TOWEF0 (Toward Effluent Zero) EVALUATION OF THE EFFECT OF THE IPPC APPLICATION ON THE SUSTAINABLE WASTE MANAGEMENT IN TEXTILE INDUSTRIES	IDENTIFICATION CODE: **TM-108-005**	DIS.: **PU**	PAG.: **1**	OF PAG.: **51**
	PARTNER: ENEA	WORKPACKAGE: **WP08**		
	EXTERNAL IDENTIFICATION CODE:			
	CONTRACT NUMBER: **EVK1-CT-2000-00063**			

TITLE:

Life Cycle Assessment of viscose fabric in I04 company

KEY WORDS:

LCA

ANNOTATIONS:

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REV.	DATE	DESCRIPTION	EDITING	VALIDATION	APPROVAL
0	30.07.03	Emission	B. Sára*	D. Mattioli	D. Mattioli

PERIOD COVERED BY REPORT	SECTIONS INCLUDED:	CO-ORDINATOR NAME:	PROJECT HOME PAGE:

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 viscose fabric products within I04 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 I04 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

I04 is an Italian company located in the Como area. Its annual production is over 1776 tons of textile products mainly made of viscose fabric (35%), mix acetate (29%), bemberg (16%), acetate (1%) and others (19%). The general organization of the company production departments is highlighted in the following material flowchart.

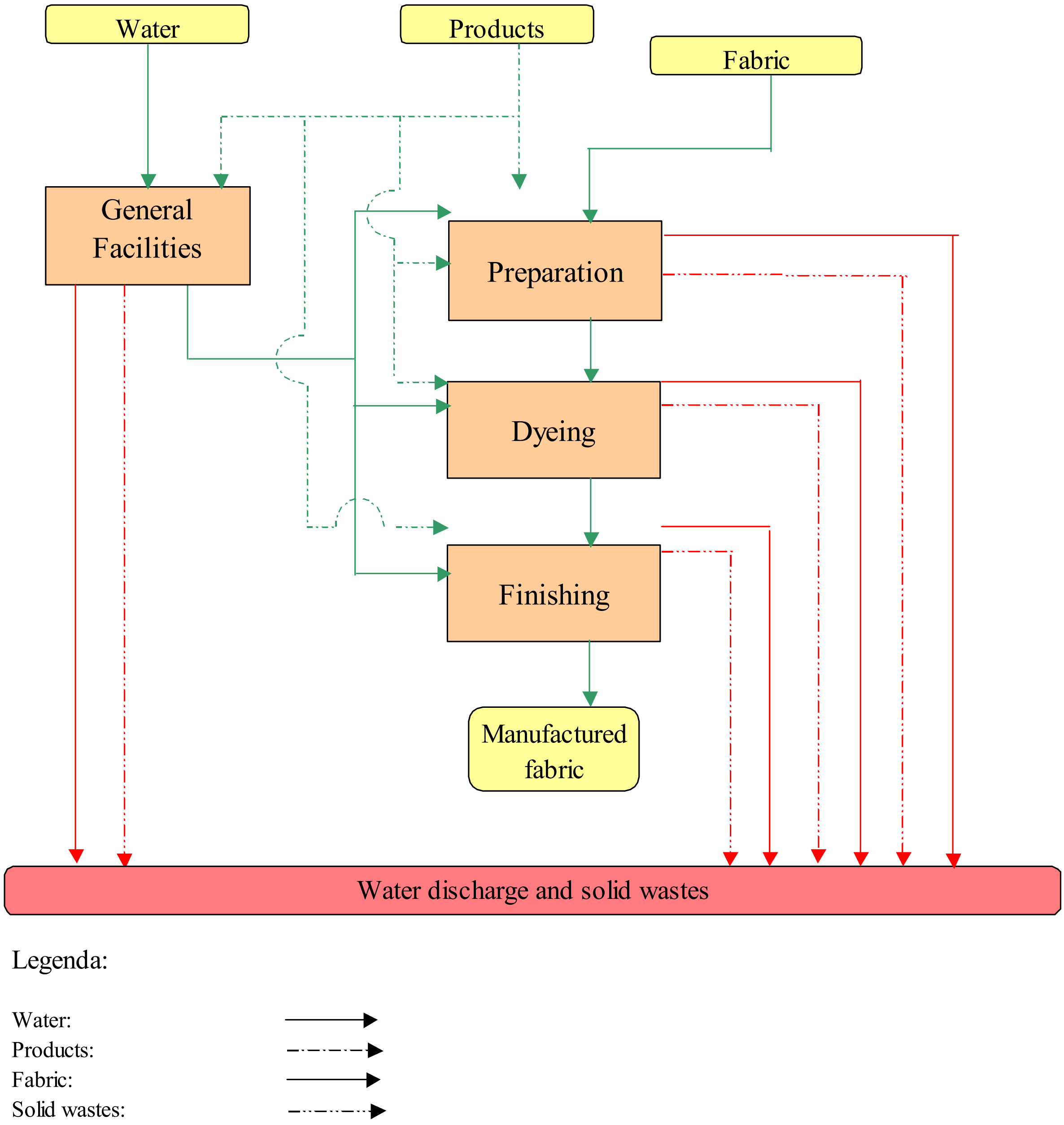

Fig. 2.1 Material flowchart of I04 company

A more detailed description of I04 company is available in the Process Identification and data Collection Sheet (PIDACS) of the company.
In this study three viscose fabric product alternatives were analysed:

- Viscose fabric dyed with dark colours through direct process in Jigger (System A);
- Viscose fabric dyed with dark colours through direct process in Pad Steam (System B);
- Viscose fabric dyed with dark colours through reactive process in Jigger (System C).

The general flow-chart of the three systems is shown in Fig 2.2. In case of direct dyeing in jigger (System A), a part of the waste water is recycled after treatment in membrane nano-filtration process.

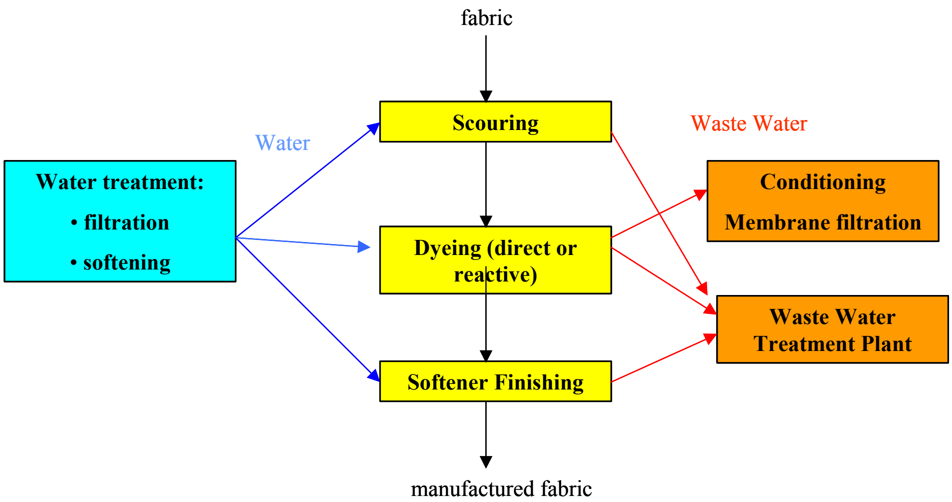

Fig.2.2 Schematic flowchart of analysed viscose fabric products

Table 2.1 shows the textile wet processes of the three product systems; the process numbers refer to I04 PIDACS classification.

Product systems	**System A**	**System B**	**System C**
Continuous scouring in mezzera	F.1.1.	-	F.1.1.
Continuous scouring in pad steam	-	F.1.2.	-
Dark direct dyeing in jigger	G.3.2.	-	-
Dark direct dyeing in pad-steam	-	G.3.1.	-
Dark reactive dyeing in jigger	-	-	G.12.1.
Soaping in pad-steam	G.13.1.	G.13.1.	G.13.1.
Softener 2 finishing	H.2.2.	H.2.2.	H.2.2.

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].

Viscose (CV)

The starting material is the cellulose that is extracted from coniferous timber and supplied to the fibre manufacture in sheets about 1cm thick. The wood contains ca. 40 – 50 % cellulose that is useable to make viscose. The cellulose is first allowed to swell in a NaOH solution. The white flakes obtained are then treated with carbon disulphide until the sodium cellulose xantogenate is formed. The xantogenate is soluble in diluted sodium hydroxide and the formed solution (pulp) is already called viscose. The pulp then needs to be spun. Spinning consists in coagulating the xantogenate solution at the outlet of the spinneret in an acid bath containing sulphuric acid, sodium sulphate and zinc sulphate.

Scouring

Scouring (also known as boiling-off or kier boiling) is aimed at the extraction of impurities present on the raw fibre or picked up at a later stage.

Scouring can be carried out as a separate step of the process or in combination with other treatments (usually bleaching or desizing) on all kind of substrates: woven fabric (sized or desized), knitted fabric and yarn. For yarn and knitted fabric, scouring is usually a batch process which is carried out in the same equipment that will subsequently be used for dyeing (mainly autoclaves or hank dyeing machines for yarn and overflows, jets, etc. for knitted fabric). Woven fabric is scoured in continuous mode using the pad-steam process.

The action of scouring is performed by the alkali (sodium hydroxide or sodium carbonate) together with auxiliaries: (non-ionic and anionic surfactants,, complexing agents, polyacrylates and phosphonates as special surfactant-free dispersing agents, sulphite and hydrosulphite as reducing agents. .

Direct dyes

Direct dyes are quite important in cellulose fibres dyeing: 75 % of the total consumption of these colourants is used, in fact, to dye cotton or viscose substrates. Direct dyes are applied directly from the dye bath together with salt (sodium chloride or sodium sulphate) and auxiliary agents, which ensure a thorough wetting and dispersing effect. Mixtures of non-ionic and anionic surfactants are used for this purpose.

In the batch process the dye is made into paste, then dissolved in hot water and added to the dye bath. The electrolyte is then added to the dye bath. After the dye bath has been drained, the fabric is washed with cold water and generally subjected to after-treatment.

Pad processes encompass the following techniques: pad-steam, pad-roll, cold pad-batch, pad-jig process (the material is padded with the dye and then passed through a salt liquor in a jigger). In all processes the material is rinsed at the end with cold water.

Reactive dyes

One third of dyes used for cellulose fibres today are reactive dyes. They are mostly applied according to the pad-batch and continuous processes for woven fabric, while batch processes are the most common for knitted fabric, loose stock and yarn.

In batch dyeing, dye, alkali (sodium hydroxide or sodium carbonate or bicarbonate) and salt are added to the dye bath in one step, at the start of the process, or stepwise. In the stepwise process the alkali is added only after the dye has absorbed to the fibre. Its amount is determined by the reactivity of the system and the desired depth of shade (cold dyers are applied at lower pH compared to warm and hot dyers). Salt is added to improve bath exhaustion: the concentration employed depends on the substantivity of the dye and on the intensity of the shade. Higher After dyeing, the liquor is drained off and the material is rinsed and then washed off with the addition of auxiliaries.

Soaping

Dyeing and printing with reactive dyes entails a number of soaping and rinsing steps to remove from the substrate the amount of unreacted and hydrolysed dye. The removal of all unfixed dyestuff from the fibre is essential for obtaining optimum wet fastness, while contributing significantly to energy, water and chemicals consumption of the overall dyeing process.

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 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).
The application of softening agents does not involve curing processes.
All these processes use sand filtered, softened, conditioned 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 preparation, dyeing and finishing of viscose 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 preparation, dyeing and finishing of a weight unit of viscose 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 viscose fabric.

2.2.4 System boundaries of product system

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

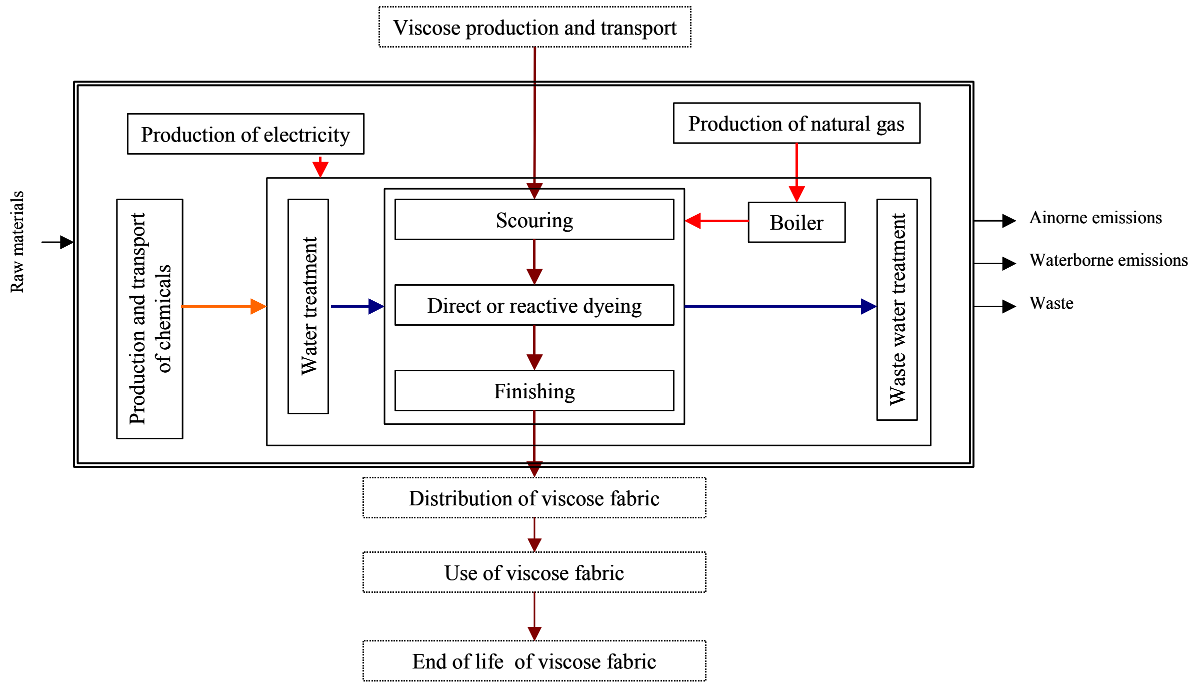

Fig 2.3 System boundaries of I04 product systems

The processes excluded from the system boundaries are:

- viscose 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:

- continuous scouring in mezzera
- continuous scouring in pad-steam
- dark direct dyeing in jigger
- dark direct dyeing in pad-steam
- dark reactive dyeing in jigger
- soaping in pad-steam
- softener 2 finishing
- water treatment (sand filtration, conditioning, separation, softening)

TEAM 3.0/Ecobilan data:

- production of electricity;
- production of methane;
- transport processes;
- boiler: general model whose process parameters and efficiency are adjusted to I04 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 on the lack of data about production of chemicals. Surrogate inventory data about the production of organic and 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 I04 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:
- <u>Steam production</u>

The annual company methane consumption as well as the annual steam consumption are measured and reported on the I04 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 of pre-treatment and dyeing processes, the specific consumption of steam has been calculated (m^3 of steam/kJoule 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 evaluate the specific methane consumption of thermosetting in finishing processes, steam consumption has been calculated on the basis of the textile production (Kg steam/Kg viscose fabric). 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 in wastewater analyses.

- Electricity consumption

The electricity consumption of specific processes has been calculated as [absorbed power] x [working 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.

- Solid waste

The annual solid waste production of the company is specified in the PIDACS. 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, an average of 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 selected viscose 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 equivalent H+
CML 92-Aquatic Eco-toxicity	1e^3 m3
CML 92-Depletion of non renewable resources	fraction of reserve
CML 92-Eutrophication	equivalent g PO4
CML 92-Human Toxicity	g
CML 92-Terrestrial Eco-toxicity	t
IPCC-Greenhouse effect (direct, 100 years)	equivalent g CO2
WMO-Photochemical oxidant formation (high)	equivalent g 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 Hauschild 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)$\leq$ 10 mg/l, or
48-hour EC_{50} (Daphnia))$\leq$ 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 I04 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 I04 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 Viscose wet processing and general facilities

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

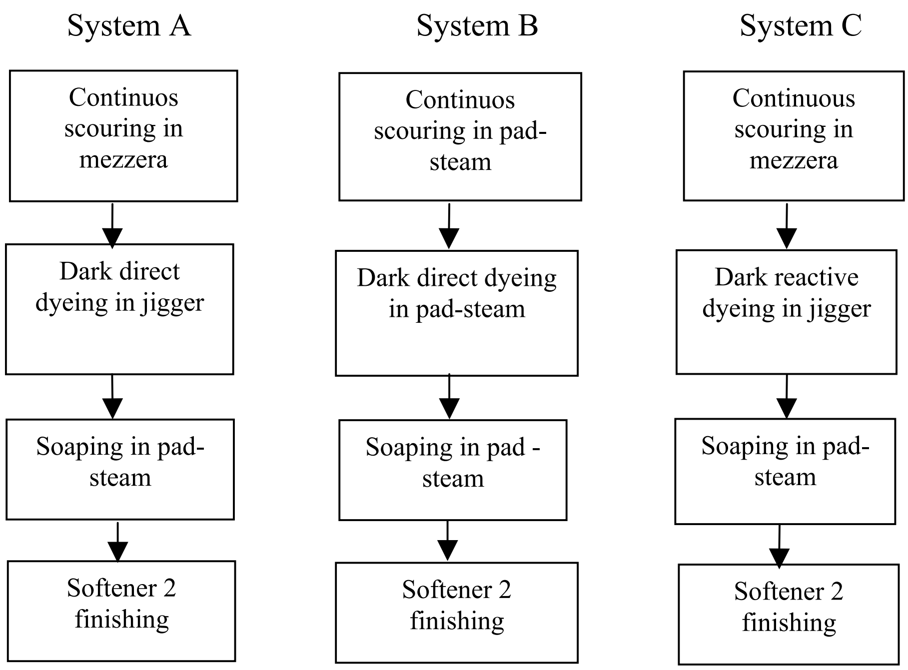

Figure 3.1 Flow-chart of the selected production lines

The most productive equipments were identified for each process of the selected production lines. Table 3.1 summarizes the annual viscose production of each process and the percentage contribution of machinery in I04 company. Four types of items were selected for the inventory analysis because of their significant contribution to the annual production:

- A2 for continuous scouring in pad-steam: **1486681 Kg fabric/yr;**
- A2 for dark direct dyeing in pad-steam: **206523 Kg fabric/yr;**
- A2 for soaping: **2062340 Kg fabric/yr;**
- Z2 for continuous scouring in mezzera: **674912 kg fabric/yr**;
- JG1 for dark direct dyeing in jigger: **186052 Kg fabric/yr;**
- JG1 for dark reactive dyeing in jigger: **187658 Kg fabric/yr;**
- R1 for softener 2 finishing: **562427 kg fabric/yr.**

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

	Continuous scouring in mezzera	**Continuous scouring in pad-steam**	**Dark direct dyeing in jigger**	**Dark direct dyeing in pad-steam**	**Dark reactive dyeing in jigger**	**Soaping**	**Softener 2 Finishing**
annual viscose production (ton)	674.912	803.796	137.682	206.523	229.470	1776.320	1687.280
Equipment							
Z2	**100%**						
A1		50%					
A2		**50%**		**100%**		**100%**	
JG1			**40%**		**40%**		
JG2			40%		40%		
JG3			20%		20%		
R1							**33%**
R2							33%
R3							33%

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

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

- rapid filtration of water: **229112 m^3 water/year** capacity;
- storage of water: **378512 m^3 water/year** capacity;
- softening of water for production processes: **187736 m^3 water/year** capacity;
- conditioning: **19344 m^3 water/year** capacity;
- membrane nano-filtration: **15750 m^3 water/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

Processes consume two types of water: “W2” is a mix of well water (133650 m^3/yr), rapid filtered water (229112 m^3/yr) and recycled/membrane nano-filtered water (15750 m^3/yr)

"W3" is produced by softening of "W2". A detailed flow-chart of the company water flows is represented in Annex 2.

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

Table 3.2 Water consumption of textile treatment processes

	Water type	Water consumption (m^3/year)
Continuous scouring in mezzera		
Doping	W3	10
Reintegration	W3	335
Scouring	W3	1425
Filling	W3	84
Rinsing	W2	5356
Neutralization	W2	21
Continuous scouring in pad-steam		
Doping	W3	1746
Steaming	W3	1287
Reintegration	W3	322
Filling	W2	23169
Rinsing	W2	22525
Neutralization	W2	129
Dark direct dyeing in pad-steam		
Dyeing bath	W3	22
Reintegration	W3	72
Steaming	W3	80
Filling	W2	1697
Rinsing	W2	1415
Neutralization	W2	10
Filling	W2	10
Reintegration	W2	26
Dark direct dyeing in jigger		
Bath	W3	425
Continuous rinsing	W2	4253
Dark reactive dyeing in jigger		
Bath	W3	429
Continuous rinsing	W2	4289
Acid bath	W2	429
1st soaping bath	W2	429
2nd soaping bath	W2	429
Continuous rinsing	W2	4289
Soaping		
Dyeing bath	W3	4464
Reintegration	W3	1339
Steaming	W3	4464
Filling	W2	11704
Rnsing	W2	17856
Neutralization	W2	446
Softener 2 finishing		
Filling	W3	4
Reintegration	W2	201

	Water type	Water consumption (m^3/year)
Rapid filtration of water		
Backwashing	W2	11933
Rinsing	W2	4773
Softening of water		
Backwashing	W2	287
Regeneration	W2	431
Rinsing	W2	144
Conditioning		
Backwashing	W2	67
Rinsing	W2	34
Membrane nano-filtration		
Chemical washing	W2	150
Rinsing	W2	18

3.2.1.2 Electricity consumptions

Table 3.3 describes the electricity consumption of each item for every process.

Table 3.3 Consumption of electricity

	item	absorbed power (kW)	working hours/year	electricity (kWh/year)
Continuous scouring in mezzera	Z2	40.5	1339	54432
Continuous scouring in pad-steam	A2	92	3218	296056
Dark direct dyeing in pad-steam	A2	92	447	39584
Dark direct dyeing in jigger	JG1*	6.9	-	15844
Dark reactive dyeing in jigger	JG1*	6.9	-	16643
Soaping	A2	92	4464	410688
Softener 2 finishing	R1	81	803	65934
Sand filtration of water	SF1			
Softening	S1	6.5	3360	22522
Conditioning	SF2	6.75	3360	22680
Membrane nano-filtration	NF	26	3360	86528

(*) no available data on yearly working hours of JG1; calculation has been done considering [run time] x [number of run/yr].

3.2.1.3 Methane consumption

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

PIDACS contains information about annual methane and steam consumptions.
Specific steam consumption for thermosetting in finishing processes has been estimated as 1 kg steam/1 kg textile by process experts of Lariana Depur. Allocation of annual steam and methane consumption for other processes was made by energy calculated with the next formula:

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

- initial water temperature = 17 °C
- density of water = 1 kg/ m^3

- specific heat of water = 4.1867 kJ/kg*°C

The value of "required heating energy" was calculated for each equipment of the I04 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 3.5 shows the calculation procedure for steam consumption of the processes of the selected production lines.

Table 3.4 Values and factors use for calculation of process specific methane and steam consumption

	Unit	Value	Comment
steam consumption	kg/year	36233000	
steam consumption for thermosetting	kg/yr	4339860	1 kg steam/1 kg textile
steam for water heating	kg/yr	31893140	
total "required heating energy"	kJ/yr	11194456	for indirect heating
factor "steam/ required heating energy"	kg/kJ	2.85	
methane consumption of I04 (use: production processes and shed heating)	m^3 /yr	4272497	
methane consumption for production processes	m^3 /yr	4058872	95% of methane consumption in I04
factor "methane/steam"	m^3 /kg	0.112	

Table 3.5 Calculation of process specific steam consumptions

	Heated water	Water temperature	Required heating energy/year	Total specific consumption of steam/year	Specific consumption of steam for thermosetting
	(m3/yr)	(°C)	(kJ/yr)	(kg /yr)	(Kg/yr)
Continuous scouring in mezzera					
Scouring	1425	50	196918	561022	
total				561022	
Continuous scouring in pad-steam					
Doping	1746	60	314259	895329	
Steaming	1287	60	231727	660192	
total				1555521	
Dark direct dyeing in jigger					
Dyeing bath	425	60	7655	218118	
total				218118	
Dark dyeing in pad-steam					
Dyeing bath	22	60	40024	11464	
Steaming	80	80	21223	60465	
total				71929	
Dark reactive dyeing in jigger					
Dyeing bath	429	60	77220	220001	
1st soaping	429	60	77232	220001	
2nd soaping	429	60	77232	220001	
total				660002	
Soaping					
Steaming	4464	60	803634	2289564	
total				2289564	
Softener 2 Finishing					
Filling					562427
total					562427

3.2.1.4 Consumption of chemicals

Table 3.6 shows the concentration of chemicals used for each process. The mass of chemicals has been calculated on the basis of consumed water (see Chapter 3.1.1.1) or treated yarn (when concentration is defined in kg of chemicals/100 kg yarn [%]).

Table 3.6 Concentration of chemicals

	Caustic soda	Soaping agent (21)	Sodium carbonate	Acetic acid	Anti reducing agent (6)	Direct dyestuffs	Soaping agent (17)	Equalizing agent (08)	Sodium sulphate	Reactive dyestuffs	Softening agent (22)	Soaping agent	Regenerating agent (NaCl)	Deoxygeneting agent	Conditioning agent	Sodium hypoclhorite	Flocculant agent
	g/l	g/l	g/l	g/l	g/l	%	g/l	g/l	g/l	%	%	g/l	kg	g/l	g/l	g/l	mg/l
Continuous scouring in mezzera																	
Doping	20																
Scouring		6															
Neutralization				0.5													
Continuous scouring in pad steam																	
Doping		19	5														
Steaming		15															
Neutralization				0.5													
Dark direct dyeing in pad-steam																	
Dyeing bath					6	>1.5											
Steaming							15										
Dark direct dyeing in jigger																	
Bath						>0.5; <1.5		2									
Dark reactive dyeing in jigger																	
Bath	3								10	<1..5							
Acid bath				4													
1st soaping bath												1					
2nd soaping bath												1					
Soaping																	
Dyeing bath							1										
Steaming							1										
Softener finishing																	
Wringing											2						
Softening of water																	
Regeneration													587				
Conditioning																	
Filtration															0.001		10
Membrane nano-filtration																	
Chemical washing																2	

3.2.1.5 Discharged water

Table 3.7 shows the COD and TSS concentrations of discharged water. 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).

Table 3.7 Discharged water (see Annex 2 for type of discharged water)

	Type	**Vol (m^3/yr)**	**COD (mg/l)**	**TSS (mg/l)**
Continuous scouring in mezzera				
doping	D3	10	300	22
scouring	D3	1425	9500	130
rinsing	D3	5356	500	50
(discharge)	D3	84	320	10
neutralization	D3	21	850	10
total			11470	222
Continuous scouring in pad-steam				
coping	D3	1746	5900	150
steaming	D3	1287	2300	130
rinsing	D3	22525	1250	50
(discharge)	D3	23169	2800	10
neutralization	D3	129	320	10
total			12570	350
Dark direct dyeing in pad-steam				
dyeing bath	D3	22	5600	180
steaming	D3	80	150	30
rinsing	D3	1415	100	20
(discharge)	D3	1697	880	33
neutralization	D3	10	50	10
filling	D3	0	100	10
total			6880	283
Dark direct dyeing in jigger				
discharge	D3	425	7920	60
continuous rinsing	D4	4253	179	25
total			8099	85
Dark reactive dyeing in jigger				
discharge	D3	429	9800	345
continuous rinsing	D3	4289	500	41
discharge	D3	429	2450	133
1st soaping (discharge)	D3	429	2080	67
2nd soaping (discharge)	D3	429	1300	38
continuous rinsing	D3	4289	120	10
total			16250	634
soaping				
dyeing bath	D3	4464	890	150
steaming	D3	4464	1520	335
rinsing	D3	17856	750	20
(discharge)	D3	11704	400	10
neutralization	D3	446	50	10
total			3610	525
Softener 2 finishing				
discharge	D3	4	4400	249
total			4400	249
Rapid filtration				
backwashing	D2	11933	100	10
rinsing	D1	4773	50	5
total			150	15
Softening of water				
backwashing	D3	287	150	15
regeneration	D3	431	100	10

	Type	Vol (m^3/yr)	COD (mg/l)	TSS (mg/l)
rinsing	D3	144	50	5
total			300	30
Conditioning				
backwashing	D3	67	450	280
rinsing	D3	34	250	60
total			700	340
Membrane nano-filtration				
nano-filtration	D3	3869	405	40
chemical washing	D3	150	300	25
rinsing	D3	80	150	20
total			855	85

3.2.1.6 Airborne emission

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, an average of the specific limit value has been assumed.

Concerning processes of the selected production lines in I04 company, there were emission sources related to pad steam and mezzera equipments (see Tab.3.8).
Table 3.9. shows the calculation of flow rates related to processes.
Table 3.10 shows the emission concentrations as described in PIDACS.

Table 3.8: Emission sources

Type(*)	Emission source	Flow rate [Nm^3/h]
G1	Pad-steam	5429
G2	Mezzera	6119
G3	Mezzera	923
G4	Pad-steam	674
G5	Drier	4636

Table 3.9:Calculation of flow rates of processes based on working ours

process	Emission sources	Working hours (h/yr)	Emission type	Off-gas flow rate (Nm^3/yr)
Continuous scouring in mezzera	Mezzera	1339	G2 G3	8193341 1235897
Continuous scouring in pad-steam	Pad-steam	3218	G1 G4	4723230 586380
Dark direct dyeing in pad steam	Pad-steam	447	G1 G4	2426763 301278
Soaping	Pad-steam	4464	G1 G4	20874505 2591530

Table 3.10: Emission concentrations

Type	G1	G2	G3	G4	G5
Ammonia [mg/Nm^3]	0,3	0,8	1,5	20	<0,1
Aldehydes [mg/Nm^3]	<0,1	0,1	<0,1	0,3	<0,1
VOC [mg/Nm^3]	<0,1	<0,1	<1	<1	<1
Particles [mg/Nm^3]	29	2,5	2,9		

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 3.11 Production of waste

	annual production (kg)	normalised to ref. flow (kg)	destination of waste
viscose fabric	5067160	100	
150106 various materials packaging	104420	5.9	Reuse
150101 board sand paper	34300	1.9	Dump
040222 textile fibres residual	900	5.06E-4	Dump
150102 plastic	16330	9.19 E-3	Reuse
170405 iron and steel	14200	7.9 E-3	Recovery
130208 oils	3220	1.8 E-3	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.
Table 3.12 summarises the sources used for the production of each chemical of System A, B and C. It must be highlighted that the LCA study has a relevant lack of data on chemicals production: 95% of chemicals in System A, 85% of chemicals in System B and 44% of chemicals in System C were excluded from the product system. These chemicals were treated as flows and characterised in the impact assessment by the EDIP method (see Chapter 2.2.8).
In the Interpretation phase of the LCA study, a sensitivity check was made to evaluate the influence of 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).

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 x km” values were calculated by multiplying transported mass and distance values. (see Table 3.13)

Table 3.12 Chemicals

Chemical class	Commercial Name	Composition	Source
caustic soda	Permaspeed AH03	caustic soda	TEAM
soaping agent	Tanalube	Acrylic Polymer	-
soaping agent	Idrosolvan M 90	Sequestring and organic alkaly mixture	-
soaping agent	Idrosolvan E 500	surfactant mixture	-
soaping agent	Permaspeed AS01	sodium alkyl-benzensulphonate	-
soda solvay		sodium carbonate	TEAM
antireducing agent	Reodal TF	Acrilic polymer sodic salt	-
direct dyestuff (*)			-
equalizing agent	Indigol NYL	ethoxilate amines and benzensulphonic acid salts	-
sodium sulphate (*)			-
reactive dyestuff (*)			-
Acetic acid	Acetic acid		TEAM
softener agent	Silicer L	Fatty acids alkyl-amides in cationic emulsion	-
regenerating agent (*)			-
deoxygeneting agent (*)			-
conditioning agent (*)			-
sodium hypochlorite (*)			-
flocculant agent (*)			-
sodium sulphate (*)			TEAM

(*) No data were available about these chemical classes relating to their composition.

Table 3.13 Types and distances of transport of chemicals

Chemical class	Supplier	Type of freight	Distance from delivery [km]
caustic soda	Permeare S.r.l.	3,5 tons< Lorry	>100
soaping agent	Bayer S.p.a.	3,5 tons< Lorry	< 50
soaping agent	Giovanni Bozzetto S.p.a.	3,5 tons< Lorry	< 50
soaping agent	Giovanni Bozzetto S.p.a.	3,5 tons< Lorry	< 50
soaping agent	Permeare S.r.l.	3,5 tons< Lorry	> 100
soda solvay	Allchital spa	3,5 tons< Lorry	< 50
antireducing agent	Dalton S.p.a.	3,5 tons< Lorry	< 50
direct dyestuff (*)		3,5 tons< Lorry	< 50
equalizing agent	Dalton Spa	3,5 tons<Lorry	<50
sodium sulphate(*)		3,5 tons< Lorry	< 50
reactive dyestuff(*)		3,5 tons< Lorry	< 50
acetic acid	Allchital spa	3,5 tons<Lorry	<50
softener agent	Ausiliari Tessili S.r.l.	3,5 tons<Lorry	> 100
regenerating agent (*)		3,5 tons< Lorry	< 50
deoxygenating agent (*)		3,5 tons< Lorry	< 50
conditioning agent (*)		3,5 tons< Lorry	< 50
sodium hypoclhorite (*)		3,5 tons< Lorry	< 50
flocculant agent		3,5 tons< Lorry	< 50
sodium sulphate (*)		3,5 tons< Lorry	< 50

(*) No data were available about these chemical classes. Type of freight and the distance from delivery were estimated.

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 I04 consumes 0.112 m^3 of methane for the production of 1 kg steam. This amount of consumed methane corresponds to 3.645 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 I04 company, the following variables were modified:

- Initial temperature of water: 17 ^oC
- Final temperature of steam: 160 ^oC
- Boiler yield: 0.75

These variables result the consumption of 3.645 MJ of energy / 1 kg of steam.

3.2.4 Waste water treatment plant (WWTP)

Table 3.14 summarizes the data used to model the WWTP.

Table 3.14 Data use for the WWTP

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

3.3 Results of inventory analysis

Results of the inventory analysis were preliminary evaluated with the impact assessment methods. Significant flows - whose summed contribution is more than 99% for an impact category- were selected. Table 3.15, 3.16 and 3.17shows the quantities of these main flows, as well as water consumption, COD and TSS emission of the textile industrial processes.

Table 3.15 Results of inventory analysis of I04 viscose fabric-System A (only main flows are listed)

	Flows	Units	Total	Continuos scouring in mezzera	Dark direct dyeing in jigger	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
INPUT	(r) Iron (Fe, ore)	kg	2.10E-01	4.12E-02	5.68E-02	5.89E-02	5.06E-02	0.00E+00	1.69E-04	1.82E-04	1.92E-04	1.69E-03
	(r) Natural Gas (in ground)	kg	4.11E+01	8.16E+00	1.13E+01	1.14E+01	9.95E+00	0.00E+00	2.14E-02	2.26E-02	2.39E-02	2.11E-01
	(r) Oil (in ground)	kg	9.10E+00	1.47E+00	1.64E+00	3.14E+00	2.13E+00	0.00E+00	3.14E-02	5.76E-02	6.07E-02	5.63E-01
	(r) Uranium (U, ore)	kg	7.67E-05	1.61E-05	2.10E-05	2.13E-05	1.79E-05	0.00E+00	4.50E-07	2.01E-09	2.12E-09	1.87E-08
	Water: Well	litre	2.04E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water to: Sand filtration	litre	3.48E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.35E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water from Membrane ultra-filtration	litre	2.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: from Storage	litre	-	7.97E+02	2.29E+03	1.45E+03	3.57E+01	2.44E+02	1.00E+03	1.50E+00	3.36E+00	0.00E+00
	Water: from Softening	litre	-	2.74E+02	2.28E+02	4.98E+02	7.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: Unspecified Origin	litre	1.10E+02	1.98E+01	2.58E+01	3.24E+01	2.56E+01	0.00E+00	3.05E+00	2.85E-01	3.01E-01	2.76E+00
OUPUT	(a) Alkane (unspecified)	g	5.46E+00	1.06E+00	1.44E+00	1.56E+00	1.31E+00	0.00E+00	5.34E-03	7.32E-03	7.72E-03	6.85E-02
	(a) Arsenic (As)	g	5.96E-03	9.75E-04	1.11E-03	2.06E-03	1.38E-03	0.00E+00	2.61E-05	3.60E-05	3.80E-05	3.34E-04
	(a) Butane (n-C4H10)	g	2.70E+00	4.85E-01	6.14E-01	8.46E-01	6.41E-01	0.00E+00	5.48E-03	9.55E-03	1.01E-02	9.07E-02
	(a) Cadmium (Cd)	g	1.14E-02	1.83E-03	2.05E-03	3.99E-03	2.63E-03	0.00E+00	4.04E-05	7.35E-05	7.76E-05	6.84E-04
	(a) Carbon Dioxide (CO2, fossil)	g	1.36E+05	2.58E+04	3.43E+04	4.01E+04	3.27E+04	0.00E+00	2.01E+02	2.76E+02	2.91E+02	2.66E+03
	(a) Ethane (C2H6)	g	1.65E+01	2.84E+00	3.44E+00	5.42E+00	3.87E+00	0.00E+00	4.45E-02	7.77E-02	8.20E-02	7.28E-01
	(a) Ethylene (C2H4)	g	2.05E+01	4.06E+00	5.63E+00	5.69E+00	4.96E+00	0.00E+00	1.36E-02	1.24E-02	1.31E-02	1.16E-01
	(a) Hydrocarbons (except methane)	g	8.40E+01	1.44E+01	1.72E+01	2.71E+01	2.03E+01	0.00E+00	2.25E-01	3.98E-01	4.20E-01	4.04E+00
	(a) Hydrogen Chloride (HCl)	g	3.95E+00	6.90E-01	7.73E-01	1.32E+00	9.05E-01	0.00E+00	2.55E-02	2.07E-02	2.18E-02	1.92E-01
	(a) Lead (Pb)	g	3.42E-02	5.82E-03	6.55E-03	9.58E-03	1.03E-02	0.00E+00	1.10E-04	1.56E-04	1.65E-04	1.45E-03
	(a) Methane (CH4)	g	4.21E+02	7.20E+01	8.62E+01	1.40E+02	9.85E+01	0.00E+00	1.26E+00	2.08E+00	2.19E+00	1.94E+01
	(a) Nickel (Ni)	g	2.24E-01	3.62E-02	4.04E-02	7.86E-02	5.18E-02	0.00E+00	7.95E-04	1.45E-03	1.53E-03	1.35E-02
	(a) Nitrogen Oxides (NOx as NO2)	g	1.33E+02	2.35E+01	2.90E+01	4.14E+01	3.18E+01	0.00E+00	3.56E-01	5.12E-01	5.40E-01	5.85E+00
	(a) Propane (C3H8)	g	4.42E+00	7.68E-01	9.40E-01	1.44E+00	1.04E+00	0.00E+00	1.17E-02	1.96E-02	2.06E-02	1.84E-01
	(a) Sulphur Oxides (SOx as SO2)	g	4.66E+02	7.63E+01	8.64E+01	1.61E+02	1.08E+02	0.00E+00	1.70E+00	2.84E+00	3.00E+00	2.65E+01
	(a) Vanadium (V)	g	8.88E-01	1.43E-01	1.59E-01	3.12E-01	2.05E-01	0.00E+00	3.16E-03	5.78E-03	6.10E-03	5.37E-02

	Flows	Units	Total	Continuos scouring in mezzera	Dark direct dyeing in jigger	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
	(s) Arsenic (As)	g	3.39E-04	6.74E-05	9.37E-05	9.38E-05	8.21E-05	0.00E+00	1.72E-07	1.80E-07	1.90E-07	1.67E-06
	(s) Chromium (Cr III, Cr VI)	g	4.25E-03	8.43E-04	1.17E-03	1.17E-03	1.03E-03	0.00E+00	2.15E-06	2.25E-06	2.37E-06	2.09E-05
	(s) Zinc (Zn)	g	1.27E-02	2.53E-03	3.52E-03	3.52E-03	3.08E-03	0.00E+00	6.46E-06	6.75E-06	7.12E-06	6.28E-05
	(w) Ammonia (NH4+, NH3, as N)	g	2.36E+01	6.87E-02	7.77E-02	1.42E-01	1.00E-01	0.00E+00	1.56E-03	2.50E-03	2.64E-03	2.32E+01
	(w) Benzene (C6H6)	g	1.24E-01	2.03E-02	2.31E-02	4.23E-02	2.92E-02	0.00E+00	4.05E-04	7.40E-04	7.81E-04	7.24E-03
	(w) Cadmium (Cd++)	g	3.67E-04	6.13E-05	7.13E-05	1.22E-04	8.77E-05	0.00E+00	1.13E-06	1.98E-06	2.09E-06	2.04E-05
	(w) Chromium (Cr III)	g	8.91E-03	1.77E-03	2.46E-03	2.46E-03	2.16E-03	0.00E+00	4.52E-06	4.72E-06	4.98E-06	4.39E-05
	(w) Chromium (Cr III, Cr VI)	g	2.20E-03	3.56E-04	3.99E-04	7.56E-04	5.15E-04	0.00E+00	7.84E-06	1.37E-05	1.44E-05	1.34E-04
	(w) COD (Chemical Oxygen Demand)	g	2.02E+02	1.93E-01	2.40E-01	3.02E-01	2.45E-01	0.00E+00	1.66E-03	2.78E-03	2.93E-03	2.01E+02
	(w) Nitrate (NO3-)	g	3.06E+01	1.40E-02	1.60E-02	2.84E-02	1.93E-02	0.00E+00	2.86E-04	4.73E-04	4.99E-04	3.05E+01
	(w) Nitrogenous Matter (unspecified, as N)	g	5.46E+01	8.33E-02	9.32E-02	1.75E-01	1.22E-01	0.00E+00	1.73E-03	3.18E-03	3.35E-03	5.41E+01
	(w) Oils (unspecified)	g	2.38E+00	4.48E-01	5.93E-01	7.04E-01	5.71E-01	0.00E+00	3.18E-03	5.14E-03	5.42E-03	5.01E-02
REMINDERS	E Feedstock Energy	MJ	3.48E+01	5.86E+00	6.85E+00	1.19E+01	8.02E+00	0.00E+00	1.10E-01	1.88E-01	1.98E-01	1.76E+00
	E Fuel Energy	MJ	2.18E+03	4.17E+02	5.58E+02	6.35E+02	5.24E+02	0.00E+00	2.92E+00	3.81E+00	4.01E+00	3.65E+01
	E Non Renewable Energy	MJ	2.16E+03	4.14E+02	5.55E+02	6.28E+02	5.19E+02	0.00E+00	2.88E+00	3.67E+00	3.87E+00	3.52E+01
	E Renewable Energy	MJ	5.36E+01	8.80E+00	9.99E+00	1.86E+01	1.24E+01	0.00E+00	1.37E-01	3.26E-01	3.44E-01	3.02E+00
	E Total Primary Energy	MJ	2.22E+03	4.22E+02	5.65E+02	6.47E+02	5.32E+02	0.00E+00	3.03E+00	3.99E+00	4.21E+00	3.83E+01
	Electricity	MJ elec	4.09E+02	6.68E+01	7.49E+01	1.43E+02	9.43E+01	0.00E+00	1.01E+00	2.56E+00	2.70E+00	2.37E+01
	COD (to membrane filtration& WWTP)	kg	5.89E+00	2.41E+00	2.03E+00	1.40E+00	3.13E-03	2.09E-02	4.74E-04	5.73E-04	2.37E-02	0.00E+00
	TSS (to membrane filtration& WWTP)	kg	2.65E-01	6.73E-02	6.48E-02	1.28E-01	1.77E-04	2.09E-03	4.74E-05	3.08E-04	2.34E-03	0.00E+00

Table 3.16 Results of inventory analysis of I04 viscose fabric-System B (only main flows are listed)

	Flow	Units	Total	Continuos scouring in pad-steam	Dark direct dyeing	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
INPUT	(r) Coal (in ground)	kg	6.13E+00	1.86E+00	1.38E+00	1.42E+00	9.86E-01	0.00E+00	2.44E-02	2.36E-02	2.49E-02	4.10E-01
	(r) Iron (Fe, ore)	kg	1.98E-01	5.77E-02	2.63E-02	5.89E-02	5.06E-02	0.00E+00	1.44E-04	2.01E-04	2.12E-04	3.49E-03
	(r) Natural Gas (in ground)	kg	3.73E+01	1.10E+01	4.54E+00	1.14E+01	9.95E+00	0.00E+00	1.82E-02	2.50E-02	2.64E-02	4.35E-01
	(r) Oil (in ground)	kg	1.38E+01	3.68E+00	3.48E+00	3.14E+00	2.13E+00	0.00E+00	2.66E-02	6.35E-02	6.70E-02	1.16E+00
	(r) Uranium (U, ore)	kg	6.75E-05	1.98E-05	8.14E-06	2.13E-05	1.79E-05	0.00E+00	3.82E-07	2.22E-09	2.34E-09	3.86E-08
	Water: Well	litre	2.51E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water to: Sand filtration	litre	4.30E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: from Membrane ultra-filtration	litre	3.69E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: from Storage	litre	-	3.08E+03	1.53E+03	1.45E+03	3.57E+01	2.69E+02	8.12E+02	1.65E+00	3.71E+00	0.00E+00
	Water: from Softening	litre	-	2.26E+02	8.43E+01	4.98E+02	7.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: Unspecified Origin	litre	1.28E+02	3.81E+01	2.27E+01	3.24E+01	2.56E+01	0.00E+00	2.59E+00	3.15E-01	3.32E-01	5.71E+00
OUTPUT	(a) Alkane (unspecified)	g	5.39E+00	1.55E+00	8.06E-01	1.56E+00	1.31E+00	0.00E+00	4.53E-03	8.08E-03	8.52E-03	1.41E-01
	(a) Arsenic (As)	g	8.74E-03	2.31E-03	2.20E-03	2.06E-03	1.38E-03	0.00E+00	2.21E-05	3.97E-05	4.19E-05	6.90E-04
	(a) Butane (n-C4H10)	g	3.28E+00	9.03E-01	6.77E-01	8.46E-01	6.41E-01	0.00E+00	4.65E-03	1.05E-02	1.11E-02	1.87E-01
	(a) Cadmium (Cd)	g	1.71E-02	4.51E-03	4.40E-03	3.99E-03	2.63E-03	0.00E+00	3.43E-05	8.11E-05	8.56E-05	1.41E-03
	(a) Carbon Dioxide (CO2, fossil)	g	1.45E+05	4.14E+04	2.46E+04	4.01E+04	3.27E+04	0.00E+00	1.70E+02	3.05E+02	3.21E+02	5.48E+03
	(a) Ethane (C2H6)	g	2.20E+01	5.92E+00	5.04E+00	5.42E+00	3.87E+00	0.00E+00	3.77E-02	8.58E-02	9.05E-02	1.50E+00
	(a) Ethylene (C2H4)	g	1.87E+01	5.49E+00	2.32E+00	5.69E+00	4.96E+00	0.00E+00	1.15E-02	1.37E-02	1.45E-02	2.39E-01
	(a) Hydrocarbons (except methane)	g	1.14E+02	3.09E+01	2.62E+01	2.71E+01	2.03E+01	0.00E+00	1.91E-01	4.40E-01	4.64E-01	8.35E+00
	(a) Hydrogen Chloride (HCl)	g	5.45E+00	1.45E+00	1.31E+00	1.32E+00	9.05E-01	0.00E+00	2.16E-02	2.28E-02	2.41E-02	3.96E-01
	(a) Lead (Pb)	g	4.86E-02	1.34E-02	1.18E-02	9.58E-03	1.03E-02	0.00E+00	9.31E-05	1.72E-04	1.82E-04	3.00E-03
	(a) Methane (CH4)	g	5.72E+02	1.55E+02	1.33E+02	1.40E+02	9.85E+01	0.00E+00	1.07E+00	2.29E+00	2.42E+00	4.01E+01
	(a) Nickel (Ni)	g	3.38E-01	8.88E-02	8.67E-02	7.86E-02	5.18E-02	0.00E+00	6.75E-04	1.60E-03	1.69E-03	2.78E-02
	(a) Nitrogen Oxides (NOx as NO2)	g	1.70E+02	4.77E+01	3.57E+01	4.14E+01	3.18E+01	0.00E+00	3.02E-01	5.65E-01	5.96E-01	1.21E+01
	(a) Propane (C3H8)	g	5.76E+00	1.56E+00	1.29E+00	1.44E+00	1.04E+00	0.00E+00	9.93E-03	2.16E-02	2.28E-02	3.79E-01
	(a) Sulphur Oxides (SOx as SO2)	g	6.89E+02	1.85E+02	1.72E+02	1.61E+02	1.08E+02	0.00E+00	1.44E+00	3.14E+00	3.31E+00	5.47E+01
	(a) Vanadium (V)	g	1.34E+00	3.53E-01	3.45E-01	3.12E-01	2.05E-01	0.00E+00	2.68E-03	6.38E-03	6.73E-03	1.11E-01

	Flow	Units	Total	Continuos scouring in pad-steam	Dark direct dyeing	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
	(s) Arsenic (As)	g	3.07E-04	9.01E-05	3.71E-05	9.38E-05	8.21E-05	0.00E+00	1.46E-07	1.98E-07	2.09E-07	3.45E-06
	(s) Chromium (Cr III, Cr VI)	g	3.84E-03	1.13E-03	4.65E-04	1.17E-03	1.03E-03	0.00E+00	1.83E-06	2.48E-06	2.62E-06	4.32E-05
	(s) Zinc (Zn)	g	1.15E-02	3.39E-03	1.40E-03	3.52E-03	3.08E-03	0.00E+00	5.48E-06	7.45E-06	7.86E-06	1.30E-04
	(w) Ammonia (NH4+, NH3, as N)	g	4.85E+01	1.69E-01	1.55E-01	1.42E-01	1.00E-01	0.00E+00	1.32E-03	2.76E-03	2.91E-03	4.79E+01
	(w) Benzene (C6H6)	g	1.83E-01	4.90E-02	4.54E-02	4.23E-02	2.92E-02	0.00E+00	3.44E-04	8.17E-04	8.62E-04	1.49E-02
	(w) Cadmium (Cd++)	g	5.23E-04	1.41E-04	1.25E-04	1.22E-04	8.77E-05	0.00E+00	9.55E-07	2.18E-06	2.30E-06	4.21E-05
	(w) Chromium (Cr III)	g	8.07E-03	2.37E-03	9.76E-04	2.46E-03	2.16E-03	0.00E+00	3.84E-06	5.21E-06	5.50E-06	9.06E-05
	(w) Chromium (Cr III, Cr VI)	g	3.30E-03	8.80E-04	8.31E-04	7.56E-04	5.15E-04	0.00E+00	6.65E-06	1.51E-05	1.59E-05	2.76E-04
	(w) COD (Chemical Oxygen Demand)	g	4.16E+02	6.98E-01	2.19E-01	3.02E-01	2.45E-01	0.00E+00	1.41E-03	3.07E-03	3.23E-03	4.14E+02
	(w) Nitrate (NO3-)	g	6.30E+01	3.27E-02	2.92E-02	2.84E-02	1.93E-02	0.00E+00	2.43E-04	5.22E-04	5.51E-04	6.29E+01
	(w) Nitrogenous Matter (unspecified, as N)	g	1.12E+02	2.06E-01	1.94E-01	1.75E-01	1.22E-01	0.00E+00	1.47E-03	3.50E-03	3.70E-03	1.12E+02
	(w) Oils (unspecified)	g	2.56E+00	7.24E-01	4.43E-01	7.04E-01	5.71E-01	0.00E+00	2.70E-03	5.67E-03	5.98E-03	1.03E-01
REMINDERS	E Feedstock Energy	MJ	4.86E+01	1.27E+01	1.18E+01	1.19E+01	8.02E+00	0.00E+00	9.33E-02	2.07E-01	2.18E-01	3.64E+00
	E Fuel Energy	MJ	2.26E+03	6.49E+02	3.64E+02	6.35E+02	5.24E+02	0.00E+00	2.48E+00	4.20E+00	4.43E+00	7.53E+01
	E Non Renewable Energy	MJ	2.23E+03	6.41E+02	3.56E+02	6.28E+02	5.19E+02	0.00E+00	2.45E+00	4.05E+00	4.27E+00	7.27E+01
	E Renewable Energy	MJ	7.86E+01	2.06E+01	1.98E+01	1.86E+01	1.24E+01	0.00E+00	1.16E-01	3.60E-01	3.79E-01	6.24E+00
	E Total Primary Energy	MJ	2.31E+03	6.62E+02	3.76E+02	6.47E+02	5.32E+02	0.00E+00	2.57E+00	4.40E+00	4.65E+00	7.90E+01
	Electricity	MJ elec	6.06E+02	1.59E+02	1.55E+02	1.43E+02	9.43E+01	0.00E+00	8.55E-01	2.83E+00	2.98E+00	4.90E+01
	COD (to WWTP)	kg	9.46E+00	7.15E+00	8.57E-01	1.40E+00	3.13E-03	2.31E-02	4.02E-04	6.32E-04	2.62E-02	0.00E+00
	TSS (to WWTP)	kg	2.98E-01	1.20E-01	4.39E-02	1.28E-01	1.77E-04	2.31E-03	4.02E-05	3.40E-04	2.58E-03	0.00E+00

Table 3.17 Results of inventory analysis of I04 viscose fabric-System C (only main flows are listed)

	Flow	Units	Total	Continuos scouring in mezzera	Dark reactive dyeing in jigger	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
INPUT	(r) Iron (Fe, ore)	kg	3.17E-01	4.12E-02	1.61E-01	5.89E-02	5.06E-02	0.00E+00	1.69E-04	2.49E-04	2.62E-04	4.25E-03
	(r) Natural Gas (in ground)	kg	6.30E+01	8.16E+00	3.29E+01	1.14E+01	9.95E+00	0.00E+00	2.14E-02	3.09E-02	3.26E-02	5.28E-01
	(r) Oil (in ground)	kg	1.08E+01	1.47E+00	2.43E+00	3.14E+00	2.13E+00	0.00E+00	3.14E-02	7.85E-02	8.29E-02	1.41E+00
	(r) Uranium (U, ore)	kg	1.23E-04	1.61E-05	6.69E-05	2.13E-05	1.79E-05	0.00E+00	4.50E-07	2.75E-09	2.90E-09	4.70E-08
	Water: Well	litre	3.10E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water to: Sand filtration	litre	5.33E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: from Membrane ultra-filtration	litre	4.56E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: from Storage	litre	-	7.97E+02	5.26E+03	1.45E+03	3.57E+01	3.33E+02	1.00E+03	2.04E+00	4.58E+00	0.00E+00
	Water: from Softening	litre	-	2.74E+02	2.29E+02	4.98E+02	7.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water: Unspecified Origin	litre	1.54E+02	1.98E+01	6.51E+01	3.24E+01	2.56E+01	0.00E+00	3.05E+00	3.89E-01	4.10E-01	6.94E+00
OUTPUT	(a) Alkane (unspecified)	g	8.20E+00	1.06E+00	4.07E+00	1.56E+00	1.31E+00	0.00E+00	5.34E-03	9.99E-03	1.05E-02	1.72E-01
	(a) Arsenic (As)	g	6.87E-03	9.75E-04	1.49E-03	2.06E-03	1.38E-03	0.00E+00	2.61E-05	4.91E-05	5.18E-05	8.39E-04
	(a) Butane (n-C4H10)	g	3.58E+00	4.85E-01	1.35E+00	8.46E-01	6.41E-01	0.00E+00	5.48E-03	1.30E-02	1.37E-02	2.28E-01
	(a) Cadmium (Cd)	g	1.27E-02	1.83E-03	2.33E-03	3.99E-03	2.63E-03	0.00E+00	4.04E-05	1.00E-04	1.06E-04	1.72E-03
	(a) Carbon Dioxide (CO2, fossil)	g	1.95E+05	2.58E+04	8.89E+04	4.01E+04	3.27E+04	0.00E+00	2.01E+02	3.77E+02	3.97E+02	6.67E+03
	(a) Ethane (C2H6)	g	2.06E+01	2.84E+00	6.38E+00	5.42E+00	3.87E+00	0.00E+00	4.45E-02	1.06E-01	1.12E-01	1.83E+00
	(a) Ethylene (C2H4)	g	3.13E+01	4.06E+00	1.63E+01	5.69E+00	4.96E+00	0.00E+00	1.36E-02	1.70E-02	1.79E-02	2.90E-01
	(a) Hydrocarbons (except methane)	g	1.08E+02	1.44E+01	3.47E+01	2.71E+01	2.03E+01	0.00E+00	2.25E-01	5.44E-01	5.73E-01	1.01E+01
	(a) Hydrogen Chloride (HCl)	g	4.77E+00	6.90E-01	1.29E+00	1.32E+00	9.05E-01	0.00E+00	2.55E-02	2.82E-02	2.98E-02	4.81E-01
	(a) Lead (Pb)	g	4.38E-02	5.82E-03	1.39E-02	9.58E-03	1.03E-02	0.00E+00	1.10E-04	2.13E-04	2.25E-04	3.64E-03
	(a) Methane (CH4)	g	5.19E+02	7.20E+01	1.53E+02	1.40E+02	9.85E+01	0.00E+00	1.26E+00	2.84E+00	2.99E+00	4.87E+01
	(a) Nickel (Ni)	g	2.51E-01	3.62E-02	4.60E-02	7.86E-02	5.18E-02	0.00E+00	7.96E-04	1.98E-03	2.09E-03	3.38E-02
	(a) Nitrogen Oxides (NOx as NO2)	g	1.75E+02	2.35E+01	6.17E+01	4.14E+01	3.18E+01	0.00E+00	3.56E-01	6.99E-01	7.37E-01	1.47E+01
	(a) Propane (C3H8)	g	5.58E+00	7.68E-01	1.81E+00	1.44E+00	1.04E+00	0.00E+00	1.17E-02	2.67E-02	2.82E-02	4.61E-01
	(a) Sulphur Oxides (SOx as SO2)	g	5.33E+02	7.63E+01	1.12E+02	1.61E+02	1.08E+02	0.00E+00	1.70E+00	3.88E+00	4.09E+00	6.65E+01

	Flow	Units	Total	Continuos scouring in mezzera	Dark reactive dyeing in jigger	Soaping in pad-steam	Softener 2 Finishing	Rapid filtration	Softening	Conditioning	Membrane nano-filtration	WWTP
	(a) Vanadium (V)	g	9.93E-01	1.43E-01	1.79E-01	3.12E-01	2.05E-01	0.00E+00	3.16E-03	7.88E-03	8.32E-03	1.35E-01
	(s) Arsenic (As)	g	5.20E-04	6.74E-05	2.72E-04	9.38E-05	8.21E-05	0.00E+00	1.72E-07	2.45E-07	2.59E-07	4.19E-06
	(s) Chromium (Cr III, Cr VI)	g	6.51E-03	8.43E-04	3.40E-03	1.17E-03	1.03E-03	0.00E+00	2.15E-06	3.07E-06	3.24E-06	5.25E-05
	(s) Zinc (Zn)	g	1.95E-02	2.53E-03	1.02E-02	3.52E-03	3.08E-03	0.00E+00	6.46E-06	9.21E-06	9.72E-06	1.58E-04
	(w) Ammonia (NH4+, NH3, as N)	g	5.87E+01	6.87E-02	1.47E-01	1.42E-01	1.00E-01	0.00E+00	1.56E-03	3.41E-03	3.60E-03	5.82E+01
	(w) Benzene (C6H6)	g	1.50E-01	2.03E-02	3.74E-02	4.23E-02	2.92E-02	0.00E+00	4.05E-04	1.01E-03	1.07E-03	1.82E-02
	(w) Cadmium (Cd++)	g	4.75E-04	6.13E-05	1.46E-04	1.22E-04	8.77E-05	0.00E+00	1.13E-06	2.70E-06	2.85E-06	5.11E-05
	(w) Chromium (Cr III)	g	1.37E-02	1.77E-03	7.15E-03	2.46E-03	2.16E-03	0.00E+00	4.52E-06	6.44E-06	6.79E-06	1.10E-04
	(w) Chromium (Cr III, Cr VI)	g	2.62E-03	3.56E-04	6.12E-04	7.56E-04	5.15E-04	0.00E+00	7.84E-06	1.86E-05	1.97E-05	3.35E-04
	(w) COD (Chemical Oxygen Demand)	g	5.09E+02	1.93E-01	4.67E+00	3.02E-01	2.45E-01	0.00E+00	1.66E-03	3.79E-03	4.00E-03	5.04E+02
	(w) Nitrate (NO3-)	g	7.67E+01	1.40E-02	9.54E-02	2.84E-02	1.93E-02	0.00E+00	2.86E-04	6.45E-04	6.81E-04	7.65E+01
	(w) Nitrogenous Matter (unspecified, as N)	g	1.36E+02	8.33E-02	1.78E-01	1.75E-01	1.22E-01	0.00E+00	1.73E-03	4.33E-03	4.57E-03	1.36E+02
	(w) Oils (unspecified)	g	3.42E+00	4.48E-01	1.56E+00	7.04E-01	5.71E-01	0.00E+00	3.18E-03	7.01E-03	7.39E-03	1.26E-01
REMINDERS	E Feedstock Energy	MJ	6.30E+01	5.86E+00	3.22E+01	1.19E+01	8.02E+00	0.00E+00	1.10E-01	2.56E-01	2.70E-01	4.42E+00
	E Fuel Energy	MJ	3.16E+03	4.17E+02	1.48E+03	6.35E+02	5.24E+02	0.00E+00	2.92E+00	5.19E+00	5.48E+00	9.16E+01
	E Non Renewable Energy	MJ	3.16E+03	4.14E+02	1.50E+03	6.28E+02	5.19E+02	0.00E+00	2.89E+00	5.00E+00	5.28E+00	8.84E+01
	E Renewable Energy	MJ	6.14E+01	8.80E+00	1.30E+01	1.86E+01	1.24E+01	0.00E+00	1.37E-01	4.45E-01	4.69E-01	7.58E+00
	E Total Primary Energy	MJ	3.22E+03	4.22E+02	1.51E+03	6.47E+02	5.32E+02	0.00E+00	3.03E+00	5.45E+00	5.75E+00	9.60E+01
	Electricity	MJ elec	4.62E+02	6.68E+01	9.09E+01	1.43E+02	9.43E+01	0.00E+00	1.01E+00	3.49E+00	3.69E+00	5.96E+01
	COD (to WWTP)	kg	8.86E+00	2.41E+00	4.99E+00	1.40E+00	3.13E-03	2.85E-02	4.74E-04	7.81E-04	3.24E-02	0.00E+00
	TSS (to WWTP)	kg	4.52E-01	6.73E-02	2.50E-01	1.28E-01	1.77E-04	2.85E-03	4.74E-05	4.20E-04	3.19E-03	0.00E+00

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 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

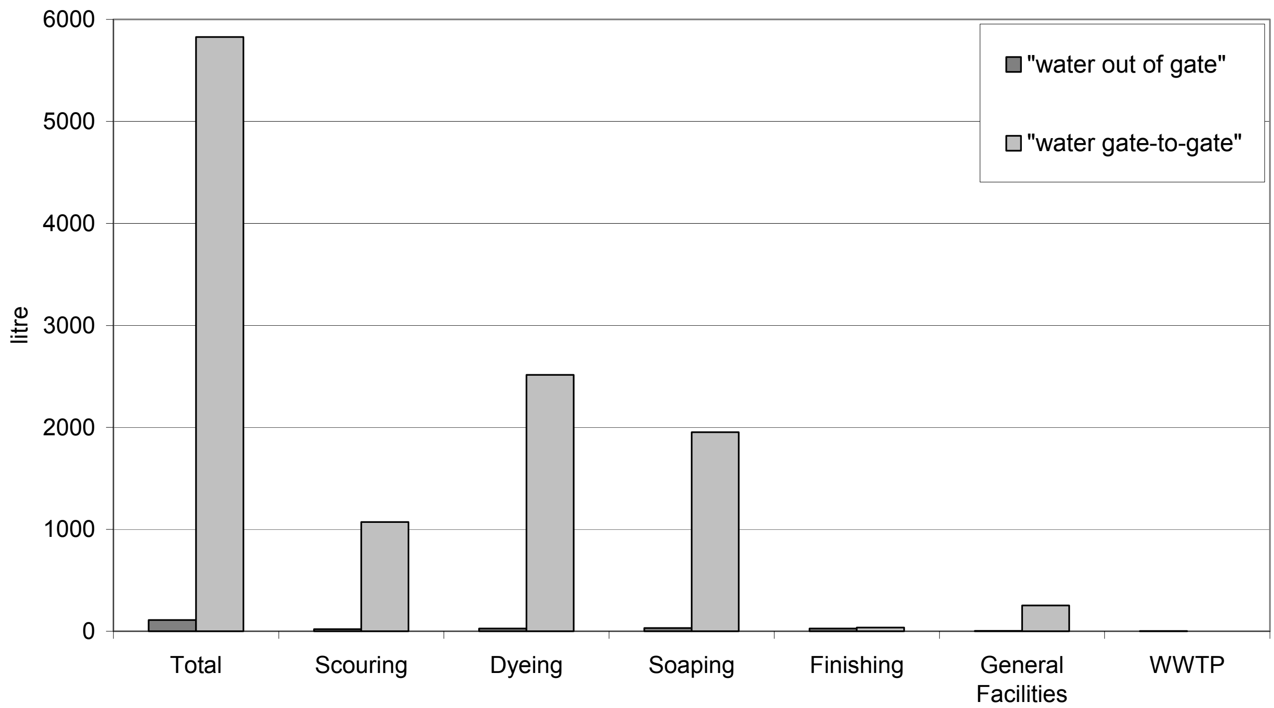

Figure 5.1 Water consumption

5.1.2 COD and TSS emissions

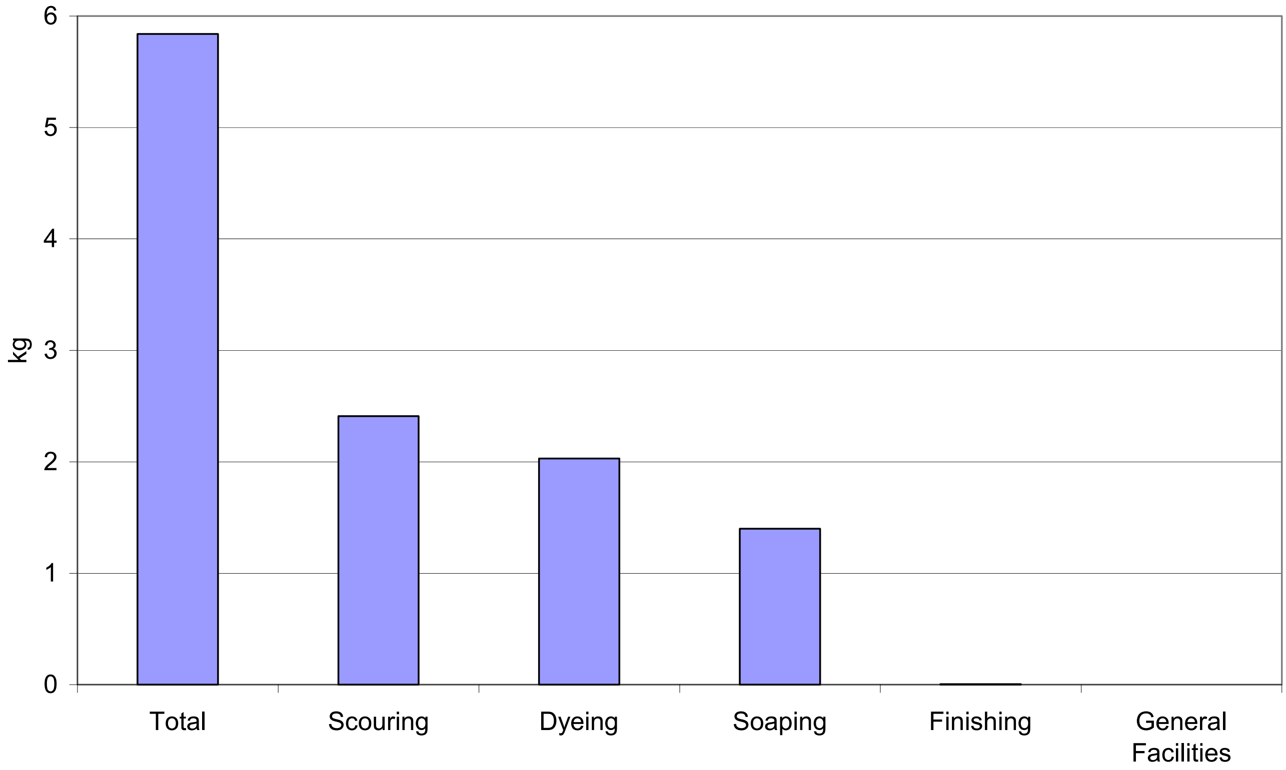

Figure 5.2 COD emission

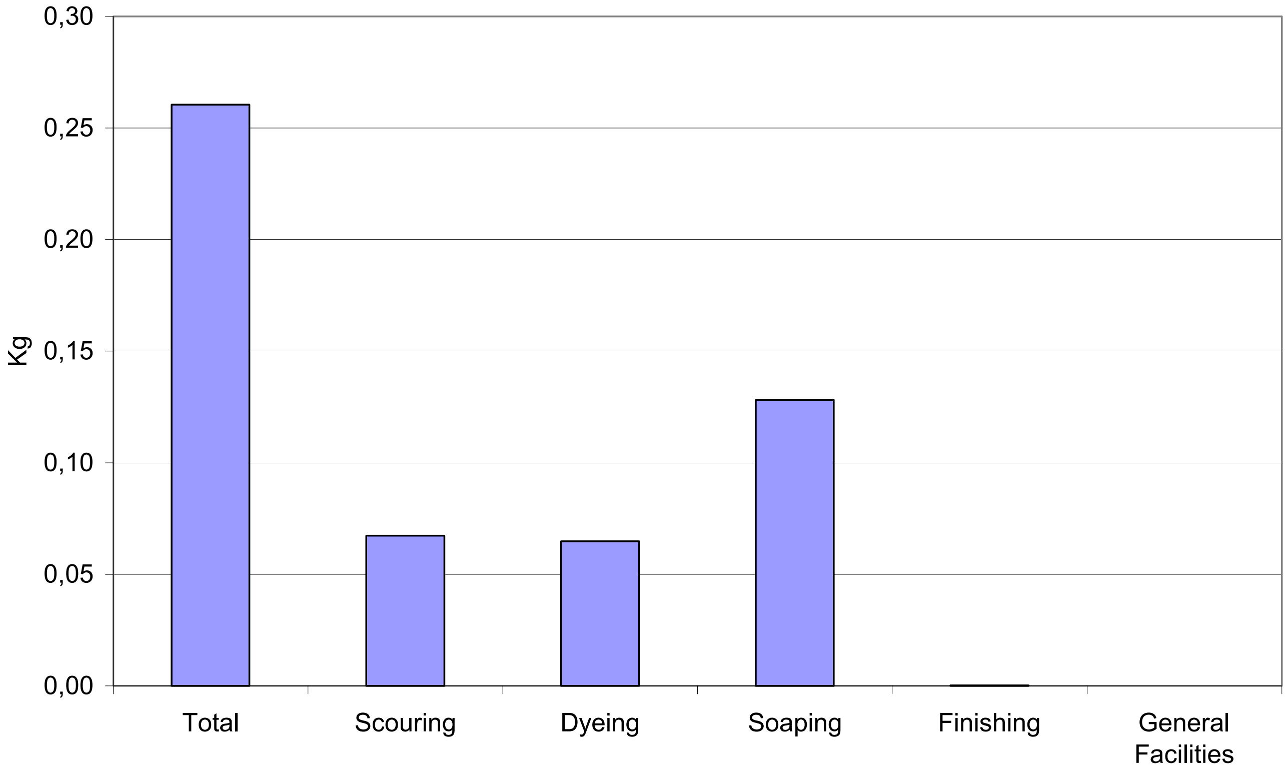

Figure 5.3 TSS emission

5.1.3 Energy indicators

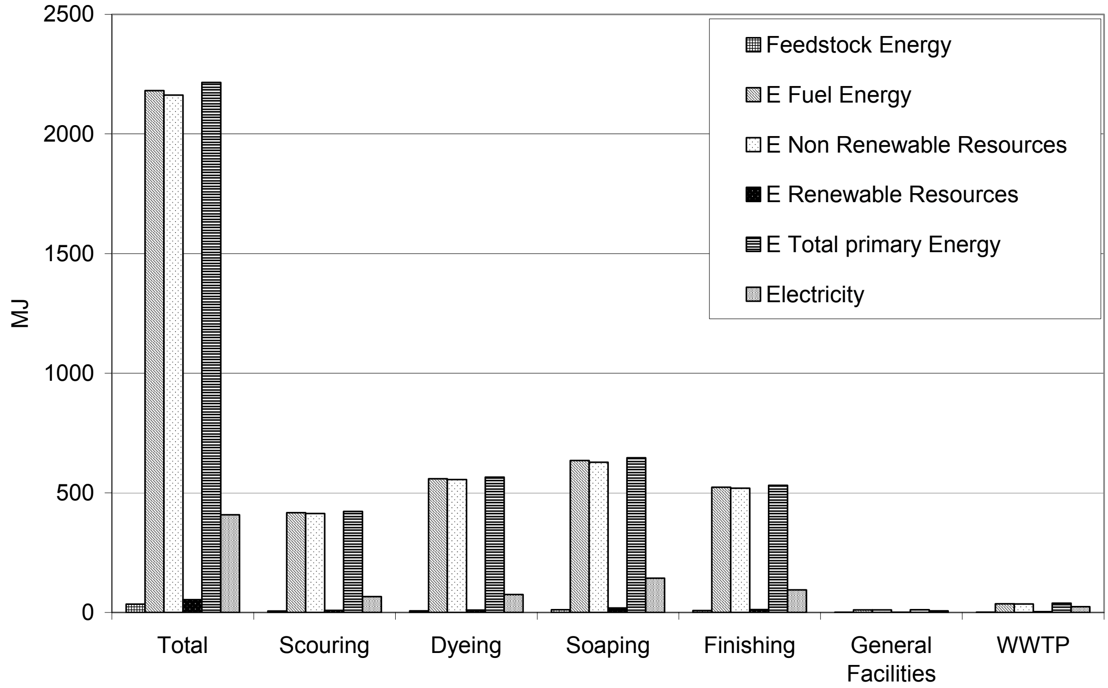

Figure 5.4 Energy indicators

5.1.4 Air Acidification

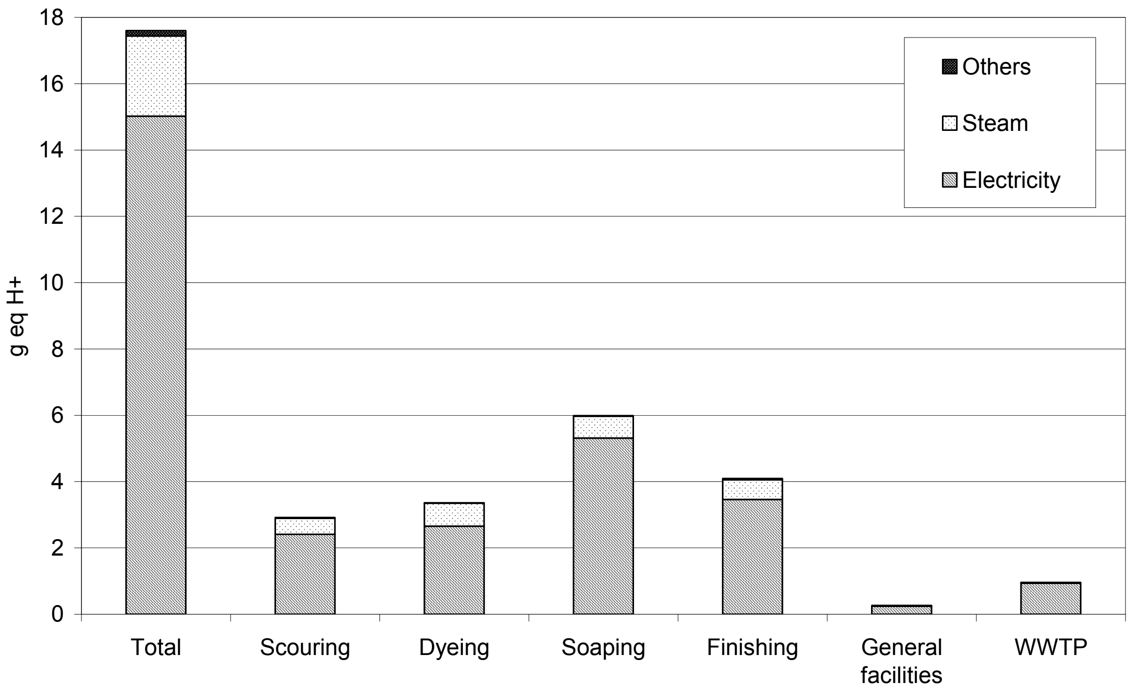

Figure 5.5 Air-Acidification

The main airborne emissions which contribute to total value are sulphur oxides (83%) and nitrogen oxides (16%).

5.1.5 Aquatic ecotoxicity

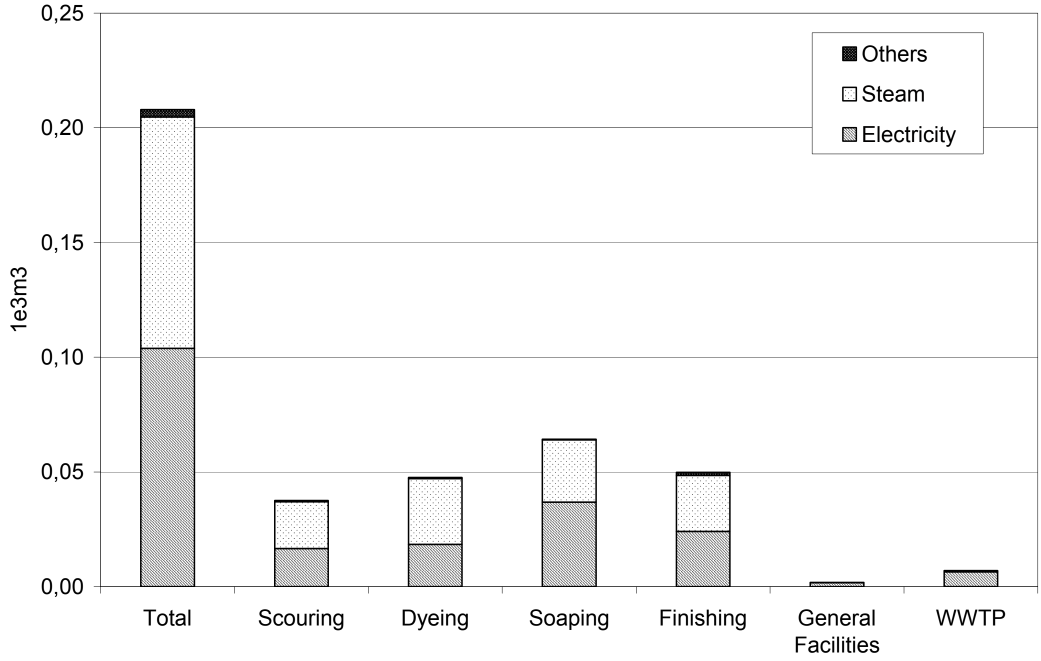

Figure 5.6 Aquatic ecotoxicity

The main waterborne emissions which contribute to total value are oils (57%) and cadmium (35%).

5.1.6 Depletion of non renewable resources

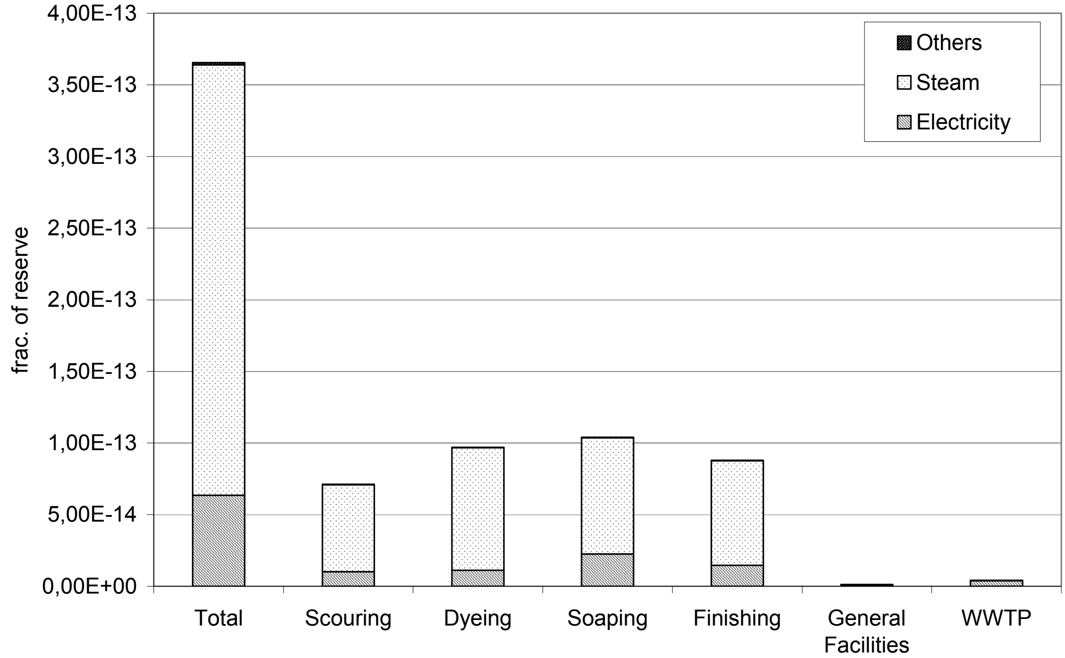

Figure 5.7 Depletion of non renewable resources

The main resources which contribute to total value are natural gas (87%) and oil (in ground) (10%).

5.1.7 Human toxicity

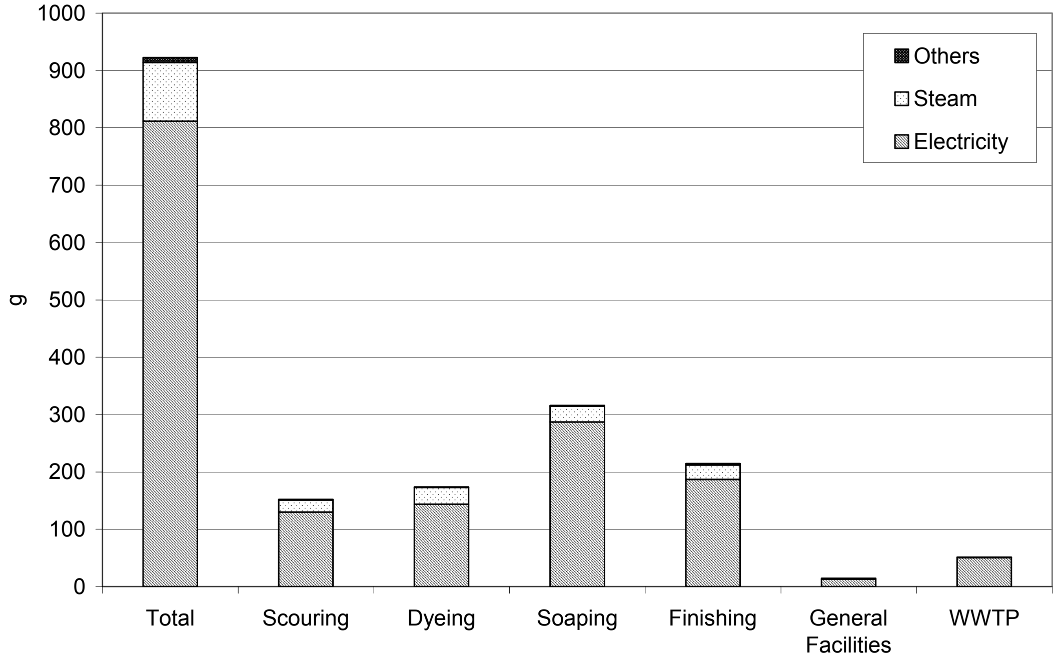

Figure 5.8 Human toxicity

The main airborne emissions which contribute to total value are sulphur oxides (61%), vanadium (12%), nitrogen oxides (11%) and nickel (11%).

5.1.8 Terrestrial ecotoxicity

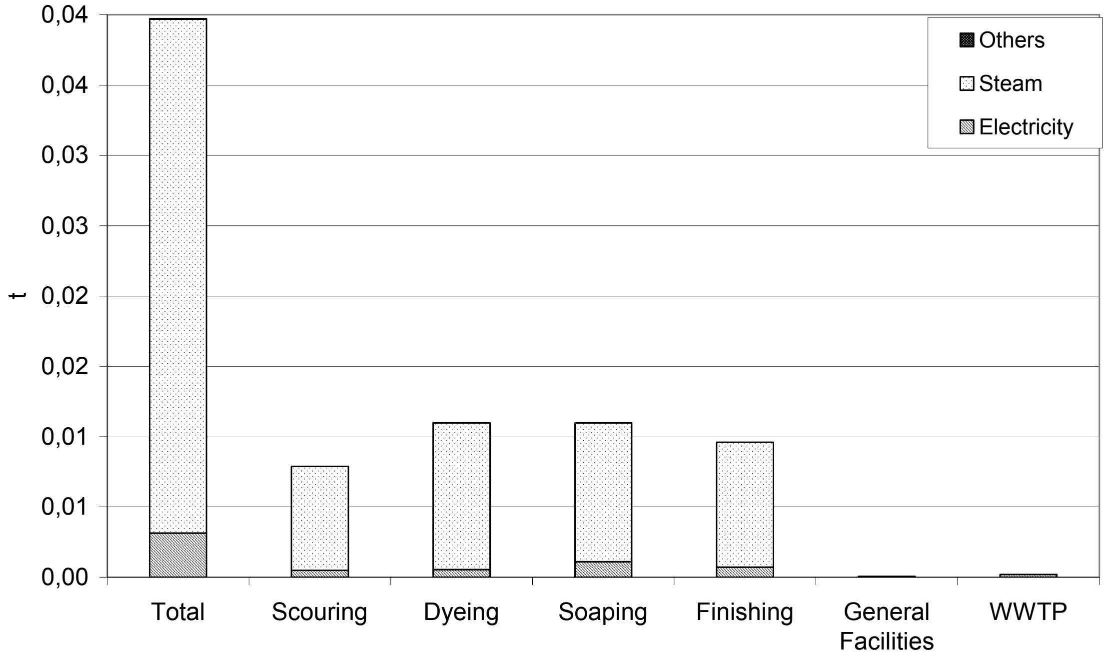

Figure 5.9 Terrestrial ecotoxicity

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

5.1.9 Eutrophication

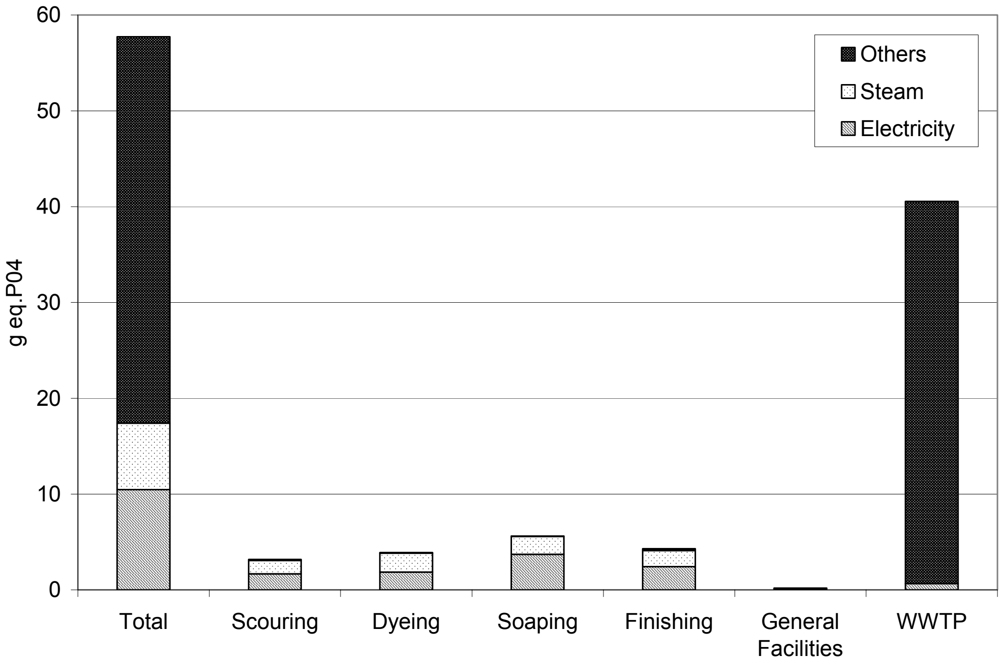

Figure 5.10 Eutrophication

The issue "Others" has very high 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 (40%), nitrogen oxides (30%) and ammonia (17%).

5.1.10 Greenhouse effect

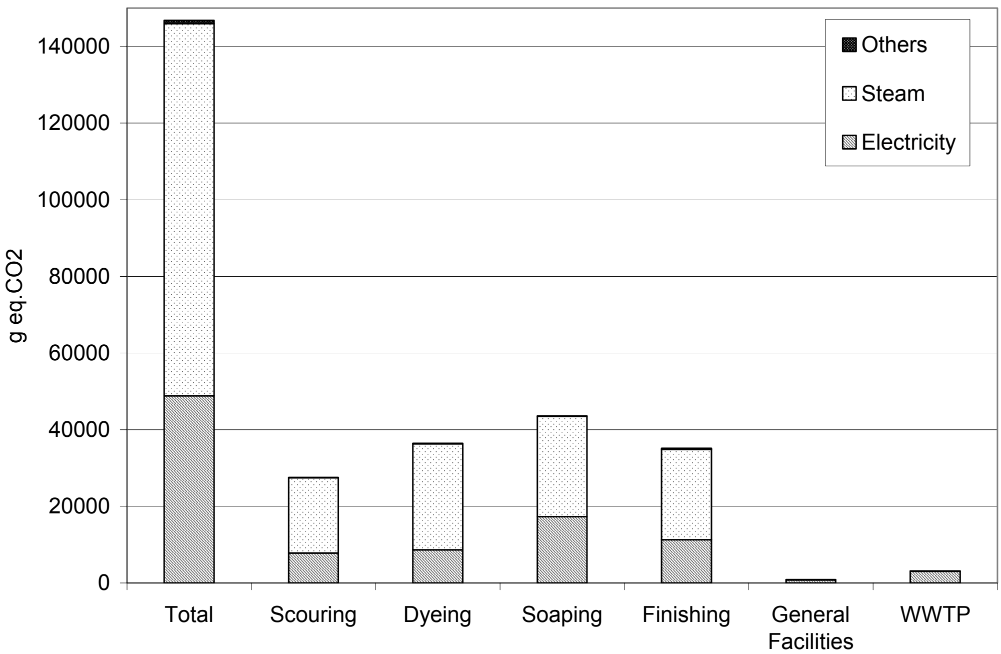

Figure 5.11 Greenhouse effect

The main airborne emission which contributes to total value is carbon dioxide (93%).

5.1.11 Photochemical smog

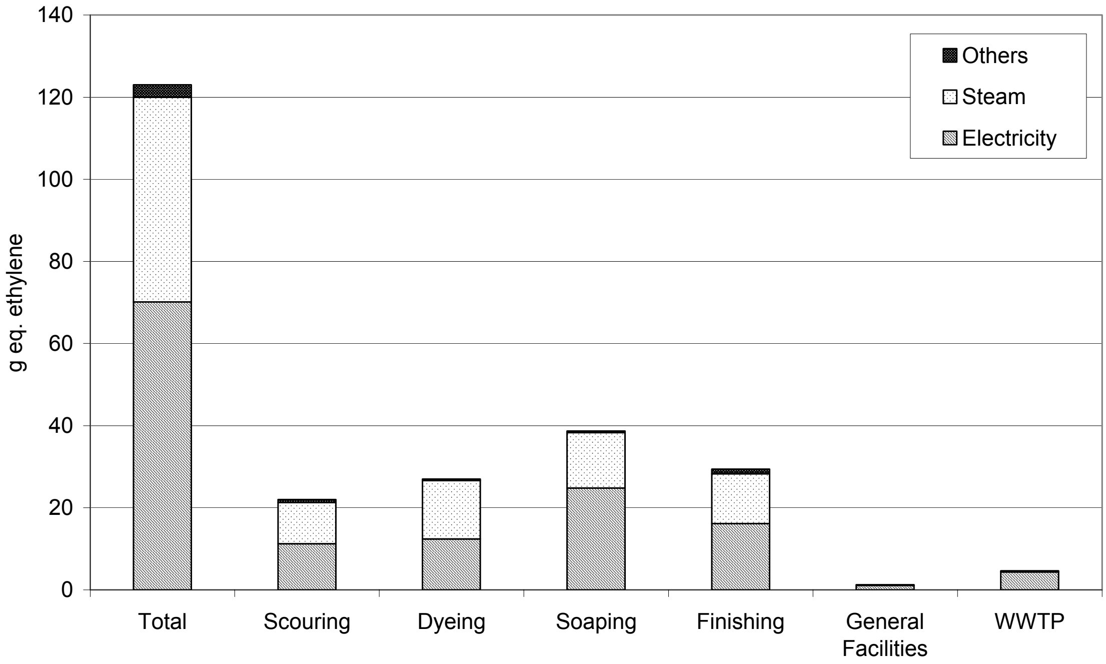

Figure 5.12 Photochemical oxidant formation

The main airborne emissions which contribute to total value are hydrocarbons (55%), ethylene (17%) and methane (10%).

5.1.12 Ecotoxicity of chemicals (screening)

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

5.2 Comparison of System A, System B and System C

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

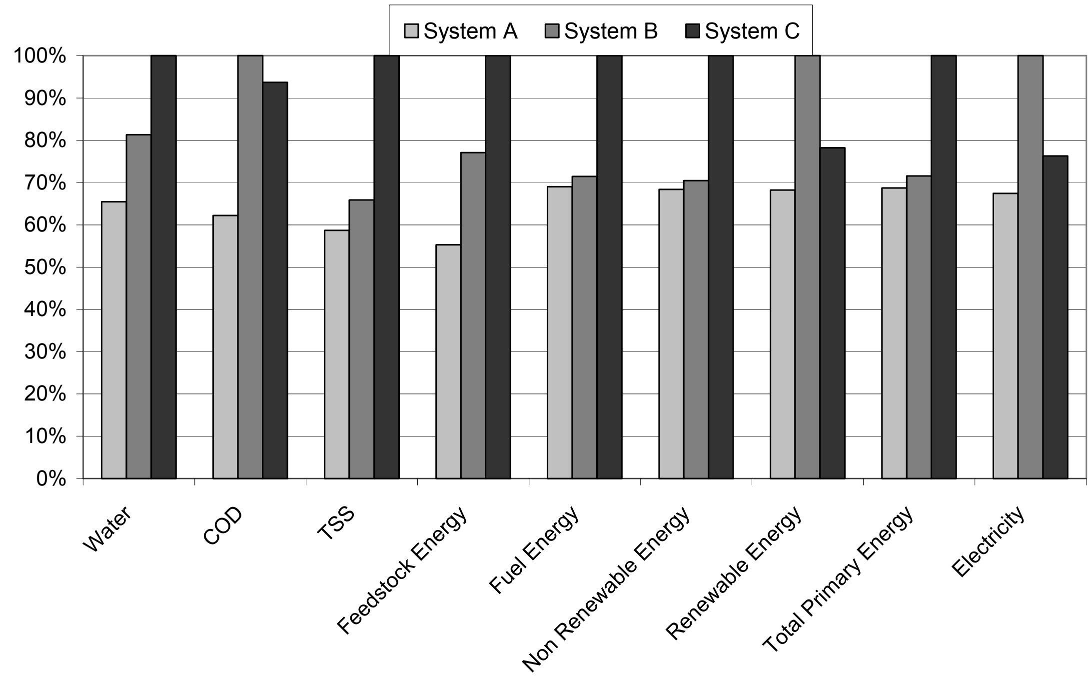

Figure 5.13 Comparison of water consumption, COD and TSS emissions and energy indicators of Systems A, B and C.

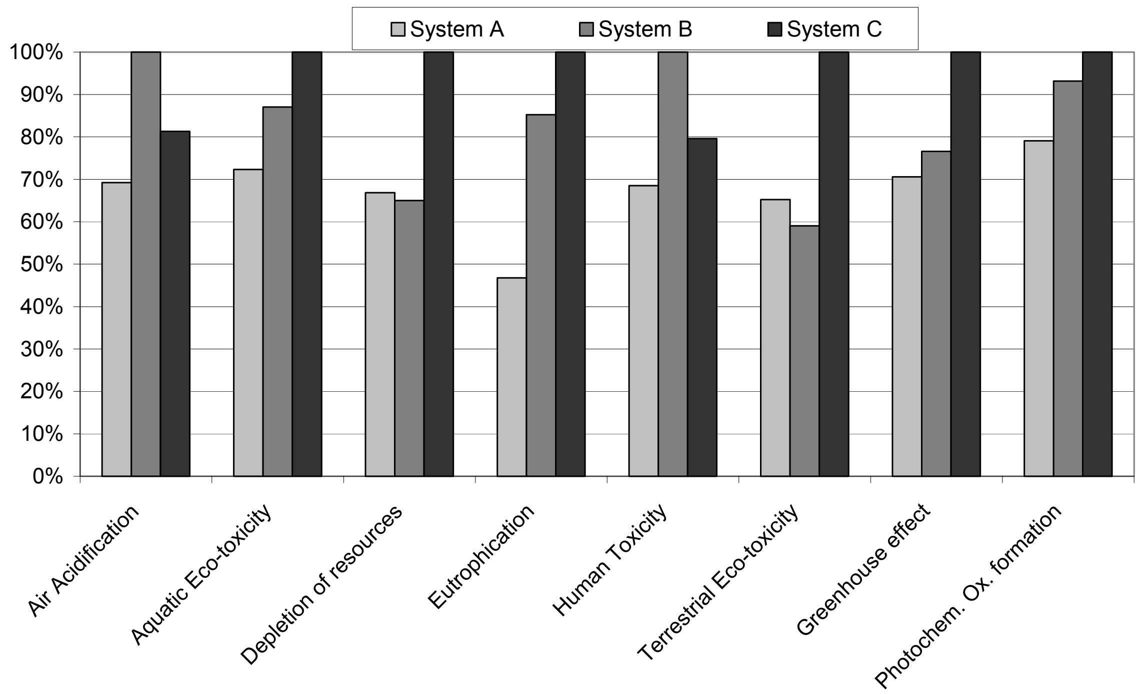

Figure 5.14 Comparison of impact assessment results of Systems A, B and C

System C has significantly (more than 10%) higher total values for several inventory and impact categories (such as feedstock energy, 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 reactive dyeing

process in jigger consumes more thermal energy (steam) than direct dyeing processes in Systems A and B.
System B has the highest values for air acidification and human toxicity because of relatively high electricity consumption of continuous scouring in mezzera and direct dyeing in pad-steam.
Reactive dyeing in jigger (System C) consumes significantly more water than dyeing processes of System A and B.
COD is the highest in System B because of emissions of continuous scouring in pad steam instead of mezzera (Systems A and C); while TSS is the highest in System C because of emissions of reactive dyeing in jigger.
Eutrophication value of System A is the lowest because direct dyeing in jigger (System A) has significantly less amount of wastewater emission than dyeing processes of Systems B and C.

5.2.1 Completeness check

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

5.2.2 Sensitivity check

5.2.2.1 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. Table 5.1 shows deviation of the results if steam consumption is increased by 10%.

Table 5.1 Sensitivity check of System A, B and C to the uncertainty of steam consumption

	System A	System B	System C
Air Acidification	1%	3%	2%
Aquatic Eco-toxicity	5%	3%	6%
Depletion of non renewable resources	8%	7%	9%
Eutrophication	1%	1%	1%
Human Toxicity	1%	1%	1%
Terrestrial Eco-toxicity	9%	9%	9%
Greenhouse effect	7%	5%	7%
Photochemical oxidant formation	4%	3%	5%
Water used (total)	0%	0%	0%
Feedstock Energy	2%	1%	2%
Fuel Energy	7%	6%	8%
Non Renewable Energy	7%	6%	8%
Renewable Energy	1%	1%	1%
Total Primary Energy	7%	6%	8%
Electricity	1%	0%	1%

10% uncertainty of steam consumption influence significantly some inventory and impact assessment results (fuel energy, non renewable energy, total primary energy, depletion of non renewable resources, terrestrial ecotoxicity and greenhouse effect).

5.2.2.2 Lack of data on chemicals production.

The lack of data about the production of several chemicals of System A, B and C can influence final results. To analyse the sensitivity of systems, surrogate inventory data on the production of chemicals were used [12]. Table 5.2 shows how the final results are influenced by the application of these generic data.

Table 5.2 Sensitivity check of Systems A, B, C to lack of data about surrogate chemicals

	System A	System B	System C
Air Acidification	8%	28%	8%
Aquatic Eco-toxicity	6%	7%	5%
Depletion of non renewable resources	5%	7%	4%
Eutrophication	3%	2%	1%
Human Toxicity	8%	7%	7%
Terrestrial Eco-toxicity	1%	1%	1%
Greenhouse effect	5%	6%	4%
Photochemical oxidant formation	7%	7%	5%
Water used (total)	0%	0%	0%
Feedstock Energy	78%	76%	47%
Fuel Energy	5%	7%	4%
Non Renewable Energy	6%	8%	5%
Renewable Energy	17%	16%	16%
Total Primary Energy	7%	9%	5%
Electricity	12%	11%	12%

All systems are sensitive to the lack of data on chemicals for some energy indicators (feedstock energy, renewable energy, electricity). These energy categories have relatively low total values compared to other energy indicators (see Figure 5.4), so electricity and heat fuel oil consumption of organic chemicals production can influence significantly these results.
Results of System B are also sensitive for acidification. It is because of the big quantity of soaping agent used for scouring in pad steam.

5.2.3 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 viscose fabric according to System A the following main conclusions can be drawn:

- The product system requires 59 litre of water for 1 kg of product. Only a negligible amount is consumed out of the company gates. Water consumptions of direct dyeing in jigger (43%) and soaping in pad steam are the highest (34%).
- COD emissions arise from scoring (41%), dyeing (35%) and soaping (24%) processes.
- TSS emissions arise mainly from soaping process (50%).
- For several inventory and impact assessment categories soaping in pad steam has the higher contribution (28-34%) followed by softener finishing (24%) or direct dyeing in jigger (19-28%) and scouring in mezzera (17-20%). These results are always related to steam and electricity consumptions. Production of steam contributes mainly to greenhouse effect and terrestrial ecotoxicity; production of electricity contributes mainly to acidification and human toxicity; and both of these aspects are responsible for photochemical oxidant formation and aquatic ecotoxicity.

- Hot-spot of eutrophication impact category is the waste water treatment plant because of its emissions to water (70% contribution of the total of category).

Comparison and analysis of three viscose fabric production lines (System A, B, C) highlighted that:

- Reactive dyeing process in jigger requires more thermal energy (production of steam) than direct dyeing processes (in jigger or in pad steam). For this reason System C has significantly (more than 10%) higher total values for several inventory and impact categories (such as feedstock energy, fuel energy, non renewable energy, total primary energy, aquatic eco-toxicity, depletion of non renewable resources, terrestrial eco-toxicity, greenhouse effect, photochemical oxidant formation).
- Continuous scouring in mezzera and direct dyeing in pad-steam consumes relatively high amount of electricity. For this reason System B has the highest values for air acidification and human toxicity.
- Direct dyeing in jigger (System A) has significantly less amount of wastewater emission than dyeing processes of Systems B and C. Lower eutrophication values of System A makes evident this difference.
- Reactive dyeing in jigger (System C) consumes significantly more water than dyeing processes of System A and B.
- Continuous scouring in pad steam (System B) has higher COD emissions than scouring in mezzera (Systems A and C); while TSS is the highest in System C because of emissions of reactive dyeing in jigger.
- Production of chemicals has not significant contribution to final results. It must be highlighted that the LCA study has a relevant lack of data on chemicals production. A sensitivity check, using surrogate data demonstrated the importance of this aspect: electricity and heat fuel oil consumption of organic chemicals production can modify significantly the results of energy indicators (feedstock energy, renewable energy, electricity). Moreover, acidification result of System B is sensitive for the lack of data about soaping agent consumed in scouring in pad steam
- Process specific steam consumption was calculated applying an allocation rule based on energy for heating of process water. A sensitivity check demonstrated that despite 10% uncertainty of this calculation has a significant influence on some categories, the study results are not invalidated.

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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 [Nm^3/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/Nm^3]									
CO [mg/Nm^3]									
Aldehydes [mg/Nm^3]									
VOC [mg/Nm^3]									
Acetic acid [mg/Nm^3]									
Formic acid [mg/Nm^3]									
Ammonia [mg/Nm^3]									
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 (***<u>all sheets have to be considered as relevant part of the whole document</u>***):

- **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:

Annex 2. Water flow chart of I04 company