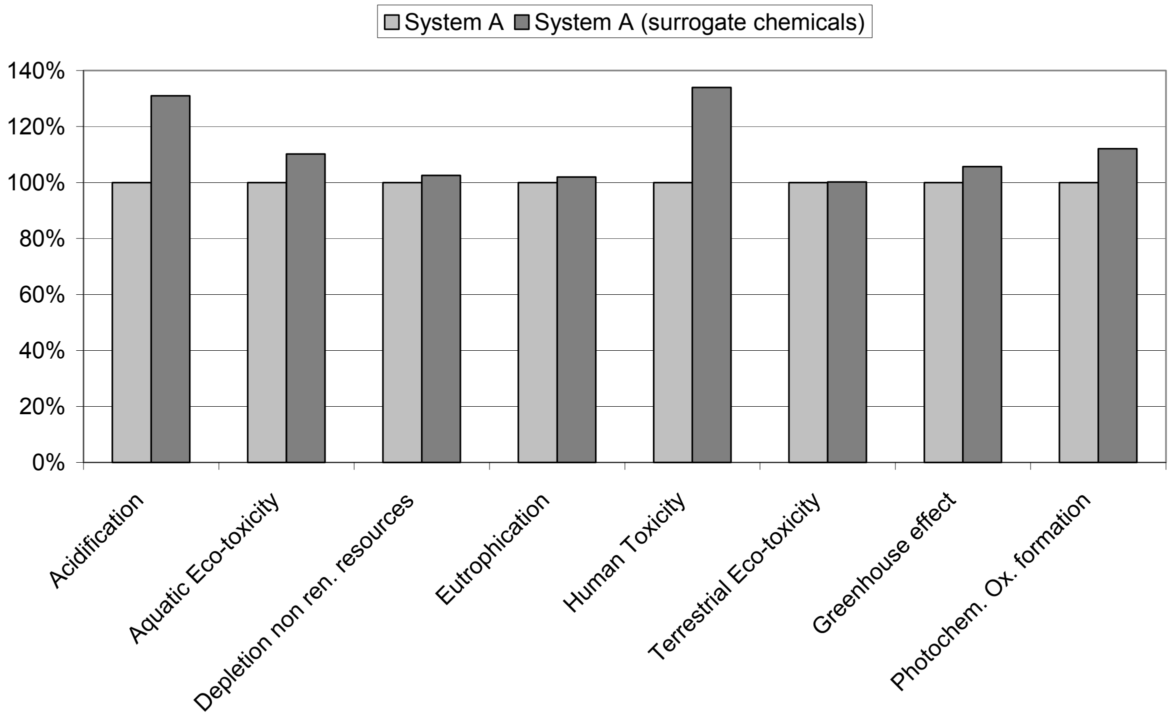

Figure 5.19 Sensitivity check of System A to the lack of data about chemicals

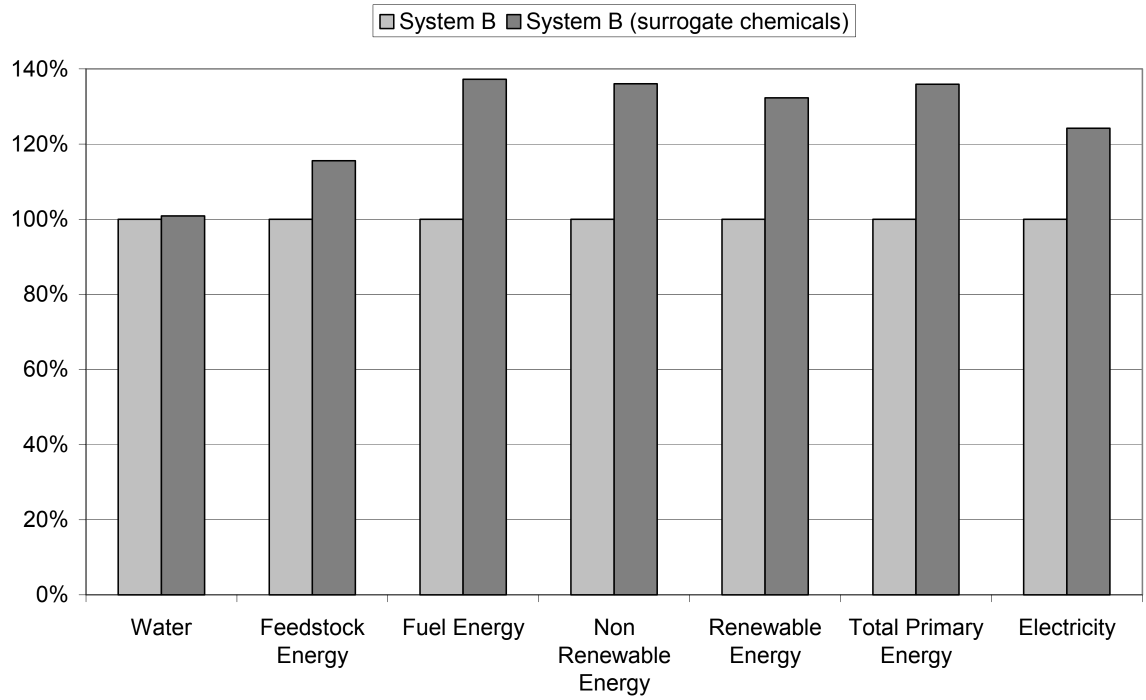

Figure 5.20 Sensitivity check of System B to the lack of data about chemicals

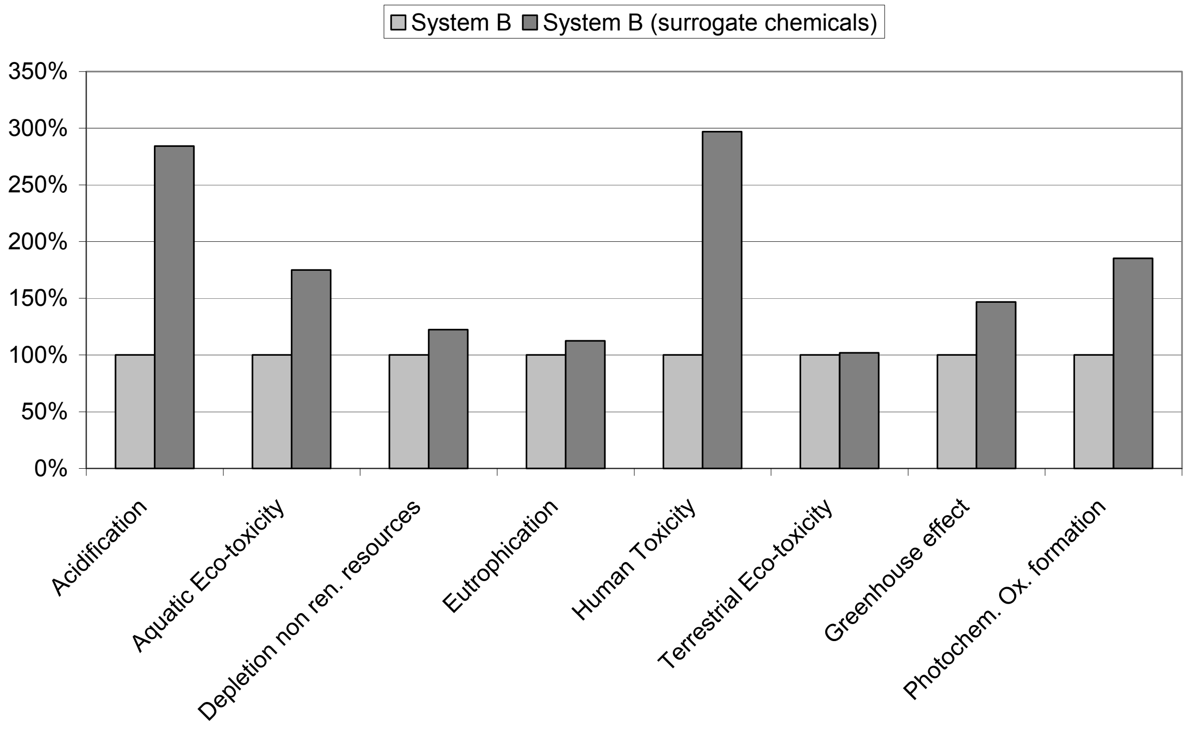

Figure 5.21 Sensitivity check of System B to the lack of data about chemicals

System A is sensitive to the lack of data on chemicals mainly for air acidification and human toxicity results (final results changes by 30-35%).

Results of System B are still more sensitive to this aspect. It is because of the big quantity of Metacrylamide used for charging the yarn. It has to be highlighted that results of System B are less reliable and specific data about the production of Metacrylamide are necessary.

5.3.3 Consistency check

This 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. The only process having a different origin is the waste water treatment plant, which influence on the overall system is limited

6 Conclusions

For the Life Cycle Assessment of two silk yarn products the following main conclusions can be drawn:

- HT Scouring of silk yarn is the most significant process (38-65% contribution) for several impact categories (energy indicators, aquatic ecotoxicity, depletion of non renewable resources, terrestrial ecotoxicity, greenhouse effect, photochemical oxidant formation) mainly because of its relevant thermal energy requirement.
- Polymer charge pre-treatment process requires less thermal energy (production of steam) than HT Scouring. This is the main reason why charged silk yarn (System B) has significantly (10-30%) lower total values for several inventory and impact categories.
- COD and TSS emissions arise mainly from pre-treatment processes: Polymer charge has higher COD emissions than HT Scouring (25%), while TSS emission is higher for System A because of scouring process (70%).
- Relatively high electricity consumption makes dark acid dyeing a “hot-spot” of air acidification and human toxicity (37% contribution).
- Water consumption of dyeing processes is the highest (55%).
- Production of chemicals (mainly Acetic acid used in dyeing and softener finishing) has significant contribution to aquatic ecotoxicity and photochemical oxidant formation (18-25%). It must be highlighted that the LCA study has a relevant lack of data on chemicals production. A sensitivity check, using surrogate data on inorganic chemicals demonstrated the importance of this aspect: System B (charged silk yarn) was very sensitive because of the lack of data about Metacrylamide used in big quantity for charging of the yarn. System A (silk yarn) was less sensitive and only for air acidification and human toxicity results (final results changes by 30-35%).
- Membrane ultra-filtration process for sericin recovery in System A was significant only for air acidification and human toxicity (11% contribution) because of its electricity consumption.
- Hot-spot of eutrophication impact category is the waste water treatment plant because of its emissions to water (87% contribution of the total of category). Moreover, the WWTP contributes significantly to air acidification and human toxicity (20-21% contribution) because of its electricity consumption.
- Process specific steam consumption was calculated applying an allocation rule based on energy for heating of process water. A sensitivity check demonstrated that a 10% uncertainty of this calculation does not significantly influence inventory and impact assessment results. In contrast, there are some categories (fuel energy, non renewable energy, total primary energy, depletion of non renewable resources, terrestrial ecotoxicity and greenhouse effect) where total results can be modified nearly by 10% because of this error.

References

[1] ISO 14040 Environmental management - Life cycle assessment - Principles and framework, 1997.
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[3] ISO 14042 Environmental management - Life cycle assessment - Life cycle impact assessment, 2000.
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[14] IPPC Guideline for National Greenhouse Gas Inventories: Reference Manual, 1996.
[15] H. Wenzel, M. Hauschild and L. Altig “Environmental Assessment of products” Vol II Chapman&Hall 1984.

Annex 1 : Structure and content of PIDACS

1) NOTES ON DATA COLLECTION.

- Reference year:.
- Sampling and data collection period:
- Compiler name:
- Company contact people:

2) GENERAL DATA.

a) Production:

Reference year:

Fiber	*Type*	*(%) of total weight*	*processed linear meters/yr*	*kg per linear meter*	*processed kg/yr*
TOTAL:					

Notes:

b) Water use:

b.1) Supplied water:

Reference year:

Source	*Quantity [m^3/yr]*	*Specific Cost [€/m^3]*	*Energy consumption [kWh/m^3]*
TOTAL:			

Notes:

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

Reference year:

Water type	*Source*	*Treatment*	*Use*	*Quantity [m^3/yr]*	*Treatment specific cost [€/m^3]*
W1					
W2					
W3					
...					

Notes:

b.3) Process water analytic features:

Reference year:

Type	*W1*	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*
T [°C]							
pH [-]							
Conductivity [mS/cm]							
COD [mg/l]							
TSS [mg/l]							
Hardness [°F]							
Chlorides [mg/l]							
Sulphates [mg/l]							
Sulphides [mg/l]							
Total phosphorous [mg/l]							
NO2-N [mg/l]							
NO3-N [mg/l]							
NH4-N [mg/l]							
TKN [mg/l]							
Hexavalent chrome[mg/l]							
Trivalent chrome [mg/l]							
Iron [mg/l]							
Copper [mg/l]							
Zinc [mg/l]							
Lead [mg/l]							
Cadmium [mg/l]							
MBAS [mg/l]							
BiAS [mg/l]							

Notes:

b.4) Steam production:

Reference year:

Steam type	*Water type*	*Quantity [t/yr]*	*T max [°C]*	*Use*
S1				

Notes:

b.5) Discharged water:

Reference year:

Type	*D1* (1)	*D2*(2)	*D3*(2)	*D4*(2)	*D5*(2)	*D6*(2) (3)
Quantity [m³/yr]						
Final destination						
Features:						
T [°C]						
Conductivity [mS/cm]						
Hardness [°F]						
pH [-]						
COD [mg/l]						

BOD5 [mg/l]						
TSS [mg/l]						
TKN [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]						
Toxic Units (for algae)						
Toxic Units (for fish)						
Toxic Units (for bacteria)						
Toxic Units (for invertebrates)						

Notes:

c) *ENERGY CONSUMPTIONS:*

Reference year:

Source	*Unit*	*Use*	*Quantity*	*Specific cost [€/]*
Methane Gas				
Electricity				

Notes:

d) *SOLID WASTES*:

Reference year:

Type	*SW1*	*SW2*	*SW3*	*SW4*		
Description						
Waste class						
Production [kg/yr]						
Disposal						
Disposal cost[€/kg]						

Notes:

e) *OFF-GAS EMISSIONS:*

e1) Identification

Reference year:

Type	*Emission source*	*Flow rate [Nm³/h]*	*Fumes temperature [°C]*	*Abatement*	*Abatement system*
G1					
G2					
G3					
G4					
G5					
G6					
G7					
G8					
G9					

Notes:

e2) Analytical features

Reference year:

Type	*G1*	*G2*	*G3*	*G4*	*G5*	*G6*	*G7*	*G8*	*G9*
NOx [mg/Nm³]									
CO [mg/Nm³]									
Aldehydes [mg/Nm³]									
VOC [mg/Nm³]									
Acetic acid [mg/Nm³]									
Formic acid [mg/Nm³]									
Ammonia [mg/Nm³]									
Particles [mg/l]									

Notes:

f) DEPARTMENTS AND WORKING TIME:

Reference year:

Department	*Operating days*	*Daily operating period*	*Weekly operating period*	*N° of shifts per days*
General facilities				
Preparation				
Dyeing				
Finishing				

Notes:

g) EQUIPMENT:

Reference year:

Department	*Equipment*	*Item*	*Quantity*	*Operating mode*	*Bath Volume [m^3]**	*Installed power [kW]*	*Absorbed power [kW]*	*Operating years*

Notes:

3) ANNEXES (***all sheets have to be considered as relevant part of the whole document***):

- **An.A:** ***Material flow chart***;
- **An.B:** ***Energetic flow chart***;
- **An.C:** ***Water flow chart;***
- **An.D:** ***Production model;***
- **An.E**: ***General Facilities - Process scheme;***
- **An**.**F**: ***Preparation - Process scheme;***
- **An**.**G** : ***Dyeing - Process scheme;***
- **An**.**H** : ***Finishing - Process scheme;***
- **An.I:** ***Water consumptions;***
- **An**.**L**: ***Water discharges;***
- **An.M**: ***Discharged water analytic data;***
- **An**.**N**: ***Chemicals safety data sheets.***

Example of a Process scheme (An.E-F-G-H)

Department	
Yarn	
Process	
Equipment	
Item	
Run time (h)	
Number of run/yr	
Processed yarn (kg/yr)	
Processed yarn per run (kg)	

Water type and volume

Chemicals concenration

Steam type

bath
T=...°C
t=... min

Discharge

Discharge type and volume
T [°C]=
pH [-]=;
Conductivity [mS/cm]=;
COD [mg/l]=
TSS [mg/l]=

Water type and volume

Steam type

Warm washing
T=...°C
t=... min

Discharge

Discharge type and volume
T [°C]=
pH [-]=;
Conductivity [mS/cm]=;
COD [mg/l]=
TSS [mg/l]=

Notes: