NUMBER C 88 | MARCH 2015 | REPORT

EcoWater report

Baseline eco-efficiency assessment of water use in industrial sectors

IVL Swedish Environmental Research Institute

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Funded by: Collaborative Research Project of the 7th Framework Programme
Report number: C 88
Edition: Only available as PDF for individual printing

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

This report is a deliverable or other report from the EU project EcoWater.

At project closure it is was also published in IVL's C-series, available from the IVL web-site.

The EcoWater project was conducted by an international consortium coordinated by NTUA (National Technical University of Athens). IVL participated in the R & D work, in addition to leading one of the industrial case studies (Volvo Trucks), represented by Volvo Technology.

EcoWater ran 2011-2014. The project is presented in more detail on http://environ.chemeng.ntua.gr/ecoWater/
The project website holds a complete repository of all public deliverables from the EcoWater project.

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Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

Collaborative project, Grant Agreement No: 282882

Deliverable 4.2

Baseline eco-efficiency assessment of water use in industrial sectors

February 2014

DOCUMENT INFORMATION

Project	
Project acronym:	EcoWater
Project full title:	Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors
Grant agreement no.:	282882
Funding scheme:	Collaborative Project
Project start date:	01/11/2011
Project duration:	36 months
Call topic:	ENV.2011.3.1.9-2: Development of eco-efficiency meso-level indicators for technology assessment
Project web-site:	http://environ.chemeng.ntua.gr/ecowater
Document	
Deliverable number:	4.2
Deliverable title:	Baseline eco-efficiency assessment of water use in industrial sectors
Due date of deliverable:	31.10.2013
Actual submission date:	27.02.2014
Editor(s):	NTUA
Author(s):	DHI, MITA, DELTARES, IVL
Reviewer(s):	NTUA
Work Package no.:	WP4
Work Package title:	Eco-efficiency assessments in industrial water uses
Work Package Leader:	DHI
Dissemination level:	Public
Version:	3
Draft/Final:	Final
No of pages (including cover):	59
Keywords:	Innovative Technologies, Industrial Sector

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under Grant Agreement No. 282882.

Abstract

Deliverable 4.2 presents results of the work undertaken during the second phase of the Case Study Development progress and the second year of the EcoWater Project, for the four industrial Case Studies:

- Case Study 5: Textile Industries in Biella Region in Italy
- Case Study 6: Cogeneration of thermal energy and electricity using water from the Rhine Channel in the Netherlands
- Case Study 7: Dairy industry in Denmark
- Case Study 8: Automotive Industry in Sweden

The Baseline Eco efficiency Assessment was based on the Value Chain Mapping of the four Case Studies, presented in Deliverable 4.1. However, the task of calculating the environmental and economic performance indicators proved to be more difficult than expected for all four Case Studies. This was due to the complexity of the processes in the production chain and the large amount of data required in order to build a representative model of each studied system. Thus, minor or major changes were made to the system boundaries of all four systems, without, however, affecting their meso-level characteristics.

The analysis has revealed the environmentally and economically weak stages and actors, providing the basis for the next and final phase of the Case Study Development, the identification and the assessment of innovative technologies.

Contents

1 Introduction

Deliverable 4.1 presents the results of the work undertaken during the second year, concerning the Baseline Eco-efficiency Assessment of the EcoWater Industrial Case Studies:

- Case Study 5: Textile Industry in Biella Region in Italy
- Case Study 6: Cogeneration of thermal energy and electricity using water from the Rhine Channel in the Netherlands
- Case Study 7: Dairy Industry, in Denmark
- Case Study 8: Automotive Industry in Sweden.

The development of all industrial cases followed the same overall methodology for the baseline eco-efficiency assessment of water use as described in the NTUA guidance document: “Eco-efficiency Assessment: The EcoWater approach”, an internal document of the EcoWater project[1].

During the Second EcoWater Annual Meeting, it was decided that the assessment of the environmental performance of the EcoWater system will follow a life-cycle oriented approach using the midpoint environmental impact categories, while the economic performance will be evaluated by using the Total Value Added (TVA) to the product due to water use, expressed in monetary units per period, in general per year (Euros/year).

Furthermore, a distinction will made between “foreground” and “background” systems of the studied value chain:

- The boundaries of the foreground system include all the processes whose selection or mode of operation is affected directly by decisions based on the study. These processes are directly related to the water supply and the water use chains.
- The background system includes all other activities and is that which delivers energy and materials to the foreground system, usually via a homogeneous market so that individual plants and operations cannot normally be identified.

Since the development of Deliverable 4.1 “Description of value chains for industrial water use”, three of the case studies have made some changes to their system description. In Case Study 5 the focus is now on the “wet” processes and the aim of the analysis is to compare different dyeing processes. In Case Study 6 a major change has been undertaken recently including a change in the project location. Due to this the SEAT and EVAT calculations are still in a preliminary phase. For the Case Study 7 the focus is now on only one of the two dairy industries presented in the Deliverable 4.1 and the process of transport has been included in the system boundaries. It is considered as a follow up to this report to include an additional dairy industry producing milk for consumption to be able to compare the eco-efficiency among different

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[1] The internal document is included in the Minutes of the 2nd Annual EcoWater Meeting – Deliverable 7.3 (EcoWater, 2013b)

dairy industries. In Case Study 8, apart from the abovementioned common methodology-related modifications, no changes have been made in the system boundaries.

In the following four Sections, the baseline eco-efficiency assessment of the EcoWater Industrial Case Studies is presented in a common outline, and in the final section of the Deliverable a preliminary comparison between them is attempted.

2 Baseline eco-efficiency assessment of the Case Study #5: Textile Industry, Biella

Biella province lies in the north part of Piemonte region (marked with a red circle in Figure 2.1) and is characterized by high annual precipitation. Biella has traditionally been an important wool processing and textile center (first textile factory dates 1254). However, during the last decade, the number of active textile units in Italy has decreased by 28%. More specifically in Biella, the crisis of the textile sector is much more acute since nearly half of the factories closed down and 50% of the employees lost their jobs

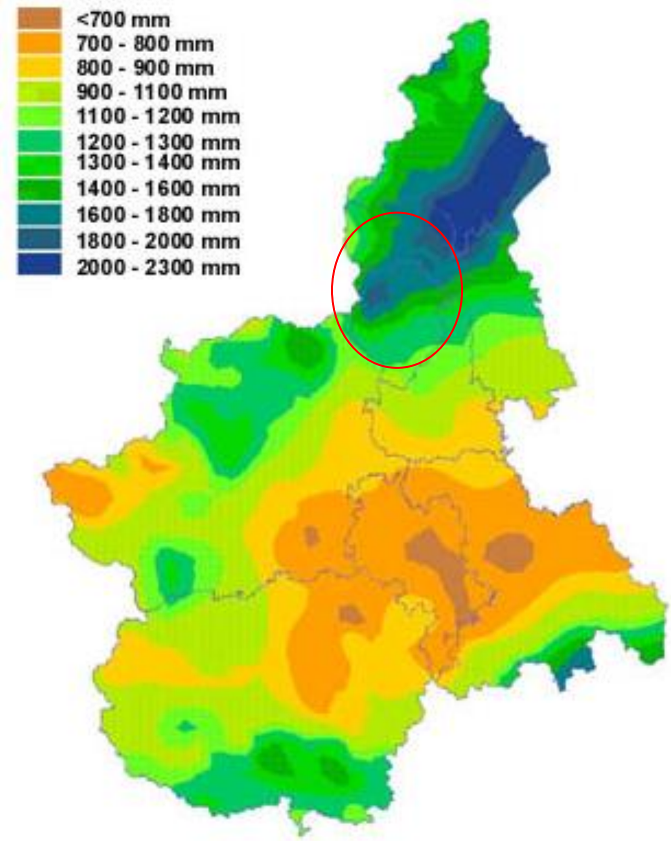

Figure 2.1 The Region of Piemonte – Annual Precipitation

2.1 Goal and scope definition

2.1.1 Objectives

The textile industry processes are, in general, responsible for the production of large amounts of toxic and stable pollutants, which are all collected into the wastewater treatment plant. The disposal of these contaminated effluents into receiving water bodies can cause significant environmental damages, directly influencing the aquatic ecosystem and even human health.

The main goal of this study is to identify and assess the environmental impacts and the eco-efficiency performance associated with the water value chain in the case of the textile industry in Biella.

The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors. The fact that the textile industry is one of the most fragmented sectors, because it is mainly characterized by small and medium enterprises, adds one extra degree of difficulty to the analysis.

2.1.2 System Boundaries

Since the submission of Deliverable 4.1, a big change has been made concerning the system boundaries. It has been decided to focus the analysis to the part of the textile industry called "wet processing", and in particular to the process of dyeing. For this process, Biella textile industries utilize a large amount of freshwater that is largely available in this area either as surface or as groundwater, but also chemicals for the dyeing processes, which may potentially have impacts on the environment and the human health. The water and wastewater processing technologies installed in the region are, to some extent, the same as when the industries were established in the previous century, but in some cases they have been upgraded to more efficient technologies.

There are more than 500 active textile production units in the region, but for simulation purpose two different types of units are identified, based on the dyeing process:

- Type A. Using standard chemical dyeing processes
- Type B. Using natural vegetal dyes and leaves

Two industrial units are selected as representative of these two types:

- Type A is represented by Tintoria Mancini. The company is a family managed dye enterprise, something which is typical for the Biella region and thus can be considered as representative for the Case Study. It has also introduced innovative technology for water treatment some years ago and for that reason historical data is available for the performance of the technology.
- Type B is represented by the company Tintoria di Quaregna, also a family managed dye enterprise, which has introduced an innovative natural dyeing process, using herbs as was in the far past, but with a technological support and laboratory research activities which are extremely modern. This "natural" way of dyeing, using natural products, instead of using chemicals, allows the company to obtain products that respond optimally to the problems related to allergies. Of course the final product is more expensive compared to the use of chemical dyes, however it may also be sold at a higher price at the market.

Thus, the system studied in the Biella Region can be divided into two clusters. Each cluster has the same water use profile (i.e. technology, socio-economic characteristics etc.) and corresponds to the production of a unique product or service. Here each cluster is differentiated by the dyeing processes used (chemical or natural dyeing).

The analysis of the textile industry encompasses the whole water value chain, starting from its natural origin as a natural resource and ending to a receiving water body after its environmental degradation in the production process. Four stages are used to divide the water value chain into water abstraction, distribution, use and wastewater treatment.

The stages and the corresponding processes of the water value chain in the textile industry are presented in Figure 2.2.

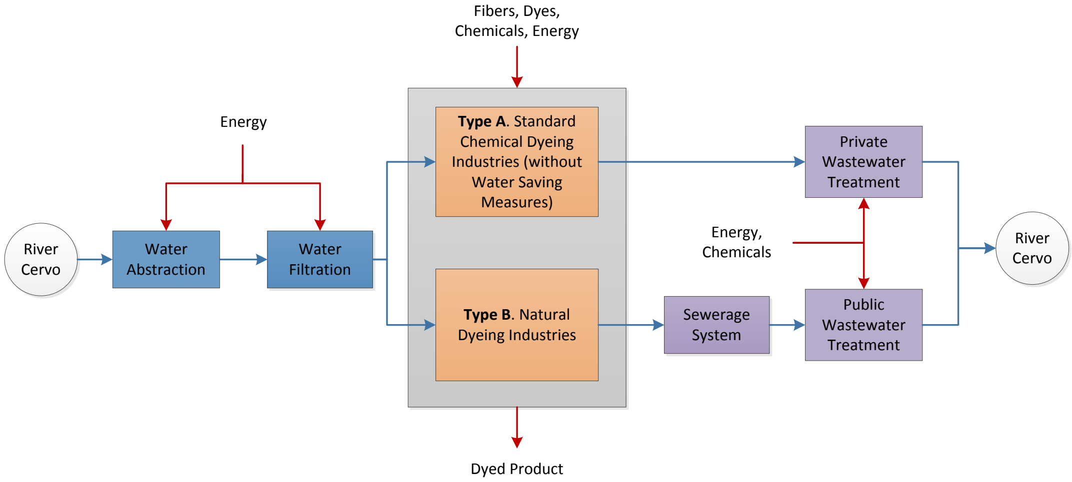

Figure 2.2 The updated value chain mapping of the Biella Textile Industry

Each stage has been defined in such a way that encloses the relevant actors involved in the system and the interactions among them. The actors involved in the aforementioned industry are:

- The Region Authority (ARPA), which has the responsibility for the water supply in the industrial sector;
- The textile industries, specifically the Tintoria Mancini and Tintoria di Quaregna units; and
- CORDAR (municipalities consortium), which is responsible for the water supply and the treatment of wastewater coming from the natural dyeing industrial unit, Tintoria di Quaregna.

2.1.3 Functional unit

The functional unit depends on the reference flow selected each time and its main purpose is to provide a reference to which environmental impacts are normalized and compared. The functional units of this case study are:

- 1 m^3 of water used during the industrial processes of dyeing
- One unit of final product, e.g. 1 kg of dyed product

2.2 Inventory Analysis

2.2.1 Resource Flows

The resources of the modelled system for CS5 are presented in Table 2.1.

Table 2.1 Resources of the Textile Industry (CS5)

Category	Symbol	Material
Water Resources	w_1	Groundwater abstracted
	w_2	Surface Water abstracted
Supplementary Resources	r_1	Electricity
	r_2	Natural Gas
	r_3	Wool
	r_4	Dyes
	r_5	Additives
Emissions to air	e_1	CO_2
	e_2	CO
	e_3	CH_4
	e_4	N_2O
	e_5	NO_x
Emissions to water	e_6	Cadmium (Cd)
	e_7	Chromium (Cr)
	e_8	Chemical Oxygen Demand (COD)
	e_9	Nickel (Ni)
	e_{10}	Nitrogen (N)
	e_{11}	Phosphorus (P)
	e_{12}	Zinc (Zn)
	e_{13}	Wastewater
Products	p_1	Dyed Product
By Products	p_2	Sludge

The input and output flows of the entire system are presented in Table 2.2. All model flows refer to annual average data values and correspond to a quantity of delivered product equal to 500 tonnes and 10 tonnes of dyed wool, for Tintoria Mancini and Tintoria di Quaregna, respectively.

The CO_2 emission factors and the environmental impacts for the fuels and energy are based on the following assumptions:

- The background environmental impacts are evaluated taking into account only the electricity production and natural gas extraction and distribution processes.
- Electricity consumption is site-specific, being influenced by factors such as the technology of the power production, the country energy mix, distribution losses etc. In this case study, the electricity country mix for Italy was used.

Table 2.2 Life cycle inventory flows of Textile Industry system

Category	Material	Quantity
Water Resources	Groundwater abstracted	90,000 m^3
	Surface Water abstracted	13,000 m^3
Supplementary Resources	Electricity	974,200 kWh
	Natural Gas	254,500 m^3
	Wool	510,000 kg
	Dyes	154,000 kg
	Additives	152,500 kg
Emissions to air	CO_2	494,399 kg
	CO	196.76 kg
	CH_4	103.30 kg
	N_2O	0.89 kg
	NO_x	1,475.73 kg
Emissions to water	Cadmium (Cd)	175 kg
	Chromium (Cr)	2,275 kg
	Chemical Oxygen Demand (COD)	0.00 kg
	Nickel (Ni)	350 kg
	Nitrogen (N)	0.00 kg
	Phosphorus (P)	0.00 kg
	Zinc (Zn)	1.05 kg
	Wastewater	85,000 m^3
Products	Dyed Product	510,000 kg
By Products	Sludge	8,700kg

2.2.2 Economic Data

The economic value of the dyed product of the modelled system was set to 3 €/kg when it is produced by the chemical dyeing industrial unit (Tintoria Mancini) and 10 €/kg, when it is produced by the natural dyeing industrial unit (Tintoria di Quaregna).

The annual fee for groundwater pumping and surface water abstraction is considered to be 2,200€, while the tariff for wastewater treatment is equal to 0.85€/m^3. Annual operation & maintenance costs for both industries are assumed to be 5,000 €, while the treatment of sludge costs around 2,500€/year.

The costs of supplementary resources are based on assumptions and information from the involved actors while the cost of additives was impossible to be specified (Table 2.3).

The cost for wool is equal to zero since the clients of the textile industries bring their own wool to be dyed.

Table 2.3 Unit costs of raw materials and supplementary resources

Resource	Price
Electricity	0.18 €/kWh
Natural Gas	0.45 €/m^3
Wool	-
Dyes (Tintoria Mancini)	3.00 €/kg
Dyes (Tintoria di Quaregna)	10.00 €/kg
Additives	-

2.3 Environmental Performance

Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project (EcoWater, 2013a), 9 impact categories are selected as the more representative for the environmental assessment of the specific system. The characterization factors which are used for the estimation of the impact of the foreground systems and the environmental impact factors for the background process are presented in Table 2.4, Table 2.5 and Table 2.6, respectively. The environmental impact factors are obtained from open access databases. Open access data was not possible to be obtained for all background processes. For this reason, no background data were included for the following processes:

- Dyes production
- Additives production
- Wool production

The indicator Freshwater ecosystem impact requires a value on the Water Withdrawal to Availability ratio. The selected value of WTA for Italy is 0.15. Since the freshwater resource depletion indicator refers to the foreground river basin, only foreground impacts are calculated.

Table 2.4 Characterization Factors of Foreground Elementary Flows - Emissions to air (Guinee et al, 2001).

Impact Category	Unit	CO_2 (per kg)	CO (per kg)	CH_4 (per kg)	N_2O (per kg)	NOx (per kg)
Climate Change	kg $CO_{2,eq}$	1	-	25	298	-
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	-	-	-	0.27	0.13
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-	0.5
Human Toxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	1.2
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	-
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	-
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	0.027	0.006	-	0.028
Abiotic Resource Depletion	kg $Sb_{,eq}$	-	-	-	-	-
Freshwater Resource Depletion	m^3	-	-	-	-	-

Table 2.5. Characterization Factors of Foreground Elementary Flows (Emissions to water) (Guinee et al, 2001)

Impact Category	Unit	Cd (per kg)	Cr (per kg)	COD (per kg)	Ni (per kg)	Zn (per kg)	P (per kg)	N (per kg)
Climate Change	kg $CO_{2,eq}$	-	-	-	-	-	-	-
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	-	-	0.022	-	-	3.06	0.42
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-	-	-	-
Human Toxicity	kg 1,4-$DB_{,eq}$	2.1	22.9	-	331	0.584	-	-
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	6.9	1,523	-	3,237	91.7	-	-
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	2.3E-19	1.4E-20	-	1.03E-18	2.5E-21	-	-
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	-	-	-	-	-
Abiotic Resource Depletion	kg $Sb_{,eq}$	-	-	-	-	-	-	-
Freshwater Resource Depletion	m^3	-	-	-	-	-	-	-

Table 2.6. Characterization Factors for Background Processes (ELCD, 2013)

Impact Category	Unit	Electricity Production (per kWh)	Natural Gas Production (per m^3)
Climate Change	kg $CO_{2,eq}$	0.00070787	0.000320518
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.00017	0.000109228
Acidification	kg $SO_2^{-}{}_{,eq}$	0.00407	0.001062144
Human Toxicity	kg 1,4-$DB_{,eq}$	0.09159	0.003383542
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	0.00184	0.000210015
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	0.00090	4.38867E-05
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	0.00018	0.00015858
Abiotic Resource Depletion	kg $Sb_{,eq}$	0.00424	0.019257498
Freshwater Resource Depletion	m^3	0.00	0.00

2.3.1 *Environmental Impact Indicators for the entire system*

The results of the environmental impacts of the entire system and the contribution of the background and foreground processes into the system are presented in Table 2.7 and in Figure 2.3.

Table 2.7. Environmental indicators results for CS5

Environmental Indicator	Unit	Value
Climate Change	t $CO_{2,eq}$	1,268
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	386
Acidification	kg $SO_2^{-}{}_{,eq}$	5,268
Human Toxicity	kg 1,4-$DB_{,eq}$	219,531
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	1,464,321
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	14,446,079
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	263
Abiotic Resource Depletion	kg $Sb_{,eq}$	9,032
Freshwater Resource Depletion	m^3	15,450

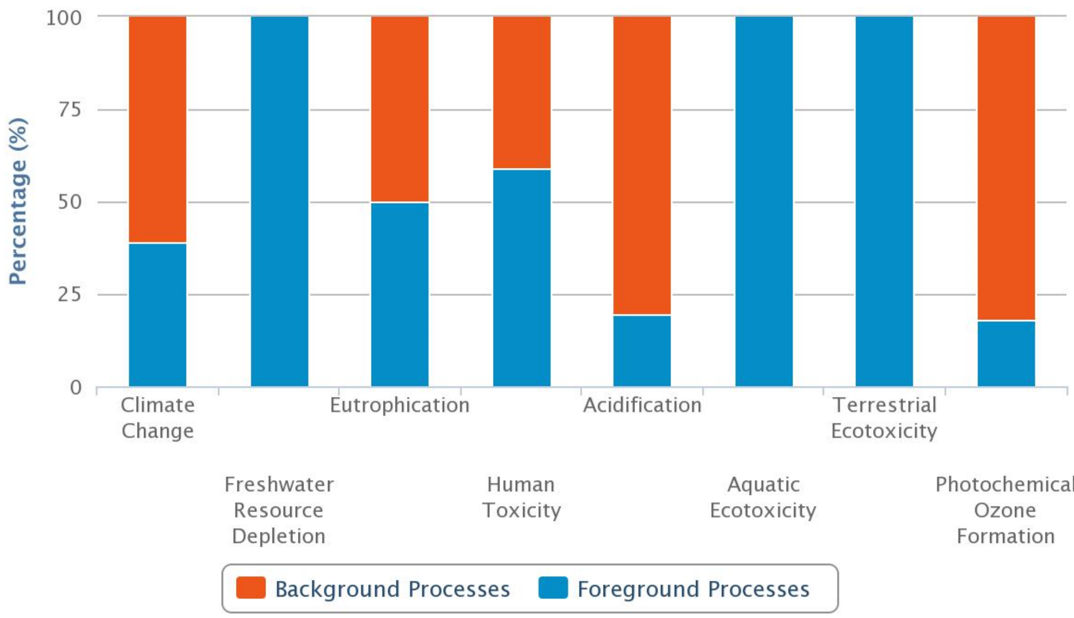

Figure 2.3 Contribution of foreground and background systems in the environmental impact categories

2.3.2 *Environmental Impact Indicators per cluster*

Apart from the environmental performance assessment of the entire system, the nine environmental indicators can be estimated for each cluster separately (Table 2.8), i.e. for each production unit (Type A. Standard chemical dyeing and Type B. Natural dyeing).

Table 2.8. Environmental indicators per cluster (CS#5) – Absolute Values

Environmental Indicator	Unit	Type A Standard chemical dyeing	Type B Natural dyeing
Climate Change	t $CO_{2,eq}$	1.062	206
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	333	52
Acidification	kg $SO_2^{-}{}_{,eq}$	4.149	1.120
Human Toxicity	kg 1,4-$DB_{,eq}$	195.165	24.366
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	1.463.832	489
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	14.445.840	239
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	213	50
Abiotic Resource Depletion	kg $Sb_{,eq}$	7.821	1.211
Freshwater Resource Depletion	m^3	13.500	1.950

2.4 Economic Performance

Table 2.9 summarizes the economic results (in €/year) for all actors involved in the system. The results are calculated using the above data and the life cycle inventory flows. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 698,574 €.

Table 2.9. Economic performance for Textile Industry system (€/year)

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Tintoria Mancini	-811,665	1,500,000	-3,675	684,660
Tintoria di Quaregna	-46,561	100,000	-47,200	6,239
Region of Biella			4,400	4,400
Municipality			1,475	1,475
CORDAR	43,200		45,000	1,800
Total Value Added:				**698,574**

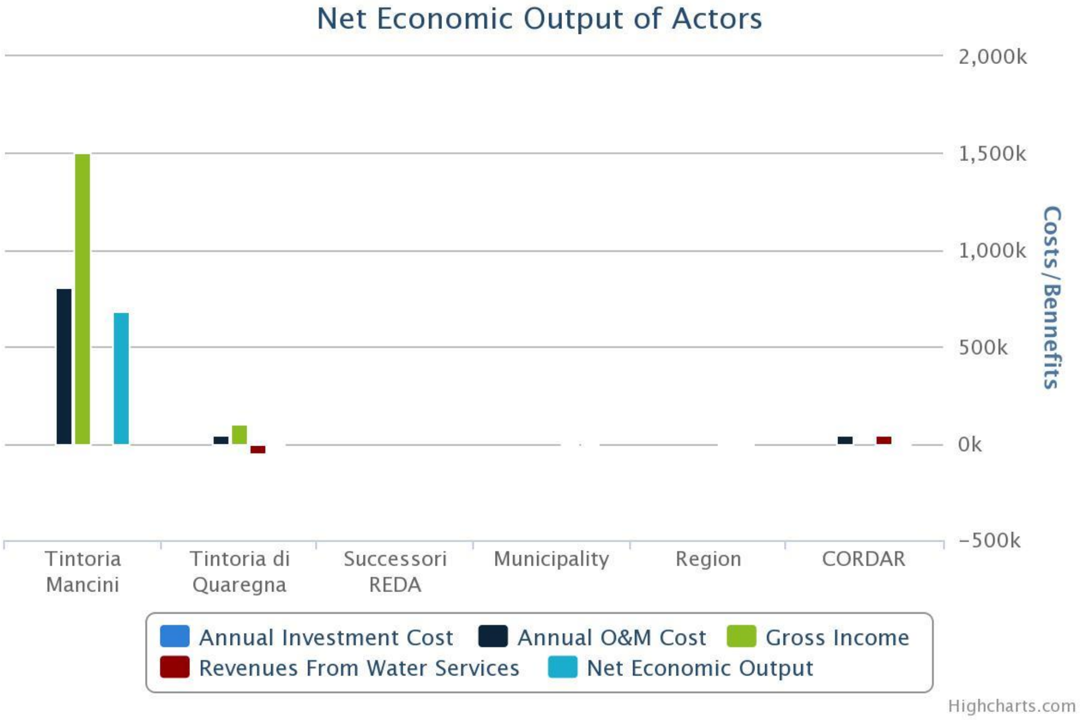

Figure 2.4. Economic Performance per actor involved in system

2.5 Eco-efficiency Indicators

The eco-efficiency indicators are calculated based on the results of environmental and value assessment presented above. Table 2.10 summarizes the values of the eco-efficiency indicators, corresponding to the 9 relevant environmental impact categories while Table 2.11 presents the eco-efficiency indicators per cluster, for the two different types of dyeing processes.

The performance of the two industries is similar in almost all eco-efficiency indicators, with the exception of Freshwater Aquatic Ecotoxicity and Terrestrial Ecotoxicity. In these two categories, the natural dyeing industrial unit has by far a better performance, which indicates that the reduced environmental impacts overcome the higher costs of supplementary resources.

Table 2.10. Eco-efficiency indicators for the entire system

Eco-efficiency Indicator	Unit	Value
Climate Change	€/t$CO_{2,eq}$	551
Eutrophication	€/kg$PO_4^{-3}{}_{,eq}$	1,812
Acidification	€/kg$SO_2^{-}{}_{,eq}$	133
Human Toxicity	€/kg1,4-$DB_{,eq}$	3.18
Freshwater Aquatic Ecotoxicity	€/kg1,4-$DB_{,eq}$	0.48
Terrestrial Ecotoxicity	€/kg1,4-$DB_{,eq}$	0.05
Photochemical Ozone Formation	€/kg$C_2H_{4,eq}$	2,657
Abiotic Resource Depletion	€/kg$Sb_{,eq}$	77.35
Freshwater Resource Depletion	€/m^3	45.22

Table 2.11. Eco-efficiency indicators per cluster

Eco-efficiency Indicator	Unit	Type A Standard chemical dyeing	Type B. Natural dyeing
Climate Change	€/$tCO_{2,eq}$	648	524
Eutrophication	€/$kgPO_4^{-3}{}_{,eq}$	2.065	2.072
Acidification	€/$kgSO_2^{-}{}_{,eq}$	166	97
Human Toxicity	€/kg1,4-$DB_{,eq}$	3,53	4,44
Freshwater Aquatic Ecotoxicity	€/kg1,4-$DB_{,eq}$	0,47	221
Terrestrial Ecotoxicity	€/kg1,4-$DB_{,eq}$	0,05	453
Photochemical Ozone Formation	€/$kgC_2H_{4,eq}$	3.233	2.160
Abiotic Resource Depletion	€/$kgSb_{,eq}$	88,02	89,31
Freshwater Resource Depletion	€/m^3	50,99	55,47

2.6 Conclusions

In conclusion, in the Biella Case Study the most important eco-efficiency indicators are ecotoxicity and human toxicity impact categories which are due to chemical dyes and other chemicals used in the majority of industries, except for the unit that utilises vegetal as dyeing-colour active ingredient (Tintoria di Quaregna).

The Freshwater Depletion indicator, in relation to the pluviometric regime of the area, must be kept under control, but will not affect so consistently the water resources; however, will be important to open the discussion on the terms of operational costs.

The upgrading of the value chain through innovative technologies should aim at the following:

1. Use less toxic dyes
2. Remove toxic substances from effluents more effectively
3. Increase the use of renewable energy resources
4. Use less water demanding technologies in the production chain
5. Recycle the energy (i.e. warm baths of dyeing) for other industrial activities energy-demanding
6. Introduce the cultivation of herbs for dyeing in this area agriculturally depressed with a lot of precipitations and modern irrigation system present in the Biella Province (water management optimisation).

3 Baseline eco-efficiency assessment of the Case Study #6: Cogeneration of Heat and Power

A combined Heat Power is generally described as a more efficient solution than the traditional power plants, in the sense that the heat produced during the generation of electricity is utilized, or at least a part of it, and is no longer discharged as waste heat with the cooling water. Although this may sound attractive, this view is too much simplified.

The present Case Study explored the CHP plant as a system that converts the energy content of the fuel into electricity and heat, with the simultaneous generation of CO_2 emissions, by using (river) water for cooling. The production of power and heat is combined, but not independent. Maximizing power production requires the lowest possible temperature at the condensing site of the generator. As a result, tapping water at elevated temperatures has a reducing effect on the efficiency of the power generation itself.

A second important issue is the profitable time window. Domestic heat demand is not constant over time, and has a daily and seasonal variation. In practice heat peak demand for domestic consumers only occurs a few days per year and heat demand for heating spaces only exists during 30 - 50% of the year. So investment costs, as well as operational and maintenance expenses weigh on a short period of demand. During the rest of the year, most of the produced heat remains waste heat to be discharged with the cooling water.

These two points make it necessary to explore the potential application of eco-efficiency enhancing techniques a bit wider than finding a profitable destination for low temperature heat.

3.1 Goal and scope definition

3.1.1 Objectives

The generation of electricity coincides with the generation of heat. Generally, the heat is cooled away with large volumes of cooling water. Modern production plants are often more flexible in adjusting the ratio of produced electricity / produced heat, and deliver the produced heat in an utilizable form. The main goal of this case is the eco-efficiency assessment of possible adaptations of the meso-level, combined, electricity – heat system, in order to maximize the beneficial use of fossil energy. This is not only a technical issue. Such systems require large budgets and the participation of several stakeholders, being both private and public parties.

3.1.2 System boundaries

The studied system in Case Study #6 has been modified, compared to the one described in Deliverable 4.1, in order to maintain good cooperation conditions with an essential stakeholder and avoid conflicts among the actors involved in this case.

The system description has been shifted to a more generic level, which also implies a small geographic shift along the Amsterdam Rhine Canal (ARC). The focus is now on the energy system fed by the Combined Heat Power (CHP) generating facilities at Diemen.

ARC Diemen Plant generates electricity using natural gas and produces heat for the district heating system of the city of Amsterdam (Zuid-Oost and Ijburg) and the city of Almere. It consists of two CHP (steam and gas turbine) plants, built in 1995:

a) Maximum electrical capacity: 266 MW and max. thermal capacity: 180 MW

b) Maximum electrical capacity: 435 MW and max. thermal capacity: 260 MW

Figure 3.1 The updated system boundaries of CS6

This plant delivers electricity to the electricity transmission network, and provides heat to some domestic areas of the cities of Amsterdam and Almere. Cooling water is abstracted from the Amsterdam Rijn Kanaal (Amsterdam-Rhine Channel - ARC). The water is pumped up, passes through the condensing site of the power plant and is discharged at elevated temperature into the IJmeer. The heat delivered by the power plant is transported to a transmission pipeline system, one to a domestic area in Amsterdam and one through an 8 km long underwater pipe to a domestic area in Almere.

The system of the cogeneration plant, described in the baseline scenario, consists of the following five elements:

- The river water system, which provides cooling water and where water is discharged;
- The energy plant;
- The distribution network equipped with a small storage facility;
- Domestic users of Heat and Power; and
- Industrial users of Heat and Power.

In the baseline scenario of the case study, described here, there is no transportation of heat to customers. It is assumed that the CHP plant maximizes its electricity production and the generated heat is discharged with the cooling water. The customers of electricity satisfy their heat demand by in-house boilers and they are not connected to a district heating system.

3.1.3 Functional unit

The functional unit depends on the reference flow selected each time. In this study two cases are investigated:

- When the unit of product delivered is the flow of interest, the functional unit is defined as one satisfied customer, expressed in terms of a household.
- When the quantity of interest is the water used for the production purposes then the functional unit is 1 m^3 of water used in the industrial sector.

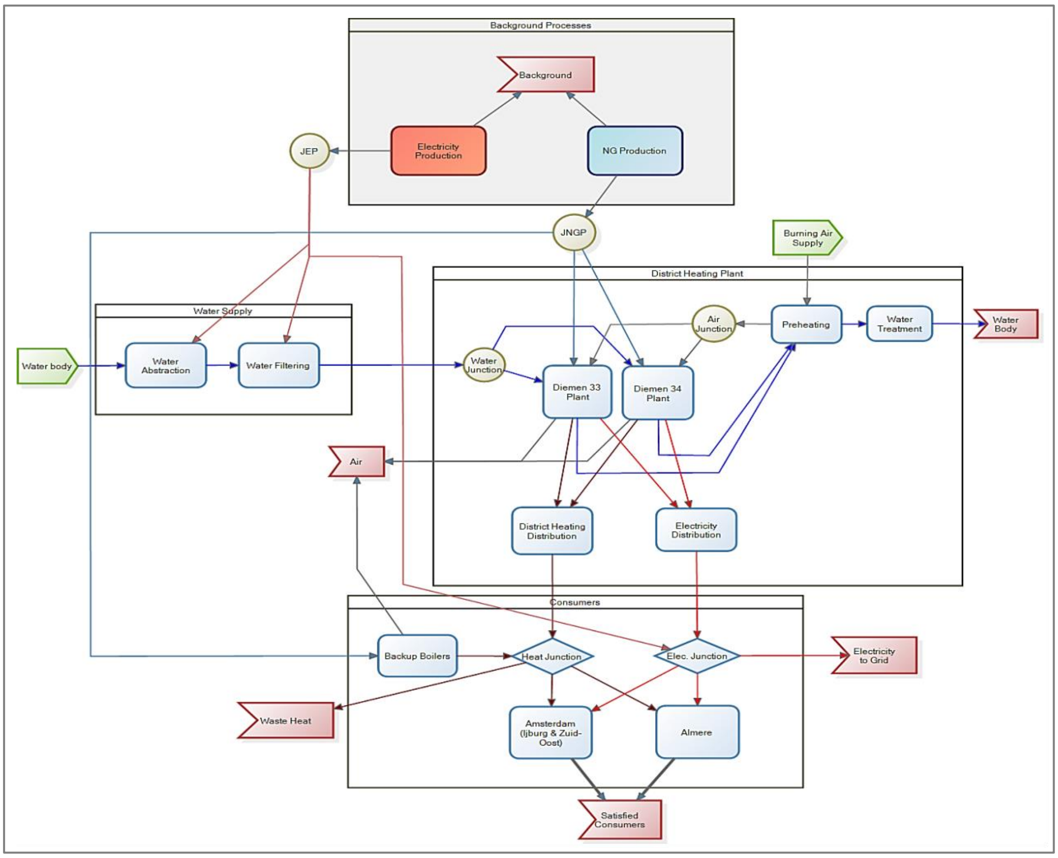

Figure 3.2 SEAT Model of CS6

3.2 Inventory analysis

3.2.1 Processes

The processes included in the SEAT model are presented in :

Table 3.1. Processes of CS6 (per stage)

Stage	Process
Water Supply	Water abstraction
	Water filtering
District Heating Plant	Electricity generation
	Heat generation
	Electricity distribution
	Heat distribution
	Preheating of air
	Cooling water treatment
Consumers	Electricity distribution (Electricity junction)
	Heat distribution (Heat junction)
	Back-up boilers
	Domestic and non-domestic consumers

3.2.2 Resource flows

The resources of the modeled system for Case Study #6 are separated into inflows and outflows, as presented in Table 3.2.

Table 3.2. Inflows and Outflows of the Cogeneration Plant System

Inflows	Outflows
Water	Cooling Water (to Water body)
Burning Air	Water Thermal Content (to Water body)
Electricity	CH_4, CO_2, CO, N_2O, NO_x (Emissions to air)
Natural Gas	Waste heat
	Electricity to grid
	Satisfied consumers (Domestic and non-domestic)

Tables 3.3-3.7 present the processes and the inventory of flows for each stage.

Table 3.3. Resource flows from Stage "Background"

Resource	Input / Output	Flow	Unit
Electricity	Output (to Electricity Junction)	29,700	GJ
Natural Gas	Output (to Natural Gas Junction)	716,502,673,80	m^3

Table 3.4. Resource flows to and from Stage "Water Supply"

Resource	Input / Output	Flow	Unit
Water	Input (to Water Abstraction)	99,000,000	m^3
	Output (to Water Junction)	99,000,000	m^3
Electricity	Input (to Water Abstraction)	19,800	GJ
	Input (to Water Filtering)	9,900	GJ

Table 3.5. Resource flows to and from Stage "District Heating Plant"

Resource	Input / Output	Flow	Unit
Water	Input (to Water Junction)	99,000,000	m^3
Air	Input (to Preheating)	4,654,545,454	m^3
Natural Gas	Input (to ARC Plant)	181,818,181	m^3
CH_4	Output (Emission to air)	72,727	kg
CO	Output (Emission to air)	145,455	kg
CO_2	Output (Emission to air)	365,476,34	kg
N_2O	Output (Emission to air)	655	kg
NO_x	Output (Emission to air)	1,090,909	kg
Electricity	Output (to Electricity Junction)	3,000,000	GJ
Heat	Output (to Heat Junction)	2,100	GJ
Water	Output (to Water body)	94,050,000	m^3
Water Thermal Content	Output (to Water body)	21,622	GJ

Demand data are derived from annual average values for Netherlands, provided by the CBS Dutch Statistical Bureau (Centraal Bureau voor de Statistiek).

In addition to the cogeneration plant, there is additional heating capacity, at industrial locations to serve as back up or as additional heat generation capacity, and in households for warming of tap water and living spaces. These facilities help to satisfy electricity and thermal energy demand, since the ratio at the power plant site does not equal the desired ratio at the demand side.

Since there are no substantial storage possibilities for electricity, operations must maintain constant equilibrium between demand and production. Unavoidable imbalances in the power system are equilibrated with the electricity transmission network. Substantial storage of thermal energy is also not possible. Heat imbalances are equilibrated by thermal discharge, if necessary.

Table 3.6. Resource flows to and from Stage "Consumers"

Resource	Input / Output	Flow	Unit
Electricity	Input (to Electricity Junction)	750,000	GJ
Heat	Input (to Heat Junction)	0.00	GJ
Natural Gas	Input (to Backup Boilers)	133,689,840	m^3
CH_4	Output (Emission to air)	53,476	kg
CO	Output (Emission to air)	106,952	kg
CO_2	Output (Emission to air)	268,732,620	kg
N_2O	Output (Emission to air)	481	kg
NO_x	Output (Emission to air)	802,139	kg
Electricity	Output (to Electricity to grid)	0.00	GJ
Heat	Output (to Waste Heat)	250,000	GJ
Households	Output	750,000	Households

Table 3.7. Resource flows to and from Stage "Industry"

Resource	Input / Output	Flow	Unit
Electricity	Input (to Industry)	2,250,000	GJ
Heat	Input (to Heat Junction)	2,100	GJ
Natural Gas	Input (to Domestic Backup Boilers)	400,994,652	m^3
CH_4	Output (Emission to air)	160,398	kg
CO	Output (Emission to air)	320,796	kg
CO_2	Output (Emission to air)	806,047,371	kg
N_2O	Output (Emission to air)	1,444	kg
NO_x	Output (Emission to air)	2,405,968	kg
Heat	Output (to Waste Heat)	0.00	GJ

3.2.3 Economic data

The unit prices used in the EVAT model are presented in Table 3.8.

Table 3.8. Unit prices of resources in the EVAT model

Resource	Price
Natural Gas (non-domestic use)	0.32 €/m^3
Natural Gas (domestic use)	0.68 €/m^3
Electricity (non-domestic use)	24.00 €/GJ
Electricity (domestic use)	28.00 €/GJ
Heat	11.23 €/GJ

The "satisfaction" of consumers can be assumed that corresponds to 1,500 €/household for the services provided by the cogeneration plant.

3.3 Environmental performance

The environmental performance is assessed, using the standard set of impact categories used in the EcoWater Approach, which distinguishes various environmental problems (EcoWater, 2013a). Nine relevant indicators are selected from the proposed list to express the environmental impacts of the Case Study (Table 3.9).

Table 3.9. Selected midpoint impact categories for CS#6

Impact category	Unit of measure
Climate Change	t $CO_{2,eq}$
Eutrophication	kg $PO_4^{-3}{}_{,eq}$
Acidification	kg $SO_2^{-}{}_{,eq}$
Human Toxicity	kg 1,4-$DB_{,eq}$
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$
Photochemical Ozone Formation	kg $C_2H_{4,eq}$
Fossil Fuels Depletion	MJ
Freshwater Resource Depletion	m^3

In order to account for the impact of the heat content in the cooling water on the receiving water body, an additional environmental impact category, called thermal pollution, was added. The unit for measure of the indicator, called water thermal content, is MJ.

The indicator "Freshwater Resource Depletion" requires a value on the Water Withdrawal to Availability ratio. The selected value of WTA for the Netherlands is 0.15. Since the freshwater resource depletion indicator refers to the foreground river basin, only foreground impacts for this indicator are calculated.

Table 3.10. Characterization factors of Foreground Processes (Guinee et al, 2001)

Impact Category	Unit	Nat. Gas (per m^3)	CO_2 (per kg)	CO (per kg)	CH_4 (per kg)	N_2O (per kg)	NO_x (per kg)
Climate Change	kg $CO_{2,eq}$	-	1	-	25	298	-
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	-	-	-	-	0.27	0.13
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-	-	0.5
Human Toxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	-	1.2
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	-	-
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-	-	-	-
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	0.027	0.006	-	0.028
Fossil Fuels Depletion	MJ	38.84	-	-	-	-	-
Freshwater Resource Depletion	m^3	-	-	-	-	-	-

Table 3.11. Characterization factors of Background Processes (ELCD, 2013)

Impact Category	Unit	Electricity (per GJ)	Natural Gas (per m^3)
Climate Change	t $CO_{2,eq}$	0.188060076	0.000320518
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.052289159	0.000109228
Acidification	kg $SO_2^{-}{}_{,eq}$	2.224362982	0.001062144
Human Toxicity	kg 1,4-$DB_{,eq}$	13.60742552	0.003383542
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	0.806943969	0.000210015
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	0.558309057	4.38867E-05
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	0.091358749	0.00015858

The results of the environmental impacts of the entire system and the contribution of the background and foreground processes into the system are presented in Table 3.12 and Figure 3.3. The results on environmental indicators are presented as percentage per stage in Figure 3.4, where solid bars represent the foreground system and transparent bars the background system.

Table 3.12. Environmental indicators results for CS6.

Environmental Indicator	Unit	Value
Climate Change	t $CO_{2,eq}$	1,683,427
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	559,569
Acidification	kg $SO_2^{-}{}_{,eq}$	3,009
Human Toxicity	kg 1,4-$DB_{,eq}$	7,987,277
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	174,442
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	48,027
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	238,428
Fossil Fuels Depletion	MJ	12,254,331,551
Freshwater Resource Depletion	m^3	14,850,000
Thermal Pollution	MJ	21,622,000

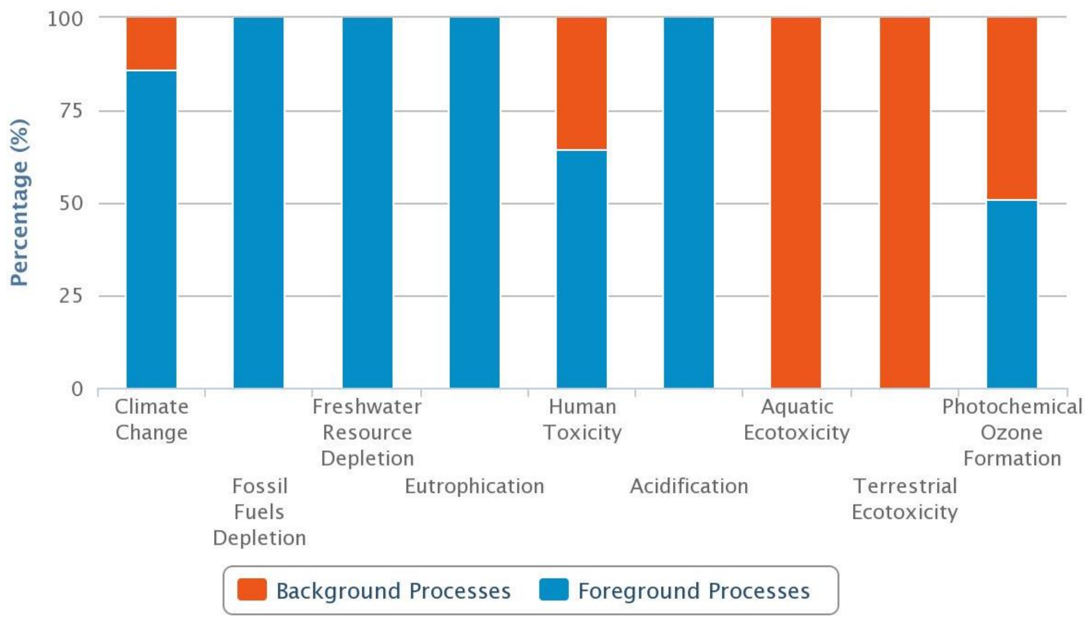

Figure 3.3. Contribution of foreground and background systems in the environmental impact categories

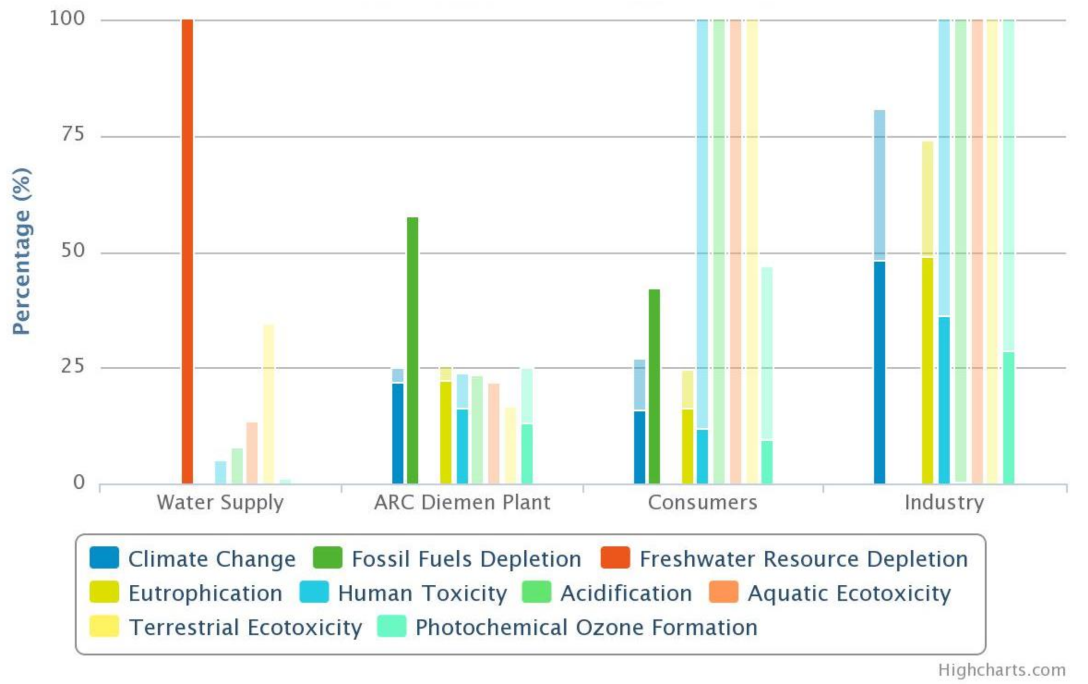

Figure 3.4. Environmental Impact Breakdown per stage

3.4 Economic performance

The economic performance of the system was calculated using the EVAT tool. Table 3.13 summarizes the economic results (in €/year) for all actors involved in the system. The results are calculated using the economic data and the life cycle inventory flows. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 184,250,196€.

Table 3.13. Economic performance for Cogeneration Plant system (€/year)

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Water Supply Operator	-765,280	0.00	0.00	-765,280.00
District Heating Plant Owner	-82,709,344	0.00	75,023,583	-7,685,762
Consumers	-94,596,417	125,000,000	-21,000,000	9,403,583
Industry	-137,678,762	375,000,000	-54,023,583	183,297,655
			Total Value Added:	**184,250,198**

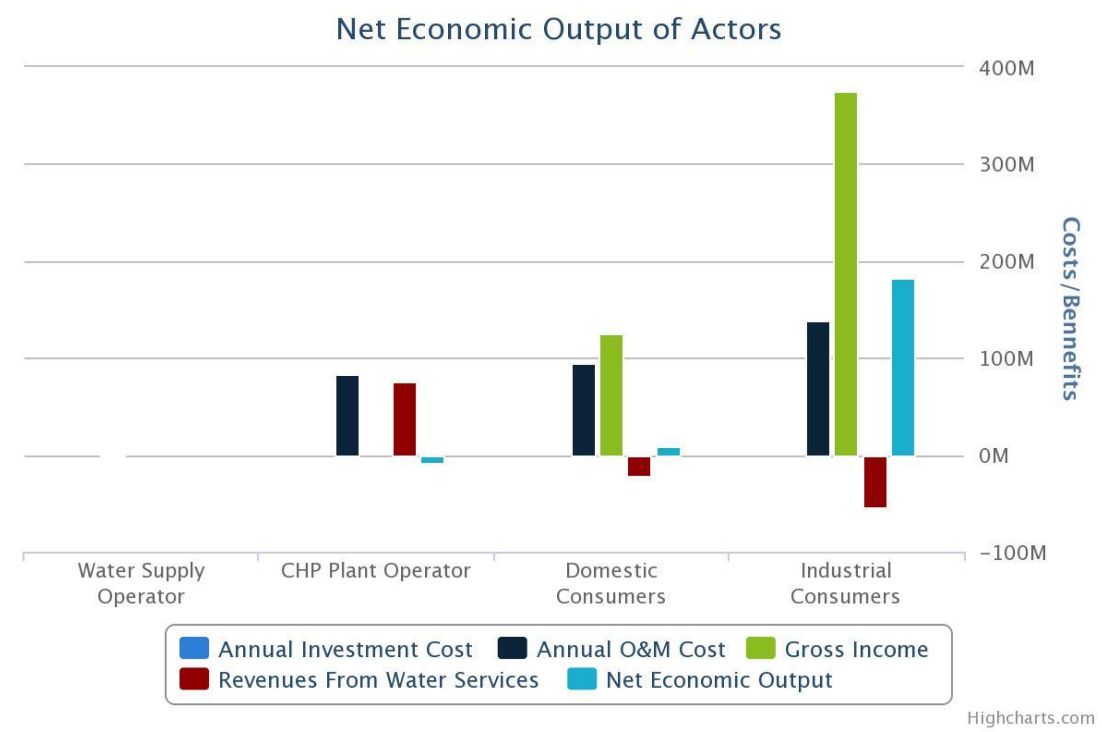

Figure 3.5. Economic Performance per actor involved in system

3.5 Eco-Efficiency Indicators

The eco-efficiency indicators are evaluated from the results of environmental and economic performance assessment presented above. Table 3.14 summarizes the values of the eco-efficiency indicators, corresponding to the 10 relevant environmental impact categories.

Table 3.14. Eco-efficiency indicators for CS6

Eco-efficiency Indicator	Unit	Value
Climate Change	€/t$CO_{2,eq}$	109.45
Eutrophication	€/kg$PO_4^{-3}{}_{,eq}$	329.27
Acidification	€/kg$SO_2^{-}{}_{,eq}$	61,226.70
Human Toxicity	€/kg1,4-$DB_{,eq}$	23.07
Freshwater Aquatic Ecotoxicity	€/kg1,4-$DB_{,eq}$	1,056.22
Terrestrial Ecotoxicity	€/kg1,4-$DB_{,eq}$	3,836.41
Photochemical Ozone Formation	€/kg$C_2H_{4,eq}$	772.77
Fossil Fuels Depletion	€/MJ	0.02
Freshwater Resource Depletion	€/m^3	12.41
Thermal Pollution	€/MJ	8.52

3.6 Conclusions

The Baseline Scenario of the Cogeneration of Heat and Power Case Study is characterized by the generation of CO_2 emissions on one hand and by large amounts of waste heat on the other. The Total Value Added is mainly determined by two terms, the price of natural gas and the price consumers have to pay for the energy they consume. Both prices depend not only on market developments, but also on governmental / political regulations.

The most obvious way to increase the eco-efficiency is by utilizing the waste heat which is discharged with the cooling water. Using the heat, the amount of gas burned in backup boilers and domestic installations to provide thermal energy will be significantly reduced. This will also contribute at an improved economic performance, by increasing the Total Added Value, and decreasing the amount of CO_2 exhausted from backup boilers, lowering the environmental impacts.

Another important point to address is the price of the CO_2 emission rights. In this base case the costs of emission rights is unrealistically low, considering the environmental impact. It is not unreasonable to expect a higher price as a result of law enforcement by governments. This might endorse the case for improvements of the eco-efficiency, if these costs would contribute substantially to the cost level of energy production.

4 Baseline eco-efficiency assessment of the Dairy Industry

4.1 Goal and scope definition

4.1.1 Objectives

The main goal of this Case Study is the assessment of the environmental impacts and of the eco-efficiency performance associated with the water value chain in the case of the Dairy Industry in Denmark. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors.

4.1.2 System boundaries

There are two major changes in system boundaries compared to what was described in Deliverable 4.1. It was decided to focus only to the production chain of the Arla HOCO plant and Rødkærsbro Dairy will not be included. It is still under consideration to include, in later stages of analysis, a fresh milk dairy industry instead.

Furthermore, it was decided to include the transport process of raw materials and waste products by trucks – as significant amounts of water is bound in these material streams. The inclusion of these processes leads to the addition of new environmental impact indicators to the analysis, in addition to the fossil fuel depletion, climate change and acidification indicators. The solid waste from the dairy industry and the sludge from wastewater treatment are used for biogas production which is converted to electricity and heat, which are sold back to the grid and used for district heating respectively.

Five overall conceptual stages are used to divide the value chain into Water supply, Dairy Operations (water use), Wastewater treatment, Energy production and Transport. Each stage represents as well one actor:

1. Water Supply Operator: Vestforsyning Water
2. Dairy Industry: HOCO
3. Wastewater Treatment Operator: Vestforsyning Wastewater
4. Energy Production Plant: Maabjerg Bioenergy Plant
5. Transport: Private transportation companies

The transport is partly done by Arla, while actually waste products from the dairy and from wastewater are treated in two different biogas plants.

The processes, as modelled in SEAT, are shown in Figure 4.1:

4.1.3 Functional unit

The functional unit depends on the reference flow selected each time. In this study two cases are investigated:

1. When the unit of product delivered is the flow of interest, the functional unit is defined as one tonne of milk powder.
2. When the quantity of interest is the water used for the production purposes then the functional unit is 1 m^3 of water used in the industrial sector.

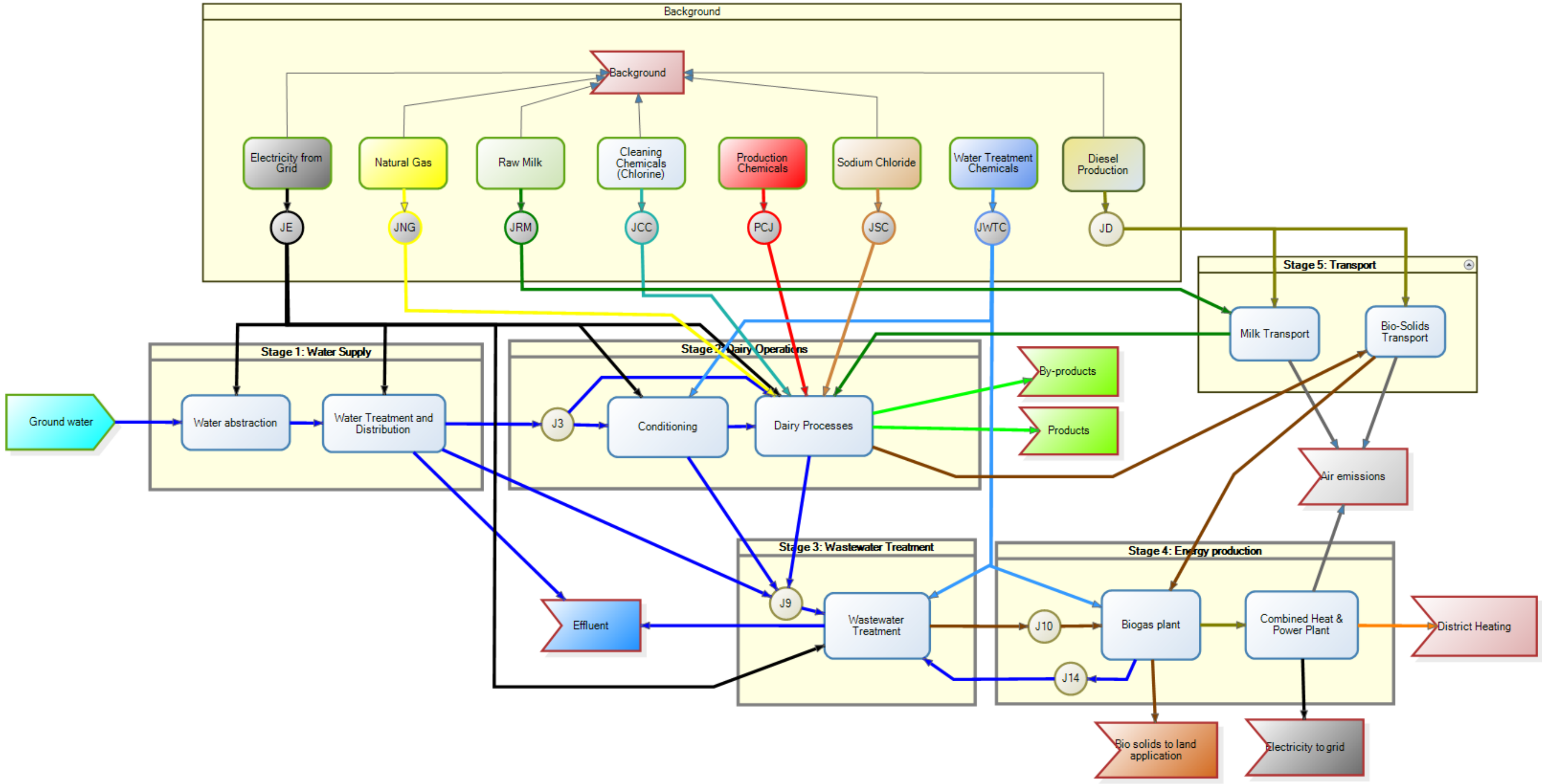

Figure 4.1. SEAT Model of CS7

4.2 Inventory analysis

4.2.1 Processes

The dairy processes in HOCO have not been broken down into sub-processes due to lack of data at a sufficiently detailed level. As such the baseline assessment looks at HOCO as more or less a black box.

A total overview of the processes considered in SEAT model is given in the following table (Table 4.1):

Table 4.1. Processes of CS7 (per stage)

Stage	Process
Water Supply	Water abstraction
	Water treatment and distribution
Dairy Operations	Conditioning
	Dairy Processes
Wastewater Treatment	Wastewater Treatment
Energy Production	Biogas Plant
	Combined Heat and Power Plant

4.2.2 Resource flows

The resources of the modelled system for CS7 are separated into inflows and outflows, as presented in Table 4.2.

Table 4.2. Inflows and Outflows of the Dairy Industry System

Inflows	Outflows
Water	Effluents (COD, N, P, Wastewater)
Electricity	Emissions to air (CH_4, CO_2, N_2O, NO_x, SO_x)
Natural Gas	Electricity to grid
Diesel	District heating
Raw Milk	Bio-solids to land application (Bio-solids, N, P)
Cleaning Chemicals (Cl_2)	Products (milk powder)
Production Chemicals	By-products (cream/whey)
Sodium Chloride (NaCl)	
Water Treatment Chemicals	

The total water, energy and materials balance of HOCO is primarily based on the HOCO's green accounts, supplemented with specific information from other actors.

The resource flows for the individual stages are given in the following tables.

Table 4.3. Resource flows to and from Stage "Water Supply"

Resource	Input / Output	Flow	Unit
Groundwater	Input (to Water Abstraction)	529,581	m^3
Electricity	Input (to Water Abstraction)	53	MWh
	Input (to Water Treatment and Distribution)	294	MWh
Wastewater	Output (to Effluent)	52,434	m^3
	Output (to J9)	4,719	m^3
Potable Water	Output (to J3)	471,904	m^3

Table 4.4. Resource flows to and from Stage "Dairy Operations"

Resource	Input / Output	Flow	Unit
Potable Water	Input (to J3)	471,904	m^3
Electricity	Input (to Conditioning)	9	MWh
	Input (to Dairy Processes)	37,063	MWh
Natural Gas	Input (to Dairy Processes)	131,670	MWh
Raw Milk	Input (to Dairy Processes)	524,241	t
Cleaning Chemicals	Input (to Dairy Processes)	1,408	t
Production Chemicals	Input (to Dairy Processes)	4,606	t
Sodium Chloride	Input (to Dairy Processes)	1,486,000	kg
Water Treatment Chemicals	Input (to Conditioning)	12,000	kg
Nitrogen	Output (to J9)	76,000	kg
Phosphorus	Output (to J9)	19,000	kg
COD	Output (to J9)	900,000	kg
Bio-solids	Output (to Biogas Plant)	435	t
Wastewater	Output (to J9)	610,427	m^3
Product (Milk powder)	Output (to Products)	17,165	t
By-products (Cream / Whey)	Output (to By-products)	253,774	t

Table 4.5. Resource flows to and from Stage "Wastewater Treatment"

Resource	Input / Output	Flow	Unit
Electricity	Input (to Wastewater Treatment)	326	MWh
COD	Input (to J9)	958,571	kg
Nitrogen	Input (to J9)	76,000	kg
	Input (to Wastewater Treatment)	23,428	kg
Phosphorus	Input (to J9)	19,000	kg
	Input (to Wastewater Treatment)	2,929	kg
Wastewater	Input (to J9)	615,146	m^3
	Input (to Wastewater Treatment)	58,571	m^3
Water Treatment Chemicals	Input (to Wastewater Treatment)	66,125	kg
COD	Output (to Effluent)	20,130	kg
Nitrogen	Output (to Effluent)	5,966	t
Phosphorus	Output (to Effluent)	570	m^3
Bio-solids	Output (to J10)	277	t
Wastewater	Output (to Effluent)	579,368	m^3

Table 4.6. Resource flows to and from Stage "Energy Production"

Resource	Input / Output	Flow	Unit
Bio-solids	Input (to Biogas Plant)	435	t
	Input (to J10)	277	t
Water Treatment Chemicals	Input (to Biogas Plant)	488,029	kg
Bio-solids	Output (to Bio-solids to land application)	598	t
CH4	Output (to Air emissions)	24.5	kg
CO2	Output (to Air emissions)	398,224	t
N2O	Output (to Air emissions)	4.90	kg
NOx	Output (to Air emissions)	0.00	kg
SOx	Output (to Air emissions)	0.00	kg
COD	Output (to Wastewater Treatment)	58,571	kg
Nitrogen	Output (to Bio-solids to land application)	26,317	kg
	Output (to Wastewater Treatment)	23,428	kg
Phosphorus	Output (to Bio-solids to land application)	17,943	kg
	Output (to Wastewater Treatment)	2,929	kg
Wastewater	Output (to Wastewater Treatment)	58,571	m^3
Electricity	Output (to Electricity to grid)	489	MWh
Heat	Output (to District Heating)	625	MWh

Table 4.7. Resource flows to and from Stage "Transport"

Resource	Input / Output	Flow	Unit
Diesel	Input (to Milk Transport)	6,657,861	L
	Input (to Bio-Solids Transport)	33,886	L
Raw Milk	Input (to Milk Transport)	524,241	L
Bio-solids	Input (to Bio-Solids Transport)	435	t
CH4	Output (to Air emissions)	87	kg
CO2	Output (to Air emissions)	21,614	t
N2O	Output (to Air emissions)	850	kg
NOx	Output (to Air emissions)	114,161	kg
SOx	Output (to Air emissions)	134	kg
Raw Milk	Output (to Dairy Operations)	524,241	L
Bio-solids	Output (to Energy Production)	435	t

4.2.3 Economic data

The economic modelling has been based on the total annual revenue of HOCO – considering that water is a very fundamental part of dairy processing.

Costs for water services as well as chemicals, power, natural gas etc. are based on actual cost values, where they are available. Certain costs, which have not been determined, have been estimated.

The unit costs of energy, water services, raw materials and chemicals are summarized in Table 4.8.

It has not been possible to obtain economic figures for the energy production stage.

Table 4.8. Unit prices of resources used in the EVAT model

Resource	Price
Electricity	135.00 €/MWh
Natural Gas	85.00 €/MWh
Raw Milk	360.00 €/t
Cleaning Chemicals	375.00 €/t
Production Chemicals	375.00 €/t
Sodium Chloride	0.05 €/kg
Water Treatment Chemicals	0.38 €/kg
Potable water	1.80 €/m^3
Wastewater	3.30 €/m^3

4.3 Environmental performance

The environmental performance is assessed, using the standard set of impact categories used in the EcoWater Approach, which distinguishes various environmental problems (EcoWater, 2013a). The impacts of the Case Study do not cover all categories because not all indicators are relevant to it. The relevant indicators are presented in the Table 4.9.

Table 4.9. Relevant midpoint impact categories for CS#7

Impact category	Unit of measure
Climate Change	t $CO_{2,eq}$
Eutrophication	kg $PO_4{}^{-3}{}_{,eq}$
Acidification	kg $SO_2{}^{-}{}_{,eq}$
Human Toxicity	kg 1,4-$DB_{,eq}$
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$
Photochemical Ozone Formation	kg $C_2H_{4,eq}$
Freshwater Resource Depletion	m^3

The Freshwater Resource Depletion indicator requires a value on the Water Withdrawal to Availability ratio. The selected value of WTA for Denmark is 0.10 (representative for western Denmark). Since the freshwater resource depletion indicator refers to the foreground river basin, only foreground impacts are calculated.

The results of the environmental impacts of the entire system and the contribution of the background and foreground processes into the system are presented in Table 4.12 and Figure 4.2. The breakdown of the environmental impact per stage is presented in Figure 4.3.

Table 4.10. Characterization factors of Foreground Processes (Guinee et al., 2001)

Impact Category	Unit	CO_2 (per kg)	CH_4 (per kg)	N_2O (per kg)	NOx (per kg)	SO_2 (per kg)	N (per kg)	P (per kg)	COD (per kg)
Climate Change	kg $CO_{2,eq}$	1	25	298			-	-	-
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	-	-	0.27	0.13		0.42	3.06	0.022
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	0.5	1.2	-	-	-
Human Toxicity	kg 1,4-$DB_{,eq}$	-	-	-	1.2	0.096	-	-	-
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-			-	-	-
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-			-	-	-
Photochemical Ozone Formation	kg $C2H4_{,eq}$	-	0.006	-	0.027	0.048	-	-	-
Fossil Fuels Depletion	MJ	-	-	-			-	-	-
Freshwater Resource Depletion	m^3	-	-	-			-	-	-

Table 4.11. Characterization factors of Background Processes (ELCD, 2013, de Boer, 2003, Thomassen et al., 2008)

Impact Category	Unit	Electricity (Danish Mix - per MWh)	Natural Gas (per MWh)	Diesel (per kg)	Raw Milk (per t)	Cleaning Chemicals (per t)	Sodium Chloride (per kg)
Climate Change	t $CO_{2,eq}$	0.786812084	0.03239126	0.38199	0.99	1.136140287	0.000164874
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.149711971	0.011038501	0.00018	58	0.365187041	5.50205E-05
Acidification	kg $SO_2^{-}{}_{,eq}$	1.453529346	0.10733937	0.00257	18	8.589409699	0.00112716
Human Toxicity	kg 1,4-$DB_{,eq}$	17.21294707	0.341937779	0.03782	N/A	9.08847614	0.001002073
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	0.559080214	0.021223936	0.00296	N/A	0.363665659	2.65682E-05
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	0.377013802	0.004435149	0.00101	N/A	19.19190018	0.000291445
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	0.055263337	0.01602593	0.00023	N/A	0.341874363	4.43468E-05

Table 4.12. Environmental indicators results for CS7

Environmental Indicator	Unit	Value
Climate Change	t $CO_{2,eq}$	977,029
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	30,500,404
Acidification	kg $SO_2^{-}{}_{,eq}$	9,613,458
Human Toxicity	kg 1,4-$DB_{,eq}$	1,056,558
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	40,928
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	47,893
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	9,227
Freshwater Resource Depletion	m^3	52,958

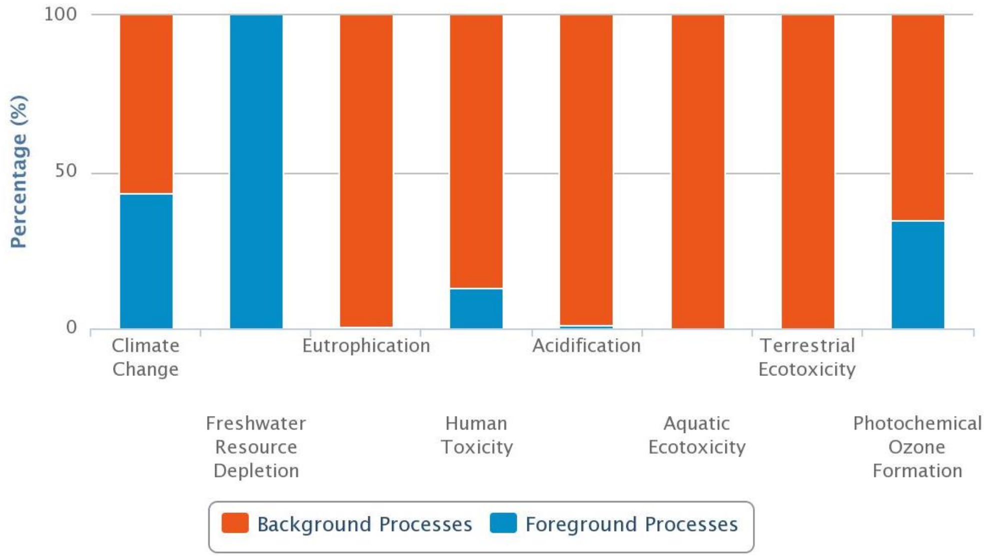

Figure 4.2. Contribution of foreground and background systems in the environmental impact categories

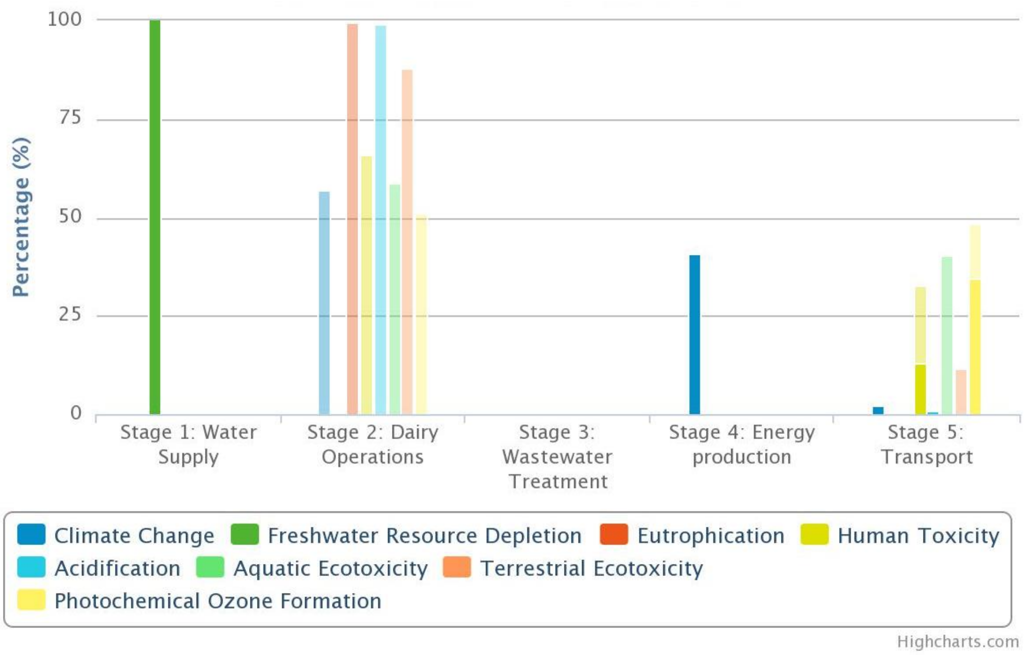

Figure 4.3. Environmental Impact Breakdown per stage. Solid bars represent the foreground system and transparent bars the background system

4.4 Economic performance

The economic performance of the system was calculated using the EVAT tool. Table 4.13 summarizes the economic results (in €/year) for all actors involved in the system. The results are calculated using the economic data and the life cycle inventory flows. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 64,617,081€.

Due to the fact that it has not been possible to obtain economic figures for the Energy production stage, the NEO of the plant operator appears to be negative. This does not represent the reality, and this number should be used only for comparison purposes with an alternative scenario.

Table 4.13. Economic performance for Dairy Industry system (€/year)

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Water Supply Operator	46,895	0.00	849,427	802,532
Dairy Industry	199,760,663	270,939,000	-10,093,713	61,084,625
WWT Operator	68,780	0.00	2,014,409	1,945,629
Energy Production Plant	423,009	0.00	0.00	-423,009
Private Transportation Companies	6,262,571	7,469,875	0.00	
			Total Value Added	**64,617,081**

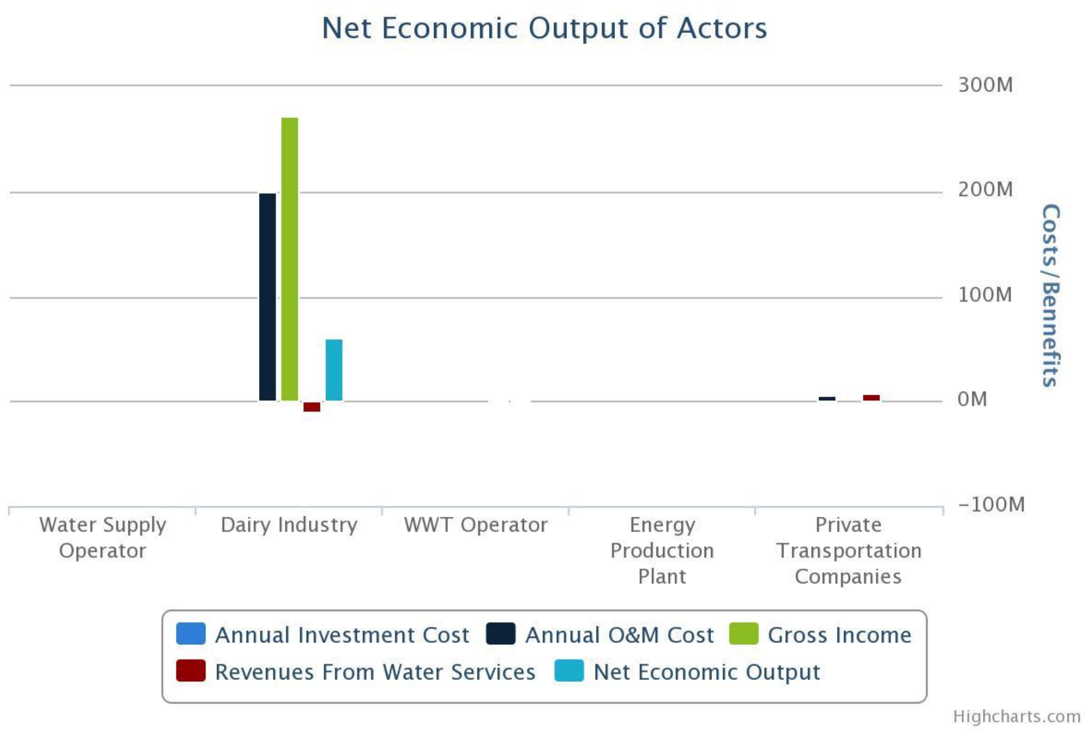

Figure 4.4. Economic Performance per actor involved in system

4.5 Eco-efficiency indicators

The eco-efficiency indicators are estimated from the results of environmental and value assessment presented above. Table 4.14 summarizes the values of the eco-efficiency indicators, corresponding to the 8 relevant environmental impact categories.

Table 4.14. Eco-efficiency indicators for CS7

Eco-efficiency Indicator	Unit	Value
Climate Change	€/t$CO_{2,eq}$	66.14
Eutrophication	€/kg$PO_4^{-3}{}_{,eq}$	2.12
Acidification	€/kg$SO_2^{-}{}_{,eq}$	6.87
Human Toxicity	€/kg1,4-$DB_{,eq}$	61.16
Freshwater Aquatic Ecotoxicity	€/kg1,4-$DB_{,eq}$	1,579
Terrestrial Ecotoxicity	€/kg1,4-$DB_{,eq}$	1,349
Photochemical Ozone Formation	€/kg$C_2H_{4,eq}$	7,003
Freshwater Resource Depletion	€/m^3	1,220

4.6 Conclusions

The net economic output of the industrial actor (Arla HOCO) is the completely dominating factor of the complete value chain – with the price of the raw milk resource being the single factor determining the total value added of the entire system – as the farmers are considered external actors to the system. Minor changes in the price of raw milk can completely change the TVA of the system – and as such the eco-efficiency indicators calculated.

Regarding the environmental and eco-efficiency performance of the system, the main weak points are the eutrophication and the acidification impact categories. However, both of them are mainly due to the background processes. The other two indicators with relatively low values, caused by the foreground system, are the climate change and freshwater resource depletion. Thus, technological solutions should be examined in order to reduce water and fossil fuels consumption in the dairy industry.

5 Baseline eco-efficiency assessment of the Automotive Industry

5.1 Goal and scope definition

5.1.1 Objectives

The main goal of this study is the assessment of the environmental impacts and the eco-efficiency performance associated with the water value chain in the case of the Volvo automotive industry in Sweden. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors.

5.1.2 System boundaries

The Case Study concerns the Volvo Group, Sweden, and will focus on the two (2) manufacturing sites of Volvo Trucks and their respective water supply chain. The sites are located in Umeå, northeast of Sweden, and Gothenburg, southwest of Sweden. Volvo Trucks Umeå is a producer of truck cabins, while Volvo Trucks Tuve produces frame beams and has a vehicle assembly line.

Four overall conceptual stages are used to divide the value chain into Water abstraction, Water treatment, Water use and Wastewater treatment (Figure 5.1). It can be noted that the actor Gothenburg Vatten has changed its name to Kretslopp & Vatten after D4.1 was published. For modelling purposes, in the SEAT-model those four stages are further divided into one stage per actor and production site, resulting in 11 individual stages in the modelling tool (Table 5.1).

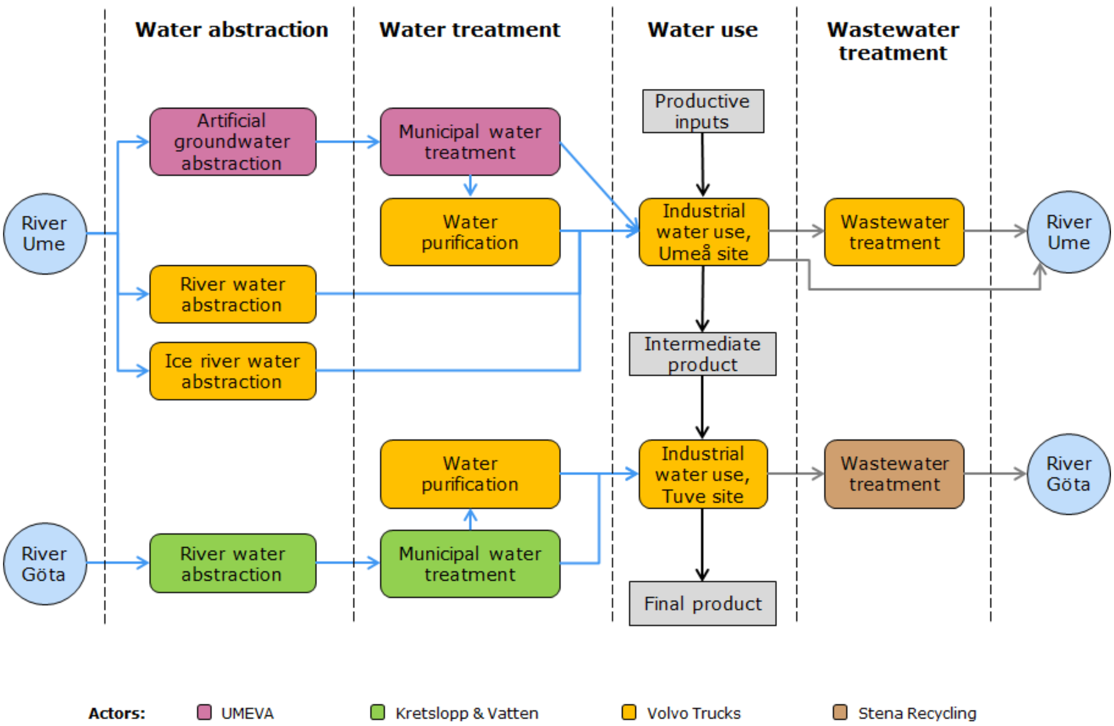

Figure 5.1. Overview of the four conceptual stages and actors of Case Study 8

Table 5.1. Stages and actors of CS8

Conceptual Stage	SEAT Model Stage	Actors
Water abstraction	1. Abstraction 1	Municipal water abstraction (UMEVA)
	2. Abstraction 2	Private water abstraction (Volvo Trucks Umeå)
	3. Abstraction 3	Municipal water abstraction (Kretslopp & Vatten)
Water treatment	4. Treatment 1	Municipal water treatment (UMEVA)
	5. Treatment 2	Private water purification (Volvo Trucks, Umeå)
	6. Treatment 3	Municipal water treatment (Kretslopp & Vatten)
	7. Treatment 4	Private water purification (Volvo Trucks, Gothenburg)
Water use	8. Water Use, Umeå	Water use in production processes (Volvo Trucks, Umeå)
	9. Water Use, Gothenburg	Water use in production processes (Volvo Trucks, Gothenburg)
Wastewater treatment	10. WW Treatment 1	Private wastewater treatment (Volvo Trucks, Umeå)
	11. WW Treatment 2	Private wastewater treatment (Stena Recycling)

There are two changes in system boundaries compared to what was described in D4.1. The first is the extension of the system to include the background processes for the production of electricity, district heating and chemicals. This allows the estimation of the background environmental impacts in addition to the impacts from the foreground processes.

The second is that in addition to the total flows of chemicals used in the production stage, the elementary P, Ni and Zn in the chemicals are also accounted. This is necessary in order to evaluate the contribution of the chemicals use in resource depletion environmental indicators. The data records of those elements, e.g. P(in chem), are to be viewed only as a simplification for indicator calculation. The actual amount of chemicals used (including the elements P, Ni and Zn) are also recorded.

Due to the lower than expected level of detail in data available from Volvo Trucks, the following changes were made regarding the processes of Water Use, Umeå:

1. The resource use and emissions of the process *Water Recycling, degreasing bath* is incorporated in the process *Degreasing*.
2. The resource use and emissions of the process *Water Recycling, final dip rinse* is incorporated in the process *Phosphating*.

Apart from that, no other changes were made to the modelled processes described in D4.1. The resulting water use processes of CS8 are presented in Figure 5.2.

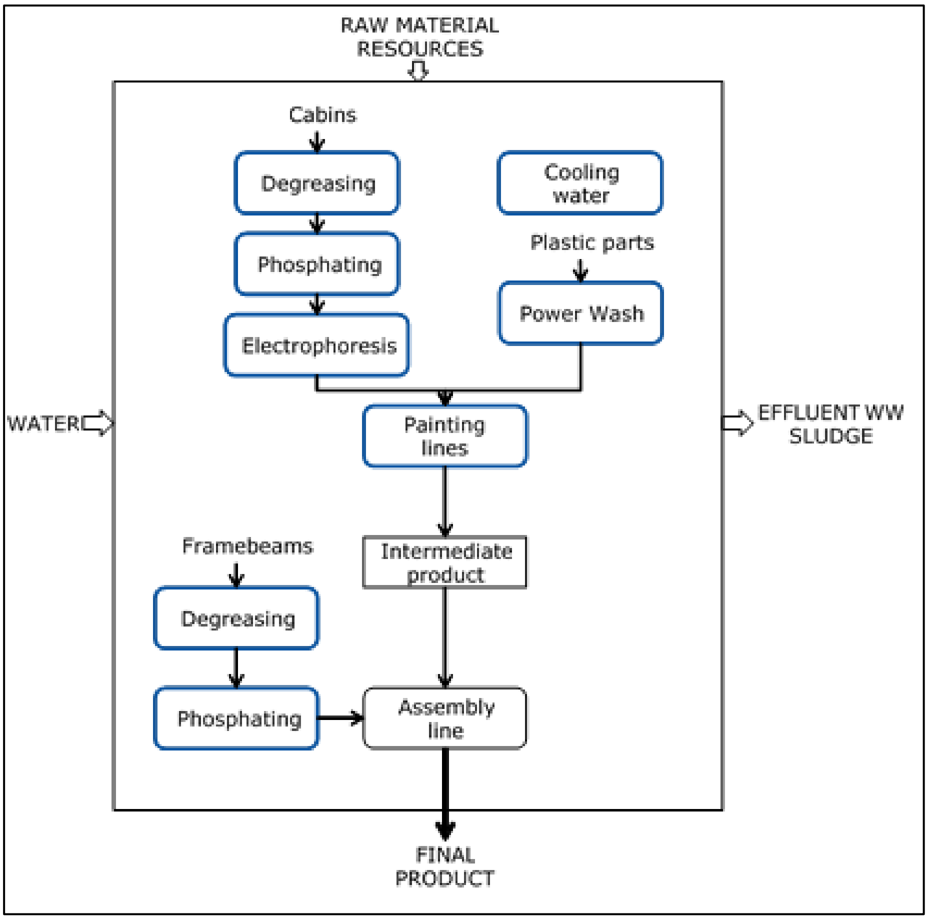

Figure 5.2. Water using processes (in blue borders) of the Volvo trucks production line. The intermediate product is produced in Umeå and shipped to Gothenburg.

5.1.3 Functional unit

The main purpose for a functional unit is to provide a reference to which environmental impacts are normalized and compared. The functional unit used in this case study is:

- One unit of final product, e.g. one truck.

5.2 Inventory analysis

5.2.1 Resource flows

The resources of the modelled system for CS8 are presented in Table 5.2. The symbols used follow the modelling convention:

- w: Water service related materials (fresh water, wastewater);
- r: Supplementary resources, used in the processes of the water supply chain or in the production chain (energy, raw materials, chemicals, etc.);
- e: Emissions generated from the processes of both chains and released to the environment; and
- p: Products/Services The main outputs of the water use stage.

Table 5.2. Resources of the Automotive Industry System (CS8)

Category	Symbol	Material
Water Service Related Materials	w_1	Surface Water
	w_2	Wastewater
Supplementary Resources	r_1	Electricity
	r_2	District heating
	r_3	Chemicals for degreasing (unspecified mix, contains P)
	r_4	Chemicals for phosphating (unspecified mix, contains P, Zn, Ni)
	r_5	Phosphorus (P, in chemicals)
	r_6	Nickel (Ni, in chemicals)
	r_7	Zinc (Zn, in chemicals)
	r_8	Coagulation agent (unspecified mix)
	r_9	Precipitation chemical (unspecified)
	r_{10}	Chemical for pH adjustment (unspecified)
	r_{11}	Chemical for flocculation (unspecified)
	r_{13}	Dolomite
	r_{13}	Sand
	r_{14}	Chlorine
	r_{15}	Activated carbon
Emissions	e_1	Carbon Dioxide to air
	e_2	COD to water
	e_3	Phosphorus to water
	e_4	Nickel to water
	e_5	Zink to water
	e_6	Sludge to incineration
	e_7	Sludge to landfill
	e_8	Used dolomite
Products	p_1	Cabins (intermediate product)
	p_2	Trucks (final product)

The water balance of CS8 for one year's production was calculated from Volvo Trucks' data (Volvo Trucks Umeå, 2012, Volvo Trucks Gothenburg, 2012 and Lindskog, 2012), an assumption on water loss in the water purification processes (15% loss in reverse osmosis at Volvo Trucks) and water loss by sludge in the wastewater treatment processes (20% water in the produced sludge). It was further assumed that there are no water losses in the abstraction stages or in the municipal water treatment stages. Cooling water passes through the production site in a closed cooling system. It is released back to the river virtually unaffected apart from a temperature change of 3-5 degrees (Lindskog, 2012). The water and waste water flows are presented in Figure 5.3. The model takes into account evaporation of water from the Degreasing and Phosphating processes of the Umeå site. There is no net evaporation at the Gothenburg site.

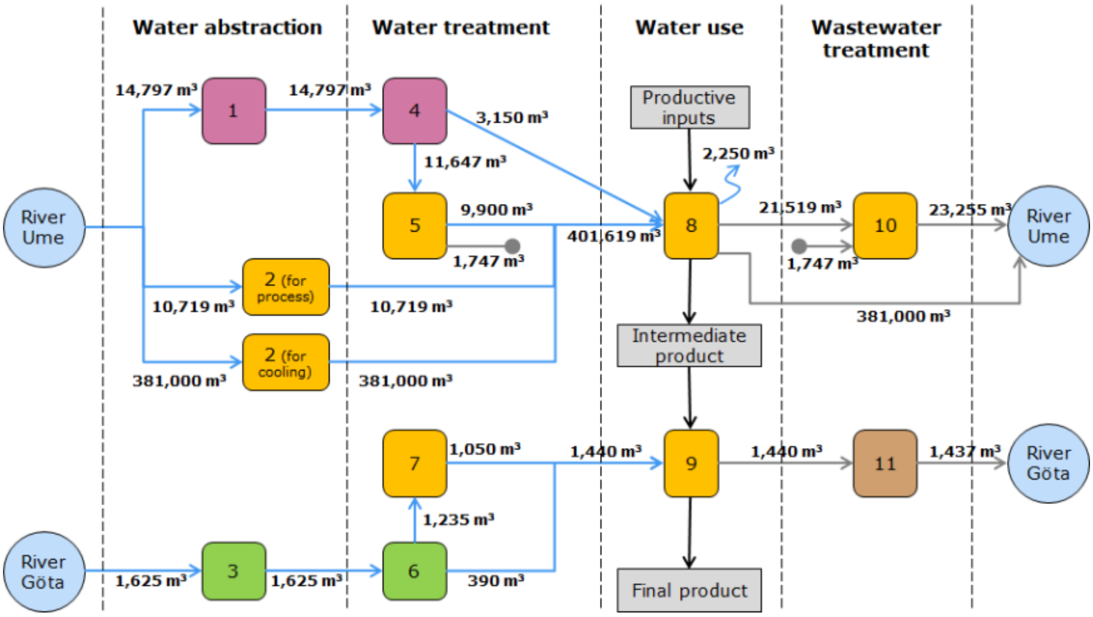

Figure 5.3. Overview of water and wastewater flows in CS8. The SEAT stages are indicated by the numbers 1-11

The flows in the water abstraction stages are summarized in Table 5.3. Electricity flows are estimated on the assumption that 0.5 kWh is required for each m^3 of water abstracted.

Table 5.3. Inventory of flows for the Water Abstraction stages, representative of one year

SEAT Stage	Symbol	Resource	Quantity
1. Municipal water abstraction (actor UMEVA)	$f_{w1,0\text{-}1}$	Surface water	14,797 m^3
	$f_{r1,1}$	Electricity	14,797 kWh
	$f_{e1,1}$	$CO_{2,eq}$	666 kg
2. Private water abstraction (actor Volvo Trucks Umeå)	$f_{w1,0\text{-}2}$	Surface water	391,719 m^3
	$f_{r1,2}$	Electricity	195,860 kWh
	$f_{e1,2}$	$CO_{2,eq}$	8,814 kg
3. Municipal water abstraction (actor Kretslopp & Vatten)	$f_{w1,0\text{-}3}$	Surface water	1,625 m^3
	$f_{r1,3}$	Electricity	813 kWh
	$f_{e1,3}$	$CO_{2,eq}$	37 kg

The water treatment stages were modelled from different available sources of data. Stage 4 (municipal water treatment of Umeå) was modelled from specific information on the municipal water works in Umeå (UMEVA, 2012) in combination with an assumption on the use of sand and dolomite for filters in the water work. Stage 5 and 7, Volvo Trucks' own water purification by reverse osmosis were modelled from existing knowledge of senior IVL staff. Stage 6, municipal water treatment of Gothenburg, was modelled with data for water treatment from the LCA database Ecoinvent (Ga-

Bi4), due to lack of available information from Kretslopp & Vatten. The dataset of the water treatment stages is summarized in Table 5.4.

Table 5.4. Inventory of flows for the Water Treatment stages, representative of one year

SEAT Stage	Symbol	Resource	Quantity
4. Municipal water treatment (actor UMEVA)	$f_{w1,1\text{-}4}$	Water	14,797 m^3
	$f_{r1,4}$	Electricity	5,919 kWh
	$f_{r12,4}$	Dolomite	0.15 kg
	$f_{r13,4}$	Sand	0.15 kg
	$f_{e1,4}$	$CO_{2,eq}$	266 kg
	$f_{e8,4}$	Used dolomite	0.15 kg
	$f_{e9,4}$	Used sand	0.15 kg
5. Private water purification (actor Volvo Trucks, Umeå)	$f_{w1,4\text{-}5}$	Water	11,647 m^3
	$f_{r1,5}$	Electricity	14,850 kWh
	$f_{e1,5}$	$CO_{2,eq}$	668 kg
6. Municipal water treatment (actor Kretslopp & Vatten)	$f_{w1,3\text{-}6}$	Water	1,625 m^3
	$f_{r1,6}$	Electricity	650 kWh
	$f_{r9,6}$	Precipitation chemical	10 kg
	$f_{r14,6}$	Chlorine	0.16 kg
	$f_{r15,6}$	Activated carbon	6.8 kg
	$f_{e1,6}$	$CO_{2,eq}$	29 kg
7. Private water purification (actor Volvo Trucks, Gothenburg)	$f_{w1,6\text{-}7}$	Water	1,235 m^3
	$f_{r1,7}$	Electricity	1,575 kg
	$f_{e1,7}$	$CO_{2,eq}$	71 kg

The water use stages were modelled based on available information from Volvo Trucks (Volvo Trucks Umeå, 2012, Volvo Trucks Gothenburg, 2012 and Lindskog, 2012). Available data from the Umeå site was more complete than data from the Gothenburg site. When data were missing for the Gothenburg site, relevant assumptions were made to fill the gaps, e.g. that use of chemicals, per treated m^2 of surface area, in degreasing and phosphating were the same at both sites. The dataset of the water use stages is summarized in Table 5.5. The wastewater treatment stages were modelled based on different available data sources. Volvo Trucks' own wastewater treatment at the Umeå production site was modelled based on data from Volvo Trucks (Volvo Trucks Umeå, 2012 and Lindskog, 2012), while the wastewater treatment of Stena Recycling was modelled by a combination of data from Stena Recycling and Volvo Trucks (Axell, 2012, Volvo Trucks Gothenburg, 2012 and Lindskog, 2012). The dataset of the water use stages is summarized in Table 5.6.

Reduction of pollutants over the wastewater treatment processes for the modelled components of the wastewater are:

- COD 90% reduction
- Ni 98% reduction
- Zn 99% reduction
- P 99% reduction

Table 5.5. Inventory of flows for the Water Use stages, representative of one year

SEAT Stage	Symbol	Resource	Quantity
8. Water use, (actor Volvo Trucks, Umeå)	$f_{w1,2\text{-}8}$	Water	381.00 m^3
	$f_{w1,4\text{-}8}$	Water	3,150 m^3
	$f_{w1,5\text{-}8}$	Water	9,900 m^3
	$f_{r1,8}$	Electricity	2,790,000 kWh
	$f_{r2,8}$	District heating	3,810,000 kWh
	$f_{r3,8}$	Chem. for degreasing	22,800 kg
	$f_{r4,8}$	Chem. for phosphating	54,000 kg
	$f_{r5,8}$	P in chem.	1,701 kg
	$f_{r6,8}$	Ni in chem.	398 kg
	$f_{r7,8}$	Zn in chem.	1,671 kg
	$f_{r8,8}$	Coagulation agent	40,800 kg
	$f_{e1,8}$	$CO_{2,eq}$	483,690 kg
	$f_{e2,8\text{-}10}$	COD (in WW)	133,296 kg
	$f_{e3,8\text{-}10}$	P (in WW)	342 kg
	$f_{e4,8\text{-}10}$	Ni (in WW)	219 kg
	$f_{e5,8\text{-}10}$	Zn (in WW)	117 kg
	$f_{e6,8}$	Sludge (incineration)	168,000 kg
	$f_{e7,8}$	Sludge (landfill)	123,000 kg
	$f_{p1,8\text{-}9}$	Cabins	30,000 psc
9. Water use (actor Volvo Trucks, Gothenburg)	$f_{w1,6\text{-}9}$	Water	390 m^3
	$f_{w1,7\text{-}9}$	Water	1,050 m^3
	$f_{r1,9}$	Electricity	252,000 kWh
	$f_{r3,9}$	Chem. for degreasing	2,730 kg
	$f_{r4,9}$	Chem. for phosphating	6,600 kg
	$f_{r5,9}$	P in chem.	205 kg
	$f_{r6,9}$	Ni in chem.	48 kg
	$f_{r7,9}$	Zn in chem.	201 kg
	$f_{e1,9}$	$CO_{2,eq}$	11,340 kg
	$f_{e2,9\text{-}11}$	COD (in WW)	405 kg
	$f_{e3,9\text{-}11}$	P (in WW)	43 kg
	$f_{e4,9\text{-}11}$	Ni (in WW)	26 kg
	$f_{e5,9\text{-}11}$	Zn (in WW)	14 kg
	$f_{e6,9}$	Sludge (incineration)	3,900 kg
	$f_{p2,9}$	Trucks	30,000 psc

Table 5.6. Inventory of flows for the Wastewater Treatment stages, representative of one year

SEAT Stage	Symbol	Resource	Quantity
10. Private wastewater treatment (actor Volvo Trucks, Umeå)	$f_{w2,5\text{-}10}$	Wastewater	1,747 m^3
	$f_{w2,8\text{-}10}$	Wastewater	21,519 m^3
	$f_{r1,10}$	Electricity	23,260 kWh
	$f_{r9,10}$	Precipitation chem.	57,000 kg
	$f_{r10,10}$	Chem. for pH adjustment	28,800 kg
	$f_{r11,10}$	Chem. for flocculation	201 kg
	$f_{e1,10}$	$CO_{2,eq}$	1,047 kg
	$f_{e2,10}$	COD	13,330 kg
	$f_{e3,10}$	P	3.4 kg
	$f_{e4,10}$	Ni	4.4 kg
	$f_{e5,10}$	Zn	1.2 kg
	$f_{e6,10}$	Sludge (landfill)	57,000 kg
11. Private wastewater treatment (actor Stena Re-cycling)	$f_{w2,9\text{-}11}$	Wastewater	1,440 m^3
	$f_{r1,11}$	Electricity	1,439 kWh
	$f_{r9,11}$	Precipitation chem.	6,900 kg
	$f_{e1,11}$	$CO_{2,eq}$	65 kg
	$f_{e2,11}$	COD	41 kg
	$f_{e3,11}$	P	0.43 kg
	$f_{e4,11}$	Ni	0.53 kg
	$f_{e5,11}$	Zn	0.14 kg
	$f_{e6,11}$	Sludge (landfill)	6,600 kg

5.2.2 Economic data

The economic value of the final product of the modelled system was set to 10,000 €/truck which is 10% of the approximate selling price of a complete truck. That is a rough estimate of how much of the value can be attributed to the water using surface treatment processes included in the model. It is not crucial to get this value as close to the true value as possible, since the basis in our forthcoming scenario evaluations will be to assume the same quality of the final product and thus the same economic value of the product.

All specific costs of services and supplier products used in the model have been normalised before reported in Tables 5.7 to 5.9. The actual costs used in the model cannot be reported here due to confidentiality agreements between Volvo Trucks and its suppliers.
Water services in the system are the supply of municipal water to Volvo Trucks and the treatment of wastewater from Volvo Trucks, Gothenburg, by Stena Recycling. The relative (normalised) costs for water services are presented in Table 5.7 (UMEVA web, 2012, and Lindskog, 2012).

Table 5.7. Normalised **c**ost of water services to Volvo Trucks in CS8

Service	Cost (normalised)	Provider
Water supply	0.13 €/m^3	UMEVA
Water supply	0.12 €/m^3	Kretslopp & Vatten
Wastewater treatment	10 €/m^3	Stena Recycling

Costs of resources to Volvo Trucks are based on information from the company (Lindskog, 2012). Costs of resources to other actors in the system are based on information available on the web and assumptions. The normalized costs of resources are presented in Table 5.8.

Table 5.8. Normalised **c**ost of resources in CS8

Resource	Price (normalised)
Activated carbon	0.17 €/kg
Chemical for flocculation	0.13 €/kg
Chemical for pH adjustment	0.08 €/kg
Chemicals for phoshpating	0.13 €/kg
Chlorine	0.08 €/kg
Degreasing agent	0.17 €/kg
District heating	0.0067 €/kWh
Dolomite	0.008 €/kg
Electricity	0.008 €/kWh
Precipitation chemicals (water work)	0.13 €/kg
Precipitation chemicals (WWTP)	0.13 €/kg
Sand	0.008 €/kg

In Sweden there are no costs associated with emissions to water, unless the company is fined for exceeding its granted emission limits. The normal emissions to water by the actors in CS8 are well below limits (Volvo Trucks Umeå, 2012, Volvo Trucks Gothenburg, 2012 and Axell, 2012) so the modelled cost for such emissions are set to 0. Costs for sludge disposal are based on information from Volvo Trucks (Lindskog, 2012). Costs for disposal of used sand and dolomite in the water work are based on assumptions. The normalised costs for disposal of sludge, used sand and used dolomite are presented in Table 5.9.

Table 5.9. Normalised **c**ost of sludge, sand and dolomite disposal in CS8

“Emission”	Cost (normalised)
Phosphating sludge (hazardous)	0.017 €/kg
Sludge from painting process	0.0042 €/kg
Other sludge	0.0067 €/kg
Used sand	0.008 €/kg
Used dolomite	0.008 €/kg

Costs of operation and maintenance are a combination of man hours and other fixed costs not covered by the use of resources reported above. Specific information was collected from Volvo Trucks (Lindskog, 2012), while operation and maintenance costs for the other actors are based on assumptions. The estimated total annual O&M costs of UMEVA, Vatten & Kretslopp and Stena Recycling are also allocated to the studied system as the Volvo Trucks' share of the actors' total water production and wastewater treatment respectively (UMEVA, 2012, Wikipedia, 2013, Stena Recycling, 2012). The costs of operation and maintenance used for modelling are presented in Table 5.10.

Table 5.10. Cost of operation and maintenance in CS8

Stage	Actor	Fixed costs (O&M), €/year
Abstraction 1	UMEVA	1.6
Abstraction 2	Volvo Trucks, Umeå	1,920
Abstraction 3	Kretslopp & Vatten	0.05
Treatment 1	UMEVA	7.9
Treatment 2	Volvo Trucks, Umeå	2,200
Treatment 3	Kretslopp & Vatten	0.25
Treatment 4	Volvo Trucks, Gothenburg	2,200
Water use, Umeå	Volvo Trucks, Umeå	60,040
Water Use, Gbg	Volvo Trucks, Gothenburg	24,010
WW treatment 1	Volvo Trucks, Umeå	42,000
WW treatment 2	Stena Recycling	1,323

5.3 Environmental performance

Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project (EcoWater, 2013a), 10 impact categories are selected as the most representative for the environmental assessment of the system. The characterization factors, which were used for the estimation of the impact of the foreground systems and the environmental impact factors for the background process are presented in Table 5.11 and Table 5.12. The environmental impact factors are obtained from open access databases. Open access data was not possible to obtain for all background processes. For that reason, no background data were included for the following processes.

- Activated carbon production
- Precipitation chemicals production
- Dolomite production
- pH adjustment chemicals production
- Coagulation chemicals production
- Flocculation chemicals production

The indicator "Freshwater Resource Depletion" requires a value on the Water Exploitation Index, WEI. The average WEI for Sweden is low compared to other European countries (EEA, 2012). As the system of CS8 contains two rivers of separate river basins, two different WEIs are required. The following values reported to EEA (Vanneuville et al, 2012) were used:

- $WEI_{river\ Ume}$ = 0.4% (River Basin District SE1)
- $WEI_{river\ Gota}$ = 2% (River Basin District SE5)

However, since the freshwater resource depletion indicator refers to the foreground river basin, only foreground impacts are calculated.

Table 5.11. Environmental Impact Factors for Background Processes

Impact Category	Unit	Degreasing Chem. (per kg)	Phosphating Chem. (per kg)	Electricity (per kWh)	District Heating (per kWh)	Chlorine (per kg)	Sand (per kg)
Climate Change	kg $CO_{2,eq}$	0.9311	1.25	0.045	0.106	1.136	1.48E-05
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.00232	0.0042	6.44E-07	1.81E-05	3.60E-04	1.32E-08
Acidification	kg $SO_2^{-}{}_{,eq}$	0.00316	0.0166	1.20E-04	1.13E-04	8.58E-03	1.14E-05
Human Toxicity	kg 1,4-$DB_{,eq}$	N/A	N/A	3.89E-03	N/A	0.009	0.00019
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	N/A	N/A	1.20E-04	N/A	3.64E-04	0.216
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	N/A	N/A	6.90E-05	N/A	0.019	2.41E-06
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	5.5E-4	0.0012	5.97E-06	5.92E-06	3.42E-04	5.16E-07
Abiotic Resource Depletion	kg $Sb_{,eq}$	N/A*	N/A*	3.05E-4	N/A	0.00603	1.16E-12
Stratospheric Ozone Depletion	kg CFC-$11_{,eq}$	3.23E-7	2.55E-7	1.78E-7	1.29E-9	N/A	3.83E-10

Note

*****Data for electricity, chlorine and sand production are obtained from ELCD database (ELCD, 2013) and for chemicals production and district heating from Bergek (2012).

**Mineral resource depletion from use of degreasing and phosphating chemicals are reported in Table 5.12

.

Table 5.12. Characterization Factors of Foreground Elementary Flows (Guinee et al, 2001**)**

Impact Category	Unit	COD (per kg)	Ni (per kg)	P (per kg)	Zn (per kg)
Climate Change	kg $CO_{2,eq}$	-	-	-	-
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.022	-	3.1	-
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-
Human Toxicity	kg 1,4-$DB_{,eq}$	-	331.1	-	0.584
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	-	3,237.6	-	91.7
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	-	-	-	-
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	-	-
Abiotic Resource Depletion	kg $Sb_{,eq}$	-	1.08E-4	8.44E-5	9.92E-4
Stratospheric Ozone Depletion	kg CFC-$11_{,eq}$	-	-	-	-

Note: The characterization factors of Nickel, Phosphorus and Zinc for "Minerals Depletion indicator" refer to the amount of these resources included in the chemicals used (as part of the Background processes), while the factors for the other indicators refer to the respective quantities in the wastewater (as part of the Foreground Elementary Flows).

Table 5.13. Environmental indicators results for CS8 baseline scenario assessment

Environmental indicator	Unit	Value*
Climate Change	t $CO_{2,eq}$	652
Ozone Depletion	kg CFC-$11_{,eq}$	0.62
Eutrophication	kg PO_4^{-3}	691
Acidification	kg $SO_2^{-}{}_{,eq}$	1,910
Human Toxicity	kg 1,4-$DB_{,eq}$	14,500
Freshwater Aquatic Ecotoxicity	kg 1,4-$DB_{,eq}$	16,400
Terrestrial Ecotoxicity	kg 1,4-$DB_{,eq}$	228
Photochemical Ozone Formation	kg$C_2H_{4,eq}$	129
Freshwater Resource Depletion	m^3	1,660
Abiotic Resource Depletion	kg $Sb_{,eq}$	1,010

*Rounded to three digits.

The results of the environmental impacts of the entire system and of the contribution of the background and foreground processes into the system are presented in Table 5.13 and Figure 5.4. The results on environmental indicators are presented as percentage per stage in Figures 5.5 to 5.7.

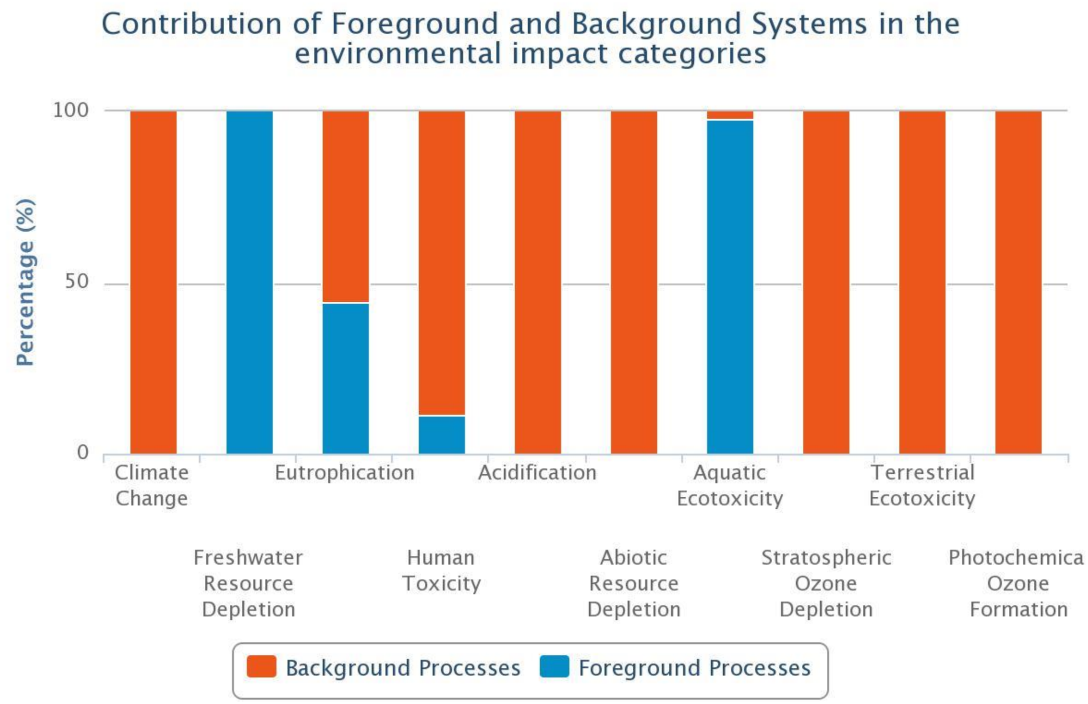

Figure 5.4. Contribution of Foreground and Background Systems in the environmental impact categories

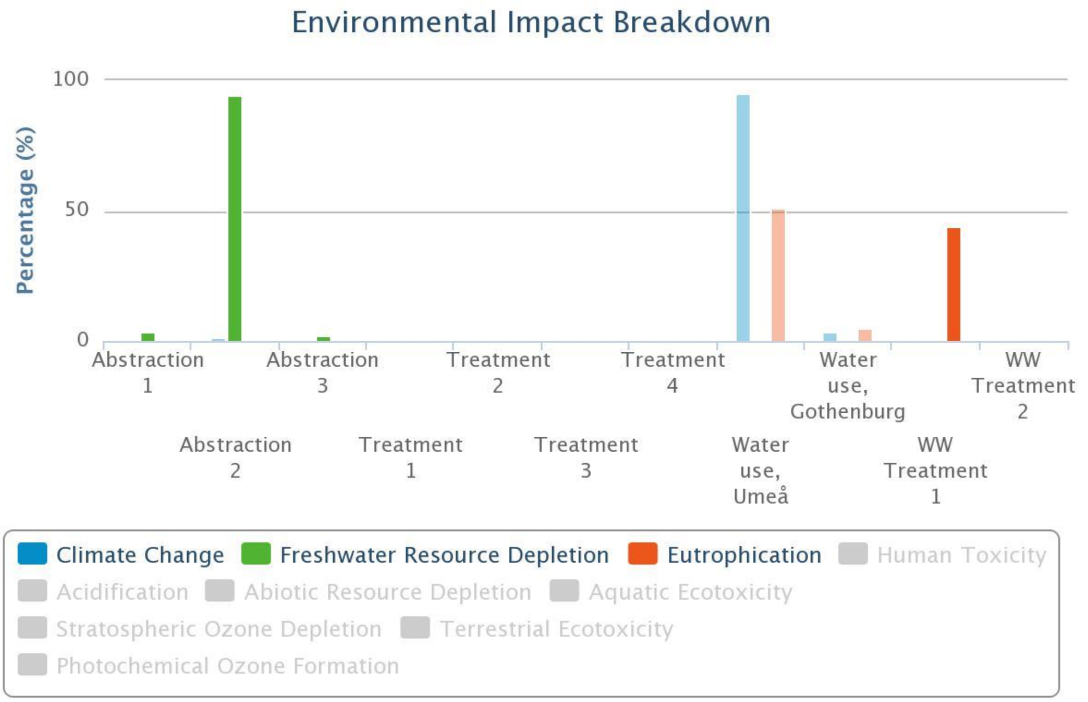

Figure 5.5. Environmental Impact Breakdown, percentage per stage (1/3). Solid bars represent the foreground system and transparent bars the background system

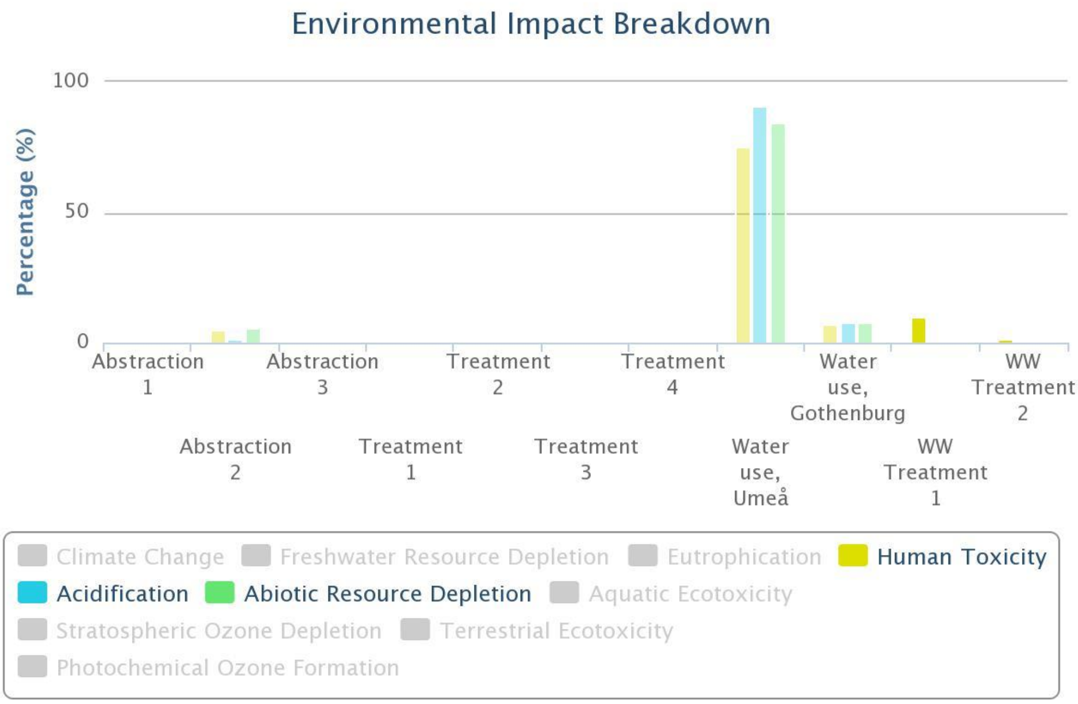

Figure 5.6. Environmental Impact Breakdown, percentage per stage (2/3). Solid bars represent the foreground system and transparent bars the background system.

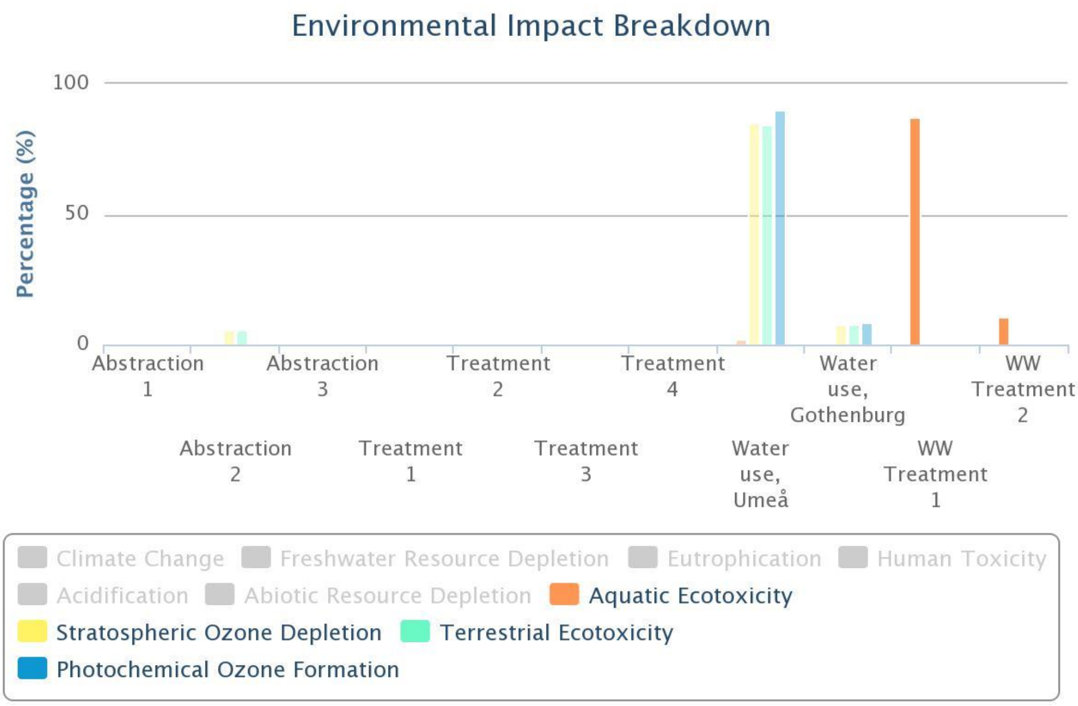

Figure 5.7. Environmental Impact Breakdown, percentage per stage (3/3). Solid bars represent the foreground system and transparent bars the background system.

5.4 Economic performance

Table 5.14 summarizes the economic performance assessment of the studied system. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 298,889,872 € (which is 9,963 €/truck).

Table 5.14. Economic performance results (all results are in €)

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
UMEVA	2,081	0	22,196	20,114
Kretslopp & Vatten	176	0	2,275	2,100
Volvo Trucks	1,095,526	300,000,000	-197,271	298,707,203
Stena Recycling	12,345	0	172,800	160,455
			Total Value Added:	298,889,872

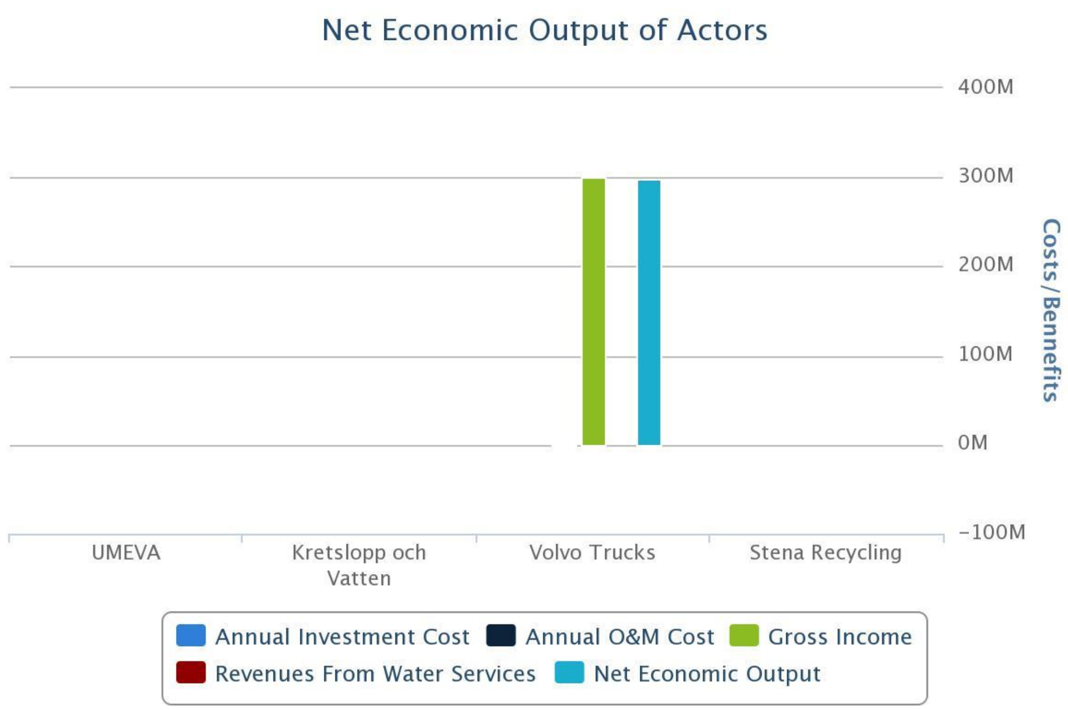

Figure 5.8. Economic Performance per Actor

5.5 Eco-efficiency indicators

The eco-efficiency indicators are estimated from the results of environmental and value assessment presented above. Table 5.15 summarizes the values of the eco-efficiency indicators, corresponding to the 10 relevant environmental impact categories.

Table 5.15. Eco-efficiency indicators

Environmental indicator	Unit	Value*
Climate Change	€/t $CO_{2,eq}$	458,000
Stratospheric Ozone Depletion	€/g CFC-$11_{,eq}$	485,000,000
Eutrophication	€/kg $PO_4^{-3}{}_{,eq}$	433,000
Acidification	€/kg $SO_2^{-}{}_{,eq}$	156,000
Human toxicity	€/kg 1,4-$DB_{,eq}$	20,700
Freshwater Aquatic Ecotoxicity	€/kg 1,4-$DB_{,eq}$	18,200
Terrestrial Ecotoxicity	€/kg 1,4-$DB_{,eq}$	1,310,000
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	2,320,000
Freshwater Resource Depletion	€/m^3	180,000
Abiotic Resource Depletion	€/g $Sb_{,eq}$	297,000

*Rounded to three digits.

5.6 Conclusions

The net economic output of the industrial actor is completely dominating the total NEO of the system, due to the high value of the product compared to the low costs associated with water services and O&M.

The environmental impacts are also dominated by the industrial actor. The results show that Volvo Trucks is the main contributor to all environmental indicators except for the Freshwater Resource Depletion, in particular the Umeå site.

Although the impact on freshwater resource depletion comes from the Water Abstraction stages, the industrial need for water is the driving force of abstraction. The minimal water losses on the way to industry mean that the search for water saving technologies should be made within the industrial water use.

It should also be remembered that the impacts of the Wastewater Treatment stage are due to the activities in the Water Use stage, which are polluting the wastewater. The wastewater treatment stage is actually making a considerable reduction of the system's total environmental impact compared to the case where the wastewater was released directly to the recipient from the Water Use stage.

Resource depletion of the elements P, Ni and Zn corresponds to at least the amounts present in the chemicals. The calculation of the indicator does not account for efficiency in refining of the used elements, although it is very likely that there is a loss of elementary resources between extraction from nature to the final chemical used at Volvo Trucks.

It seems clear that new technologies of interest are those that can be implemented at Volvo Trucks in order to:

- Reduce water use, which will also reduce use of electricity for pumping in the whole system,
- Reduce energy used for heating,
- Reduce the use of scarce elements in chemicals,
- Reduce the use of elements that become toxic pollutants in the wastewater,
- Reduce the use elements that become nutrients in the wastewater, causing eutrophication.

6 Concluding remarks

Tables 6.1 and 6.2 present the comparison of the environmental performance and the eco-efficiency indicators of the four industrial Case Studies, respectively. Due to the different products and the diverse group for processes that belong to the water use stage, the absolute values of the environmental indicators are not easily comparable. However, they give a first indication, about the main environmental problems of each area (e.g. Freshwater Aquatic Ecotoxicity and Terrestrial Ecotoxicity in Case Study #5, Fossil Fuel Depletion in Case Study #6 and Acidification in Case Study #7).

All the above conclusions are confirmed from the eco-efficiency indicators presented in Table 6.2. First of all, it should be noted that the Automotive Industry seems to be the most eco-efficient industrial unit between the four examined Case Studies. Although, this may be true, it should be noted that the automotive industry has the higher valued product, which increases significantly both the TVA from water use and the respective eco-efficiency indicators.

The textile industry shows very low eco-efficiency values in the following three impact categories:

- Human Toxicity
- Freshwater Aquatic Ecotoxicity
- Terrestrial Ecotoxicity

This is due to the heavy metals and the other toxic pollutants released from the standard chemical dyeing industry. Furthemore, this Case Study has the lowest value in the freshwater resource depletion indicator, which is result of both the water intensive processes and the high (compared to the other Case Studies) Water Stress Index of the region.

The energy industry has a very low value for the fossil fuel depletion, which is something expected since the natural gas is the main productive input of the plant. The other main environmental issue, the thermal pollution is unique for this case study and is not highlighted through these comparative tables.

Finally, the dairy industry has the lowest values in climate change, acidification and eutrophication. However, only the first one is due to the foreground system, while the other two have a low value mainly due to the milk production processes (which are part of the background system)

Concerning the economic performance, the water use stage is the dominating stage/actor in the water value chain. Based on the identification of the environmentally and economically weak stages and actors, each CS will proceed with the selection and assessment of innovative technologies towards the eco-efficiency improvement of the system.

Table 6.1. Environmental Performance Indicators for the Industrial Case Studies

Indicator	Unit	CS#5	CS#6	CS#7	CS#8
Climate Change	t CO2,eq	1,268	958,407	953,033	652
Stratospheric Ozone Depletion	kg CFC-11$_{,eq}$	-	-	-	0.62
Eutrophication	kg $PO_4^{-3}$$_{,eq}$	386	357,392	70,653	691
Acidification	kg $SO_2^{-}$$_{,eq}$	5,268	1,597	9,519,103	1,910
Human Toxicity	kg 1,4-DB$_{,eq}$	219,531	8,946,557	709,014	14,500
Freshwater Aquatic Ecotoxicity	kg 1,4-DB$_{,eq}$	1,464,321	371,762	24,449	16,400
Terrestrial Ecotoxicity	kg 1,4-DB$_{,eq}$	14,446,079	218,653	42,270	228
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	263	158,135	4,743	129
Abiotic Resource Depletion	kg $Sb_{,eq}$	9,032	-	-	1,010
Fossil Fuels Depletion	GJ	-	14,767,931	-	-
Freshwater Resource Depletion	m^3	15,450	-	52,958	1,660

Table 6.2. Eco-efficiency Indicators for the Industrial Case Studies

Indicator	Unit	CS#5	CS#6	CS#7	CS#8
Climate Change	€/t$CO_{2,eq}$	551	110	66	458,000
Stratospheric Ozone Depletion	€/kg CFC-11$_{,eq}$	-	-	-	485,000,000
Eutrophication	€/kg$PO_4^{-3}$$_{,eq}$	1,812	329	2.12	433,000
Acidification	€/kg$SO_2^{-}$$_{,eq}$	133	61.226	6.87	156,000
Human Toxicity	€/kg1,4-DB$_{,eq}$	3.18	23.1	61	20,700
Freshwater Aquatic Ecotoxicity	€/kg1,4-DB$_{,eq}$	0.48	1,056	1,579	18,200
Terrestrial Ecotoxicity	€/kg1,4-DB$_{,eq}$	0.05	3,836	1,349	1,310,000
Photochemical Ozone Formation	€/kg$C_2H_{4,eq}$	2,657	773	7,003	2,320,000
Abiotic Resource Depletion	€/kg$Sb_{,eq}$	77	-	-	297,000
Fossil Fuels Depletion	€/MJ	-	0.02	-	-
Freshwater Resource Depletion	€/m^3	45	-	1,220	180,000

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