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Technology assessment and scenario analysis

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Abstract

Deliverable 4.4 presents results of the work undertaken during the third phase of the Case Study Development progress and the third 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 presented in Deliverable 4.2 based on the Value Chain Mapping of the four Case Studies, presented in Deliverable 4.1.- Technologies for upgrading the value chains were presented in Deliverable 4.3.

The task of calculating the environmental and economic performance indicators with the identified technologies proved to be more difficult and time consuming than expected for all four Case Studies and in particular for Case Study 6.

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 some of the systems, without, however, affecting their meso-level characteristics.

The assessment of innovative technologies and scenarios showed that:

- The water use stages were the dominant contributors to both the total value added and the environmental impacts of the industrial water value chains studied;
- The technologies which result in an increased eco-efficiency in the water value chain are sector specific;
- Combinations of technologies (scenarios) provide more eco-efficient solutions than single technologies;
- Eco-innovative solutions were identified- with significant improvements in environmental performance and smaller improvements in economic performance;
- Economic performance was primarily improved for the industries- while suppliers of water and energy experienced losses;
- As a more general observation from the dialogue with the industries during the analysis we learned that industries understand “business cases and rate of return of investment”. However, there is need to be educated on the use of eco-efficiency and total value added in decision making.

Contents

1 Introduction 15

2 Case Study #5 Textile Industry in Biella 16

- 2.1 Finalized baseline scenario assessment 16
  - 2.1.1 System and Boundaries 16
  - 2.1.2 Baseline Scenario Assessment 17
  - 2.1.3 Objectives for the introduction of innovative technologies 20
- 2.2 Individual assessment of innovative technologies 20
  - 2.2.1 Smart pumping systems 20
  - 2.2.2 Automatic Dye Dispensing Systems 22
  - 2.2.3 Low-Liquor-ratio jet dyeing 23
  - 2.2.4 Use of Natural Dyes 24
  - 2.2.5 Advanced oxidation processes 25
  - 2.2.6 Membrane Bioreactor 26
  - 2.2.7 Overall individual technology eco-efficiency assessment 28
- 2.3 Assessment of Technology Scenarios 29
  - 2.3.1 Technology scenario focusing on resource efficiency 29
  - 2.3.2 Technology scenario focusing on pollution prevention 30
  - 2.3.3 Overall eco-efficiency assessment 30
- 2.4 Policy Recommendations 31

3 Case Study #6 Cogeneration of electricity and heat 32

- 3.1 Introduction 32
- 3.2 Background 33
  - 3.2.1 Case study description 33
  - 3.2.2 Combined Heat Power generating systems 34
- 3.3 District heating systems 34
- 3.4 Finalized baseline scenario assessment 36
  - 3.4.1 System and Boundaries 36
  - 3.4.2 Baseline Scenario Assessment 41
  - 3.4.3 Objectives for the introduction of innovative technologies 49
- 3.5 Individual assessment of innovative technologies 49
  - 3.5.1 BAU without heat buffer 49
  - 3.5.2 BAU without heat buffer and without heat-only boilers 53
  - 3.5.3 Retrofitting 50000 homes 56
  - 3.5.4 Insulating 50000 retrofitted homes 58
  - 3.5.5 Pre-heating potable water 61
  - 3.5.6 Implementing micro-CHP 63
- 3.6 Assessment of Technology Scenarios 67

3.6.1 Technology scenario focusing on resource efficiency 67
3.6.2 Technology scenario focusing on pollution prevention.................... 68
3.6.3 Overall eco-efficiency assessment discussion 69
3.7 Conclusions and policy Recommendations... 70
4 Case Study #7 Dairy industry 72
4.1 Finalized baseline scenario assessment.. 73
4.1.1 Systems boundaries and functional unit... 73
4.1.2 Baseline scenario assessment 75
4.1.3 Objectives for the introduction of innovative technologies............... 77
4.2 Individual assessment of innovative technologies............................... 77
4.2.1 Anaerobic digestion 77
4.2.2 Advanced oxidation and UV treatment 79
4.2.3 Product and water recovery in Cleaning in Place system 80
4.2.4 Cleaning and reuse of condensate... 82
4.2.5 More efficient diffusors in the waste water treatment plant 83
4.2.6 Increased loading capacity of trucks 84
Technology assessment 84
4.2.7 Overall assessment of individual technologies................................ 86
4.3 Assessment of Technology Scenarios 86
4.3.1 Anaerobic digester combined with advanced oxidation................... 87
4.3.2 Anaerobic digester combined with advanced oxidation and product and water recovery.. 88
4.3.3 Product and water recovery combined with cleaning and reuse of condensate... 89
4.3.4 Advanced oxidation combined with cleaning and reuse of condensate... 90
4.3.5 Overall assessment of technology scenarios 91
4.4 Policy recommendations 92
5 Case Study #8: Automotive Industry 94
5.1 Finalized baseline scenario assessment... 94
5.2 Individual assessment of innovative technologies............................... 97
5.2.1 Membrane distillation.. 98
5.2.2 Electro-Deionisation 100
5.2.3 Silane-based metal surface treatment... 102
5.2.4 Recirculation of process water and chemicals 105
5.3 Assessment of Technology Scenarios 107
5.3.1 Technology scenario focusing on resource efficiency 107
5.3.2 Technology scenario focusing on pollution prevention.................. 109
5.3.3 Technology scenario promoting circular economy 111
5.4 Policy Recommendations Automotive industry 113

6 Conclusions 115
7 References 116

List of Figures

Figure 2-1. Schematic representation of the examined system 17

Figure 2-2. Individual eco-efficiency assessment of the six selected technologies .. 28

Figure 2-3. Economic performance assessement of technologies per actor 28

Figure 2-4. Eco-efficiency assessment of the alternative technology scenarios 30

Figure 3-1. Case study area... 33

Figure 3-2. Combined Heat Power plat schematics. 34

Figure 3-3. City thermal energy network Amsterdam. 35

Figure 3-4. Water use service system of the case study. 36

Figure 3-5. Stages in the Cogeneration Case Study (Focus on business as usual). 37

Figure 3-6. SEAT model of the cogeneration case study. 39

Figure 3-7. Spider diagram of the relative athmospheric pollution (unit circle concerns the heat only boiler).. 45

Figure 3-8. Distribution of environmental impact over foreground and background (BAU) 47

Figure 3-9. Distribution of environmental impact over stages 48

Figure 3-10. Distributional effects of costs and benefits (BAU)................................ 48

Figure 3-11. Distributional effects of costs and benefits: BAU and BAU without heat buffer. 51

Figure 3-12. Graphical representation of the eco-efficiency of BAU and BAU without the thermal energy buffer eco-efficiency. “- B” depicts environmental pressures resulting from background processes. 52

Figure 3-13. Relative difference in environmental performance for two months for the BAU and the BAU minus Heat only boilers minus buffer scenario........................... 53

Figure 3-14. Distributional effects of costs and benefits: BAU, BAU without thermal buffer and BAU without thermal buffer and without heat-only boilers. 55

Figure 3-15. Graphical representation of the eco-efficiency of BAU and BAU without the thermal energy buffer eco-efficiency and without the heat-only buffer. “- B” depicts environmental pressures resulting from background processes. 55

Figure 3-16. Distributional effects of costs and benefits: BAU and 50000 retrofitted houses.. 57

Figure 3-17. Graphical representation of the eco-efficiency of BAU and 50000 retrofitted houses. “- B” depicts environmental pressures resulting from background processes.. 58

Figure 3-18. Distributional effects over actors of BAU and BAU plus 50000 retrofitted and insulated homes. 60

Figure 3-19. Graphical representation of the eco-efficiency of BAU, 50000 retrofitted houses, and 50000 retrofitted and insulated houses. “- B” depicts environmental pressures resulting from background processes. 60

Figure 3-20. Distributional effects over actors of BAU and BAU plus potable water preheating. 62

Figure 3-21. Graphical representation of the eco-efficiency of BAU and potable water preheating. “- B” depicts environmental pressures resulting from background processes. 63

Figure 3-22. Distributional effects over actors of BAU and BAU plus 25000 retrofitted houses and 25000 mCHP. 65

Figure 3-23. Graphical representation of the eco-efficiency of BAU and potable water preheating. “- B” depicts environmental pressures resulting from background processes. 66

Figure 3-24. Environmental performance versus economic performance for BAU without thermal buffer and heat only boilers, compared to the BAU which is the origin. 68

Figure 3-25. Environmental performance versus economic performance for 50000 retrofitted and insulated houses compared to the BAU which is the origin. 69

Figure 4-1. Location of dairies in Denmark showing also the dairy studies 72

Figure 4-2. Water, energy and waste water discharge and milk equivalents 73

Figure 4-3. (a + b) Schematic representation of the foreground and background systems including the processes and the involved actors of the water-use-system. 74

Figure 5-1. System overview, Case Study 8, colour coded by actor. 94

Figure 5-2. Environmental impact breakdown over stages. Transparent bars represent background impact. 97

Figure 5-3. Technology implementation overview. Implementation of Membrane distillation is individually assessed at both industrial sites. 98

Figure 5-4. Eco-efficiency indicators for the Membrane distillation technology implemented at Volvo Trucks, Umeå and Tuve. (Values are normalized to Baseline = 1) 100

Figure 5-5. Eco-efficiency indicators for the Electro-deionisation technology implemented at Volvo Trucks, Umeå. (Values are normalized to Baseline = 1) 101

Figure 5-6. Eco-efficiency indicators for the Silane-based metal surface treatment technology implemented at Volvo Trucks, Tuve. (Values are normalized to Baseline = 1) 104

Figure 5-7. Eco-efficiency indicators for Recirculation implemented at Volvo Trucks, Umeå. (Values are normalized to Baseline = 1) 106

Figure 5-8. Eco-efficiency indicators for the technology scenario on Resource efficiency. (Values are normalized to Baseline = 1) 107

Figure 5-9. Resource efficiency technology scenario with environmental impact breakdown over stages. Transparent bars represent background impact. 108

Figure 5-10. Eco-efficiency indicators for the technology scenario on Pollution prevention. (Values are normalized to Baseline = 1) 110

Figure 5-11. Pollution prevention technology scenario with environmental impact breakdown over stages. Transparent bars represent background impact. 110

Figure 5-12. Eco-efficiency indicators for the technology scenario on Circular economy. (Values are normalized to Baseline = 1) 112

Figure 5-13. Circular economy technology scenario with environmental impact breakdown over stages. Transparent bars represent background impacts. 112

List of Tables

Table 2-1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario 19

Table 2-2. Comparison of the environmental performance between the two units for the baseline scenario 19

Table 2-3. Financial costs of the two industrial units 20

Table 2-4. Baseline eco-efficiency assessment 20

Table 2-5. Environmental performance assessment for smart pumping systems 21

Table 2-6. Economic performance assessment for smart pumping systems (Values in €) 21

Table 2-7. Eco-efficiency assessment for smart pumping systems 21

Table 2-8. Environmental performance assessment for automatic dispensing systems 22

Table 2-9. Economic performance assessment for automatic dispensing systems (Values in €) 22

Table 2-10. Eco-efficiency assessment for automatic dispensing systems 23

Table 2-11. Environmental performance assessment for LLR jet dyeing machines . 23

Table 2-12. Economic performance assessment for LLR jet dyeing machines (Values in €) 24

Table 2-13. Eco-efficiency assessment for LLR jet dyeing machines 24

Table 2-14. Environmental performance assessment for natural dyes 24

Table 2-15. Economic performance assessment for natural dyes (Values in €) 25

Table 2-16. Eco-efficiency assessment for natural dyes 25

Table 2-17. Environmental performance assessment for advanced oxidation process 26

Table 2-18. Economic performance assessment for advanced oxidation process (Values in €) 26

Table 2-19. Eco-efficiency assessment for advanced oxidation process 26

Table 2-20. Environmental performance assessment for mebrane bioreactor 27

Table 2-21. Economic performance assessment for membrane bioreactor (values in €) 27

Table 2-22. Eco-efficiency assessment for membrane bioreactor 27

Table 2-23. Alternative technology scenarios 29

Table 2-24. Environmental performance assessment of RE Scenario 29

Table 2-25. Environmental performance assessment of PP Scenario 30

Table 2-26. Net economic output (NEO) of all the involved actors and the total valued added of the system 31

Table 3-1. Stages description in the Cogeneration Case Study 37

Table 3-2. Stages and processes of the SEAT model. 40

Table 3-3. Key input data and assumptions 42

Table 3-4. Explanation to the operational data tables 46

Table 3-5. SEAT input data for the business as usual scenario 46

Table 3-6. Environmental Impacts BAU 47

Table 3-7. Eco-efficiency per midpoint indicator. (*) denotes midpoint indicators predominantly determined by background processes. 49

Table 3-8. SEAT input data for the BAU without heat buffer scenario. 50

Table 3-9. Environmental comparison between BAU and BAU without the thermal energy buffer. (*) denotes midpoint indicators predominantly determined by background processes. 51

Table 3-10. Background electricity demand (GJ). 52

Table 3-11. SEAT input data for the BAU without heat buffer and without heat-only boilers scenario 54

Table 3-12. Environmental comparison between BAU and BAU without the thermal energy buffer. (*) denotes midpoint indicators predominantly determined by background processes. 54

Table 3-13. SEAT input data for the BAU with 50000 retrofitted houses 56

Table 3-14. Environmental comparison between BAU and BAU plus 50000 retrofitted houses. (*) denotes midpoint indicators predominantly determined by background processes. 57

Table 3-15. SEAT input data for the BAU with 50000 retrofitted and insulated houses 59

Table 3-16. Environmental comparison between BAU and BAU plus 50000 retrofitted and insulated homes. 59

Table 3-17. SEAT input data for the BAU with potable water preheating scenario... 61

Table 3-18. Environmental comparison between BAU and BAU plus potable water preheating. 62

Table 3-19. SEAT input data for the BAU with 25000 retrofitted and 25000 micro CHP houses 64

Table 3-20. Environmental comparison between BAU and BAU 25000 retrofitted house and 25000 micro-CHP (mCHP) houses. 65

Table 3-21. Operations of the energy plants D33 and D34. 67

Table 4-1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario 75

Table 4-2. Economic evaluation of the value chain. 76

Table 4-3. Baseline eco-efficiency assessment 76

Table 4-4. Alternative technologies to upgrade the dairy value chain 77

Table 4-5. Environmental impact of baseline and anaerobic digestion (indicators are expressed per kg of milk powder produced) 78

Table 4-6. Net economic output of baseline and anaerobic digestion 78

Table 4-7. Eco-efficiency of baseline and anaerobic digestion 78
Table 4-8. Environmental impact of baseline and advanced oxidation and UV (indicators are expressed per kg of milk powder produced) 79
Table 4-9. Net economic output of baseline and advanced oxidation and UV.......... 80
Table 4-10. Eco-efficiency of baseline and advanced oxidation and UV 80
Table 4-11. Environmental impact of baseline and product and water recovery (indicators are expressed per kg of milk powder produced) 81
Table 4-12. Net economic output of baseline and product and water recovery 81
Table 4-13. Eco-efficiency of baseline and product and water recovery................... 81
Table 4-14. Environmental impact of baseline and cleaning and reuse of condensate (indicators are expressed per kg of milk powder produced) 82
Table 4-15. Net economic output of baseline and cleaning and reuse of condensate 83
Table 4-16. Eco-efficiency of baseline and cleaning and reuse of condensate 83
Table 4-17. Environmental impact of baseline and efficient diffusors 83
Table 4-18. Net economic output of baseline and efficient diffusors......................... 84
Table 4-19. Eco-efficiency of baseline and efficient diffusors 84
Table 4-20. Environmental impact of baseline and increased loading capacity of trucks (indicators are expressed per kg of milk powder produced)........................... 85
Table 4-21. Net economic output of baseline and increased loading capacity of trucks 85
Table 4-22. Eco-efficiency of baseline and increased loading capacity of trucks 85
Table 4-23. Summary of eco-efficiencies of individual technologies......................... 86
Table 4-24. Technology scenarios combining individual technologies 87
Table 4-25. Environmental impact of baseline and combined technologies (indicators are expressed per kg of milk powder produced) 87
Table 4-26. Net economic output of baseline and combined technologies............... 87
Table 4-27. Eco-efficiency of baseline and combined technologies 88
Table 4-28. Environmental impacts of baseline and combined technologies (indicators are expressed per kg of milk powder produced) 88
Table 4-29. Net economic output of baseline and combined technologies............... 88
Table 4-30. Eco-efficiency of baseline and combined technologies 89
Table 4-31. Environmental impact of baseline and combined technologies 89
Table 4-32. Net economic output of baseline and combined technologies............... 89
Table 4-33. Eco-efficiency of baseline and combined technologies 90
Table 4-34. Environmental impact of baseline and combined technologies 90
Table 4-35. Net economic output of baseline and combined technologies............... 90
Table 4-36. Eco-efficiency of baseline and combined technologies 91
Table 4-37. Eco-efficiency assessment of technology scenarios............................. 91
Table 4-38. Net economic output of baseline and combined technologies............... 92

Table 5-1. Baseline environmental performance of the Volvo Trucks Case Study... 95

Table 5-2. Baseline economic performance (in €) of the Volvo Trucks Case Study. 96

Table 5-3. Baseline eco-efficiency of the Volvo Trucks Case Study. 96

Table 5-4. Values used for assessment of Membrane distillation. 99

Table 5-5. Environmental impact results for Membrane distillation. 99

Table 5-6. Economic performance results for Membrane distillation. Net Economic Output per actor and the Total Value Added. 99

Table 5-7. Eco-efficiency results for Membrane distillation. 100

Table 5-8. Values used for assessment of Electro-deionisation. 101

Table 5-9. Environmental impact from Electro-deionisation. 102

Table 5-10. Economic performance results for Electro-deionisation. Net Economic Output per actor and the Total Value Added. 102

Table 5-11. Eco-efficiency results for Electro-deionisation. 102

Table 5-12. Values used for assessment of Silane-based metal surface treatment. 103

Table 5-13. Environmental impact from Silane-based surface treatment. 104

Table 5-14. Economic performance results for Silane-based surface treatment. Net Economic Output per actor and the Total Value Added. 104

Table 5-15. Eco-efficiency results for Silane-based metal surface treatment. 105

Table 5-16. Values (for the degreasing process) used for assessment of Recirculation of process water and chemicals 106

Table 5-17. Environmental impact from Recirculation of process water and chemicals. 106

Table 5-18. Economic performance results for Recirculation of process water and chemicals. Net Economic Output per actor and the Total Value Added. 107

Table 5-19. Eco-efficiency results for Recirculation of process water and chemicals. 107

Table 5-20. Environmental impact of the Resource efficiency scenario. 108

Table 5-21. Economic performance results for the Resource efficiency scenario. Net Economic Output per actor and the Total Value Added. 108

Table 5-22. Economic performance results for the Resource efficiency scenario. Details per actor. 109

Table 5-23. Economic performance per stage, Resource efficiency scenario. 109

Table 5-24. Environmental impact of the Pollution prevention scenario. 110

Table 5-25. Economic performance results for the Pollution prevention scenario. Net Economic Output per actor and the Total Value Added. 111

Table 5-26. Economic performance results for the Pollution prevention scenario. Details per actor. 111

Table 5-27. Economic performance per stage, Pollution prevention scenario. 111

Table 5-28. Environmental impact of the Circular economy scenario. 112

Table 5-29. Economic performance results for the Circular economy scenario. Net Economic Output per actor and the Total Value Added. 113

Table 5.30. Economic performance results for the Circular economy scenario. Details per actor. 113

Table 5-31. Economic performance per stage, Circular economy scenario. 113

1 Introduction

Deliverable 4.4 presents results of the work undertaken during the third phase of the Case Study Development progress and the third 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 presented in Deliverable 4.2 based on the Value Chain Mapping of the four Case Studies, presented in Deliverable 4.1.- Technologies for upgrading the value chains were presented in Deliverable 4.3

The task of calculating the environmental and economic performance indicators with the identified technologies proved to be more difficult and time consuming than expected for all four Case Studies and in particular for Case Study 6,

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 some of the systems, without, however, affecting their meso-level characteristics.

The results of the eco-efficiency assessment of technologies and policy recommendations are shown for each of the cases in chapter 2 (textile industry), chapter 3 (co-generation of thermal energy and electricity), chapter 4 (dairy industry), chapter 5 (automotive industry). Chapter 6 concludes on the results of the eco-efficiency assessment, identification of eco-innovative technologies and policy recommendations for further uptake of eco-innovative technologies.

2 Case Study #5 Textile Industry in Biella

The Biella district has traditionally been an important wool processing and textile centre. However, during the last decade, the active textile units in Italy have 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.

Textile industry utilizes an extensive amount of freshwater, especially during wet processing operations, such as dyeing, as water is the medium in which dyes, chemicals and dyeing auxiliaries are dissolved. The textile wastewater is rated as the most polluting, considering its volume and composition, among the industrial sector. The generated wastewater includes toxic and stable pollutants, characterised by a significant amount of suspended solids, nutrients, salts, high chemical and biological oxygen demand (COD, BOD), as well as heavy metals and increased colour concentrations. The disposal of these contaminated effluents into receiving water bodies results in environmental problems, influencing the aquatic and terrestrial ecosystem, and even the human health (Chequer, et al., 2013). In the Biella region, the textile industry has a critical impact on the environment, particularly by polluting river waters through process effluents.

On the basis of the above described picture the analysis that follows is mainly focused on the study of the dyeing process. Prospects for improving the system's overall eco-efficiency are investigated. Through the identification of the environmentally weak stages of the system, as well as the selection and implementation of innovative technologies that would upgrade the value chain, two alternative technology scenarios are formulated and compared to the baseline scenario.

2.1 Finalized baseline scenario assessment

2.1.1 System and Boundaries

For the purpose of the analysis, two representative units of the textile industry are considered (Figure 2-1):

- A unit with in-house wastewater treatment plant, where the dyeing process is done by using standard chemical methods (Unit A); and
- A unit which uses both standard chemical dyes and natural herbal dyes (in separate production lines) and is connected to the municipal wastewater network (Unit B).

The studied system is divided into the foreground and the background sub-systems. The foreground system contains two different chains, the water supply and the water use chain. The water supply chain is divided into four stages, namely water abstraction, distribution, use and wastewater treatment. These are defined in such way to enclose the relevant actors involved in the system and the interactions among them. The actors of the system, both directly and indirectly involved, are the following:

- The regional authorities, responsible for the water supply to industry;
- The textile industry, including the chemical and natural dyeing units; and
- The municipalities' consortium, which is responsible for the operation of the wastewater treatment plant and the sewage disposal network.

The background system consists of the production processes of the supplementary resources (electricity and natural gas) and raw materials (dyes, additives, wool). However, only the electricity and natural gas production processes are taken into consideration for the eco-efficiency assessment, due to lack of data for the other processes.

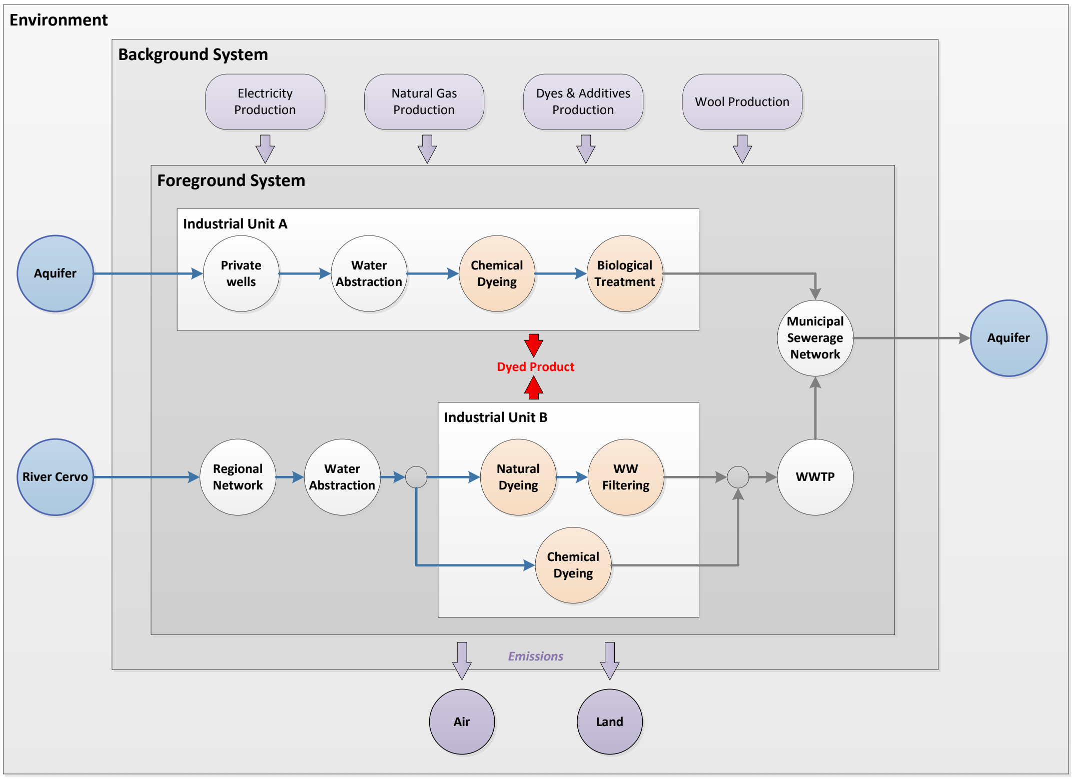

Figure 2-1. Schematic representation of the examined system

The functional unit depends on the reference flow selected each time and the purpose of the analysis. In the current study, two different cases are examined. When the goal is the comparison between the two units, then the flow of interest is the unit of product delivered and the functional unit is defined as 1 kg of dyed product. On the contrary, when alternative technologies are compared, the quantity of interest is the water used for the production purposes and the functional unit is 1 m^3 of water used in the dyeing process.

2.1.2 Baseline Scenario Assessment

Unit A, the standard chemical dyeing unit, has an annual output of 500,000 kg dyed product. For the dyeing process, it is estimated that 1kg of dyes and additives are required, while 1.02 kWh of electricity and 0.64 m^3 of natural gas are consumed per kg of wool. Furthermore, the dyeing process needs 0.15 m^3 of water per kg of wool, which is abstracted from private wells using electric groundwater pumps. The electricity consumption of the pump is estimated at 0.13 kWh per m^3 of water abstracted. Finally, the in-house wastewater treatment plant consumes 0.7 kWh of electricity per m^3 of wastewater treated.

Unit B, the unit with two separate production lines, produces annually 392,000 kg of chemically dyed product and 98,000 kg of naturally dyed product. The requirements of the chemical dyeing production line are the following: 0.32 kg of dyes and additives, 1.44 kWh of electricity, 0.59 m^3 of natural gas and 0.16 m^3 of water per kg of wool. The natural dyeing process requires less electricity (1.27 kWh per kg of wool) but higher quantities of dyes and water (0.5 kg of dyes and 0.19 m^3 of water per kg of wool), while the required amount of natural gas remains the same. In both cases, water is abstracted from Quargnasca Torrent (Cervo River Basin) and is pumped using electricity driven pumps, which consume 0.11 kWh per m^3 of water abstracted.

Unit B also performs a filtering of the wastewater before sending it to the municipality consortium owned wastewater treatment plant. The filtering process consumes electricity (0.55 kWh per m^3 of wastewater treated) and produces solid waste (0.27 kg of sludge from the natural dyeing process per m^3 of wastewater treated).

2.1.2.1 Environmental assessment

The environmental performance of the system is assessed through eight environmental midpoint indicators, representative for the specific system and relevant to the textile industry. The background processes, which are taken into account for the assessment of the environmental impacts, are electricity and natural gas production,as it was not possible to collect data for the other background processes, including wool, dyes and additives production. The characterisation factors included in the CML-IA database are used for the calculation of the environmental impacts of the foreground system, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (Guinee, et al., 2001).

The environmental assessment of the baseline scenario is summarized in Table 2-1 and Table 2-2. Table 2-1 presents the normalized values of environmental indicators per volume of water used, for the entire system and the contribution of the foreground and the background system separately. It is obvious that the most significant environmental problems are toxicity related issues (including human toxicity and ecotoxicity), due to chemicals used in the dyeing process, and freshwater depletion.

Table 2-2 displays the environmental performance of the two industrial units for the baseline scenario. The figures presented include both the foreground and the background system contribution. It is apparent that Unit A has better performance in climate change, freshwater resource depletion and acidification due to less electricity and water consumption. On the contrary, Unit B has lower values in the two ecotoxicity indicators due to the natural dyeing production line, which produces cleaner wastewater. However, the human toxicity indicator does not follow the same pattern, because in that case the contribution of the background electricity production counterbalances the direct environmental impact from the water effluents of the dyeing process.

Table 2-1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario

Midpoint Impact Category	**Environmental Performance Indicator**	**Foreground Contribution**	**Background Contribution**
Climate change	0.01 $kgCO_{2eq}/m^3$	51%	49%
Freshwater Resource Depletion	0.15 m^3/m^3	100%	0%
Eutrophication	0.02 $kgPO_4^{3}{}_{-,eq}/m^3$	90%	10%
Human toxicity	2.68 $kg1,4DCB_{,eq}/m^3$	73%	27%
Acidification	0.05 $kgSO_2^{-}{}_{,eq}/m^3$	28%	72%
Aquatic Ecotoxicity	22.45 $kg1,4DCB_{,eq}/m^3$	99%	1%
Terrestrial Ecotoxicity	1.94 $kg1,4DCB_{,eq}/m^3$	99%	1%
Photochemical Ozone Formation	0.003 $kg\ C_2H_{4,eq}/m^3$	25%	75%

Table 2-2. Comparison of the environmental performance between the two units for the baseline scenario

Midpoint Impact Category	**Unit**	**Ind. Unit A**	**Ind. Unit B**
Climate change	$kgCO_{2eq}$/kg product	0.002	0.003
Freshwater Resource Depletion	m^3/kg product	0.023	0.029
Eutrophication	$kgPO_4^{3}{}_{-,eq}$/kg product	0.003	0.003
Human toxicity	$kg1,4DCB_{,eq}$/kg product	0.440	0.482
Acidification	$kgSO^{2-}{}_{,eq}$/kg product	0.008	0.009
Aquatic Ecotoxicity	$kg1,4DCB_{,eq}$/kg product	3.865	3.856
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}$/kg product	0.352	0.334
Photochemical Ozone Formation	$kg\ C_2H_{4,eq}$/kg product	$<10^{-3}$	$<10^{-3}$

2.1.2.2 Value assessment

All financial costs required for the calculation of the Total Value Added are summarized in Table 2-3. The purchase cost for all the supplementary resources (i.e. electricity, natural gas) is the same for both units. The main difference is the price of dyes, which is assumed to be 5-6 €/kg of chemical dye but in the case of natural herbal dyes it reaches 11 €/kg. However, similar is also the difference in the price of the finished dyed product. In the case of chemical dyeing processes, it ranges from 5.5 € to 7 €/kg whereas a naturally dyed product can be sold for as much as 15 €/kg. Unit A has lower expenses for water abstraction (due to private wells) and wastewater treatment and disposal (due to in-house treatment) but has an extra expenditure for sludge treatment and disposal.

The TVA (Total Value Added) from water use to the dyed product is estimated to be 18.36 € per m^3 of water used. Furthermore, both industrial units have positive annual economic balance. The annual net economic output for Industrial Unit A is 548,946 € whereas for Industrial Unit B is 2,434,621 €.

2.1.2.3 Eco-efficiency assessment

Table 2-4 presents the results of the baseline eco-efficiency assessment both for the overall system and for each industrial unit separately. It is confirmed that the major environmental impacts of the studied system are toxicity related issues and freshwater resource depletion,. The results of the assessment also indicate a clear superiority of the Industrial Unit B concerning eco-efficiency, by having higher values in all eight indicators and thus better performance. Despite the similar environmental performance, Unit B is more eco-efficient due to increased profit, since the natural dyed product are sold in a much higher price.

Table 2-3. Financial costs of the two industrial units

Expenditure	Ind. Unit A	Ind. Unit B (Chemical)	Ind. Unit B (Natural)
Electricity	0.18 €/kWh		
Natural Gas	0.45 €/m^3		
Dyes and Additives	5.2 €/kg	6.0€/kg	11.0€/kg
Water Abstraction	2,200 €/yr	50,000 €/yr	
Wastewater Treatment and Disposal	0.35 €/m^3	0.85 €/m^3	0.85 €/m^3
Sludge Treatment and Disposal	0.85 €/kg sludge	-	-
Operation and Maintenance Cost	0.16 €/kg product	0.21 €/kg product	

Table 2-4. Baseline eco-efficiency assessment

Midpoint Impact Category	Unit	Overall	Ind. Unit A	Ind. Unit B
Climate Change	€/kgCO_{2eq}	1,350.72	515.54	2,122.05
Freshwater Resource Depletion	€/m^3	122.44	50.86	178.95
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	1,024.68	377.11	1,666.96
Human Toxicity	€/kg1,4$DCB_{,eq}$	6.85	2.60	10.80
Acidification	€/kg$SO^{2-}_{,eq}$	366.14	147.09	549.87
Aquatic Ecotoxicity	€/kg1,4$DCB_{,eq}$	0.82	0.30	1.35
Terrestrial Ecotoxicity	€/kg1,4$DCB_{,eq}$	9.45	3.43	15.58
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	6,958.75	2,731.69	10,659.82

2.1.3 Objectives for the introduction of innovative technologies

The baseline eco-efficiency assessment and the identification of the environmental weaknesses of the system will lead to the selection of innovative technologies, which can upgrade the examined value chain. Thus, based on the results, two main objectives are set for the upgrading of the studied system: (a) increase of resource efficiency, focusing on freshwater, and (b) pollution prevention, focusing on treatment of water effluents. After discussing with the directly involved actors in the system and reviewing the relevant literature, six alternative technologies are selected for implementation in the current system and they are described in the following paragraphs.

2.2 Individual assessment of innovative technologies

2.2.1 Smart pumping systems

Smart pumping systems are centrifugal pumps equipped with special instrumentation and a microprocessor that can be operated at variable speed. Through their application to a water abstraction process, a 30-40% reduction in energy consumption and a subsequent reduction in air emissions can be achieved. The investment cost of this technology is 15,000 - 20,000€ and its lifetime is estimated to be 15 years. The operation and maintenance costs are reduced due to the decreased energy consumption (Stavale, 2001).

2.2.1.1 Main assumptions

For the application in Biella region, it is assumed that the smart pumping systems are installed in the water supply stage for both industrial units.

2.2.1.2 Technology Assessment

The assessment of the smart pumping systems reveals that the implementation has a very slight positive influence to the system. Individually, it does not provide a lot to the system; however it can a be sumpplementary technological to a resource efficienct pathway. The explicit values on the environmental performance (Table 2-5), the economic performance (Table 2-6) and the eco-efficiency indicators (Table 2-7) for its implementation are reported below.

Table 2-5. Environmental performance assessment for smart pumping systems

Midpoint Impact Category	Unit	Baseline	Smart pumping
Climate change	€/kgCO_{2eq}	2,311	2,304
Freshwater Resource Depletion	€/m^3	25,500	25,500
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	3,047	3,045
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	455,009
Acidification	€/kg$SO^{2-}{}_{,eq}$	8,527	8,485
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	3,817,022
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	330,532
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	449	447

Table 2-6. Economic performance assessment for smart pumping systems (Values in €)

Actor	Baseline	Smart pumping
Industrial Unit A	548,946	548,229
Industrial Unit B	2,434,621	2,434,715
Region	52,200	52,200
CORDAR	86,365	86,365

Table 2-7. Eco-efficiency assessment for smart pumping systems

Midpoint Impact Category	Unit	Baseline	Smart pumping
Climate change	€/kgCO_{2eq}	1,351	1,354
Freshwater Resource Depletion	€/m^3	122	122
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	1,025	1,025
Human toxicity	€/kg1,4DCB$_{,eq}$	6.85	6.86
Acidification	€/kg$SO^{2-}{}_{,eq}$	366	368
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	0.82	0.82
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	9.45	9.44
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	6,959	6,987

2.2.2 Automatic Dye Dispensing Systems

Automatic dye and chemical dispensing consists of automatic and semi-automatic weighting, dissolving and measuring systems that enable the precise delivery of dyeing chemicals and auxiliaries. The environmental performance of the proposed technology is characterised by a reduction in the amount of water abstracted, as well as in energy and dyes consumed, by 15% each. The investment cost is 150,000-300,000€ with a lifetime of 15 years, while the annual operation and maintenance costs are 20,000€ (Cotton Inc., 2009).

2.2.2.1 Main assumptions

It is assumed that the automatic dye dispensing systems are installed only in the industrial unit with chemical dyeing processes.

2.2.2.2 Technology Assessment

The values on the environmental performance (Table 2-8), the economic performance (Table 2-9) and the eco-efficiency indicators (Table 2-10) for its implementation are reported below.

Table 2-8. Environmental performance assessment for automatic dispensing systems

Midpoint Impact Category	**Unit**	**Baseline**	**Automatic dispensing**
Climate change	€/kgCO$_{2eq}$	2,311	2,180
Freshwater Resource Depletion	€/m^3	25,500	21,675
Eutrophication	€/kgPO$_4^3{}_{-,eq}$	3,047	3,015
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	439,018
Acidification	€/kgSO$^{2-}_{,eq}$	8,527	7,774
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	3,816,701
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	330,375
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	449	415

Table 2-9. Economic performance assessment for automatic dispensing systems (Values in €)

Actor	**Baseline**	**Automatic dispensing**
Industrial Unit A	548,946	916,207
Industrial Unit B	2,434,621	2,583,797
Region	52,200	52,200
CORDAR	86,365	86,365

The assessment of the automatic dye dispensing systems shows that the implementation has significant positive impact in all eight eco-efficiency indicators. Thus, it can be a part of an overall technology scenario aiming both for resource efficient and pollution prevention. However, the highest value is observed for the freshwater resource depletion (+37%).

Table 2-10. Eco-efficiency assessment for automatic dispensing systems

Midpoint Impact Category	Unit	Baseline	Automatic dispensing
Climate change	€/kgCO$_{2eq}$	1,351	1,669
Freshwater Resource Depletion	€/m^3	122	168
Eutrophication	€/kgPO$_4$^{3}-,$_{eq}$	1,025	1,207
Human toxicity	€/kg1,4DCB$_{,eq}$	6.85	8.29
Acidification	€/kgSO^{2-}$_{,eq}$	366	468
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	0.82	0.95
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	9.45	11.01
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	6,959	8,760

2.2.3 Low-Liquor-ratio jet dyeing

Low-liquor-ratio (LLR) jet dyeing machines are based on the principle of accelerating water through a venturi construction or nozzle to transport fabrics. The system's environmental performance is improved since abstracted water decreases by 50%, energy consumption for water heating is reduced by 40% and the quantity of dyes and additives used by 20%. The investment cost of this technology varies from 150,000 to 300,000€, the annual operation and maintenance cost is 20,000€ and its lifetime is 10 years (Cotton Inc., 2009).

2.2.3.1 Main assumptions

It is assumed that LLR jet dyeing machines are installed only in the chemical dyeing processes.

2.2.3.2 Technology Assessment

The assessment of the LLR jet dyeing machines indicates that their implementation has significant positive impact in all eight eco-efficiency indicators. Thus, it can be a part of an overall technology scenario aiming both for resource efficient and pollution prevention. However, the biggest improvement is observed for the freshwater resource depletion (+119%), which is expected since this is the main objective of this technology. The results for the environmental, economic and eco-effieciency assessment are presented in the following tables (Table 2-11, Table 2-12 & Table 2-13).

Table 2-11. Environmental performance assessment for LLR jet dyeing machines

Midpoint Impact Category	Unit	Baseline	LLR Jet Dyeing
Climate change	€/kgCO$_{2eq}$	2,311	2,100
Freshwater Resource Depletion	€/m^3	25,500	14,175
Eutrophication	€/kgPO$_4$^{3}-,$_{eq}$	3,047	2,992
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	433,467
Acidification	€/kgSO^{2-}$_{,eq}$	8,527	7,411
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	3,816,571
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	330,319
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	449	385

Table 2-12. Economic performance assessment for LLR jet dyeing machines (Values in €)

Actor	Baseline	LLR Jet Dyeing
Industrial Unit A	548,946	1,097,778
Industrial Unit B	2,434,621	2,577,795
Region	52,200	52,200
CORDAR	86,365	86,365

Table 2-13. Eco-efficiency assessment for LLR jet dyeing machines

Midpoint Impact Category	Unit	Baseline	LLR Jet Dyeing
Climate change	€/kgCO$_{2eq}$	1,351	1816
Freshwater Resource Depletion	€/m^3	122	269
Eutrophication	€/kgPO$_4^{3}$$_{-,eq}$	1,025	1,275
Human toxicity	€/kg1,4DCB$_{,eq}$	6.85	8.80
Acidification	€/kgSO$^{2-}_{,eq}$	366	515
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	0.82	1.00
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	9.45	11.55
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	6,959	9,904

2.2.4 Use of Natural Dyes

The use of natural dyes, derived from plants, minerals and animals, can make textile processes more sustainable. A reduction by 50% in additives and 15% in energy consumption is achieved, while water used during the dyeing processes is slightly increased, by 15%. The use of natural dyes results in the absence of heavy metals in the wastewater effluents, having a positive impact on toxicity indicators. As already mentioned, the price of natural dyes is higher than the standard chemical ones; however, the dyed product can be sold in a much higher price

2.2.4.1 Main assumptions

For the application in the studied system, it is assumed that Unit B increases the capacity of the natural dyeing production line to 75% of its total production volume.

2.2.4.2 Technology Assessment

The detailed environmental, economic and eco-effieciency assessments are presented in the following tables (Table 2-14, Table 2-15 & Table 2-16).

Table 2-14. Environmental performance assessment for natural dyes

Midpoint Impact Category	Unit	Baseline	Natural Dyes
Climate change	€/kgCO$_{2eq}$	2,311	2,307
Freshwater Resource Depletion	€/m^3	25,500	25,500
Eutrophication	€/kgPO$_4^{3}$$_{-,eq}$	3,047	2,471
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	374,451
Acidification	€/kgSO$^{2-}_{,eq}$	8,527	8,500
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	2,873,050
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	249,040
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	449	447

Table 2-15. Economic performance assessment for natural dyes (Values in €)

Actor	Baseline Scenario	Natural Dyes
Industrial Unit A	548,946	548,946
Industrial Unit B	2,434,621	3,273,878
Region	52,200	52,200
CORDAR	86,365	92,145

Table 2-16. Eco-efficiency assessment for natural dyes

Midpoint Impact Category	Unit	Baseline	Natural Dyes
Climate change	€/kgCO$_{2eq}$	1,351	1,720
Freshwater Resource Depletion	€/m^3	122	156
Eutrophication	€/kgPO$_4^{3}{}_{-,eq}$	1,025	1,606
Human toxicity	€/kg1,4DCB$_{,eq}$	6.85	10.59
Acidification	€/kgSO$^{2-}_{,eq}$	366	467
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	0.82	1.38
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	9.45	15.93
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	6,959	8,865

The assessment of the LLR jet dyeing machines indicates that their use in a higher percentage of the total production has significant positive impact in all eight eco-efficiency indicators. The biggest improvement is observed in the indicators expressing water pollution (+68% for aquatic ecotoxicity and +56% for eutrophication) and terrestrial ecotoxicity (+68%).

2.2.5 Advanced oxidation processes

Advanced oxidation processes (AOPs) are used in wastewater treatment and are based on the generation of very reactive free radicals (i.e. hydroxyl radicals), which in sufficient amounts oxidise most of the chemicals present in textile wastewater. AOPs are classified into two groups; non-photochemical and photochemical. Fenton process is a non-photochemical oxidation process, used as a wastewater pre-treatment, achieving full decolourization and a 55-65% reduction in COD and heavy metals quantities present in textile effluents (Bautista, et al., 2008). The investment cost required to upgrade the existing plant is 100,000 € and the operation and maintenance cost is 0.29 €/m^3 wastewater. The technology lifetime is approximately 10 years (Yonar, 2011).

2.2.5.1 Main assumptions

To apply this option to Biella case study, the main assumption is that the advanced oxidation process is installed only in Industrial Unit A.

2.2.5.2 Technology Assessment

Table 2-17, Table 2-18 and Table 2-19 show the results of environmental, economic and eco-efficiency assessment correspondingly, after the implementation of Advanced Oxidation Process.

Table 2-17. Environmental performance assessment for advanced oxidation process

Midpoint Impact Category	Unit	Baseline	AOP
Climate change	€/kgCO_{2eq}	2,311	2,311
Freshwater Resource Depletion	€/m^3	25,500	25,500
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	3,047	3,016
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	356,884
Acidification	€/kg$SO^{2-}{}_{,eq}$	8,527	8,527
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	2,661,140
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	230,749
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	449	449

Table 2-18. Economic performance assessment for advanced oxidation process (Values in €)

Actor	Baseline	AOP
Industrial Unit A	548,946	522,722
Industrial Unit B	2,434,621	2,434,621
Region	52,200	52,200
CORDAR	86,365	86,365

Table 2-19. Eco-efficiency assessment for advanced oxidation process

Midpoint Impact Category	Unit	Baseline	AOP
Climate change	€/kgCO_{2eq}	1,351	1,339
Freshwater Resource Depletion	€/m^3	122	121
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	1,025	1,016
Human toxicity	€/kg1,4DCB$_{,eq}$	6.85	6.79
Acidification	€/kg$SO^{2-}{}_{,eq}$	366	363
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	0.82	0.81
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	9.45	9.37
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	6,959	6,900

It is obvious that the application of this technology has positive impact in four of the indicators concerning the environmental performance of the system. However, due to its high investment cost, the overall eco-efficiency is not always positively affected. Thus, this technology can be a part of an overall technology scenario focusing on pollution prevention, having that observation in mind.

2.2.6 Membrane Bioreactor

Membrane Bioreactor consists of a membrane process (i.e. microfiltration, ultrafiltration) combined with a suspended growth bioreactor and is used for industrial and municipal wastewater treatment. This technology can significantly decrease the quantities of BOD, COD and heavy metals in the effluents, improving the eutrophication and toxicity indicators. Membrane bioreactors are characterised by higher energy consumption compared to other biological treatment, but lower sludge production (Bolzonella and Fatone, 2008; Badani, et al., 2005). The investment cost is 2,800 € per m^3 of wastewater treated, the operation and maintenance cost is 1.70

€/m^3, while the lifetime of the technology, regarding the membrane, is 10 years (Cheryan and Rajagopalan 1998).

2.2.6.1 Main assumptions

For the application of this technology to the studied system, it is assumed that the membrane bioreactor is installed only in the chemical dyeing industrial Unit A.

2.2.6.2 Technology Assessment

The installation of a membrane bioreactor has a significant positive impact in four of the indicators, expressing the environmental performance of the system (eutrophication, aquatic and terrestrial ecotoxicity and human toxicity, while the other four indicators are not affected. However, due to its high investment cost, the overall eco-efficiency is not always positively affected. Thus, this technology can be a part of an overall technology scenario focusing on pollution prevention. The environmental, economic and eco-efficiency assessment in case of membrane bioreactor are presented in the following tables (Table 2-20, Table 2-21 & Table 2-22).

Table 2-20. Environmental performance assessment for mebrane bioreactor

Midpoint Impact Category	**Unit**	**Baseline**	**MBR**
Climate change	€/kgCO_{2eq}	2,311	2,311
Freshwater Resource Depletion	€/m^3	25,500	25,500
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	3,047	3,004
Human toxicity	€/kg1,4$DCB_{,eq}$	455,971	388,244
Acidification	€/kg$SO^{2-}{}_{,eq}$	8,527	8,527
Aquatic Ecotoxicity	€/kg1,4$DCB_{,eq}$	3,817,041	2,847,170
Terrestrial Ecotoxicity	€/kg1,4$DCB_{,eq}$	330,541	235,555
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	449	449

Table 2-21. Economic performance assessment for membrane bioreactor (values in €)

Actor	**Baseline**	**MBR**
Industrial Unit A	548,946	522,723
Industrial Unit B	2,434,621	2,434,621
Region	52,200	52,200
CORDAR	86,365	86,365

Table 2-22. Eco-efficiency assessment for membrane bioreactor

Midpoint Impact Category	**Unit**	**Baseline**	**MBR**
Climate change	€/kgCO_{2eq}	1,351	1,309
Freshwater Resource Depletion	€/m^3	122	119
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	1,025	1,007
Human toxicity	€/kg1,4$DCB_{,eq}$	6.85	7.80
Acidification	€/kg$SO^{2-}{}_{,eq}$	366	355
Aquatic Ecotoxicity	€/kg1,4$DCB_{,eq}$	0.82	1.06
Terrestrial Ecotoxicity	€/kg1,4$DCB_{,eq}$	9.45	12.85
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	6,959	6,746

2.2.7 Overall individual technology eco-efficiency assessment

A preliminary eco-efficiency assessment of the six selected technologies is presented in Figure 2-2. It is obvious from the chart that the smart pumping systems and LLR jet dyeing systems improve significantly three of the indicators; namely climate change, freshwater resource depletion and acidification while natural dyes and MBR show the bigger improvement in aquatic and terrestrial ecotoxicity.

Furthermore, the economic performance assessment reveals that the actor responsible for Industrial Unit B has the higher net economic output compared to the other actors, while the lowest NEO corresponds to CORDAR. Figure 2-3 depicts the economic performance of the selected technologies per actor.

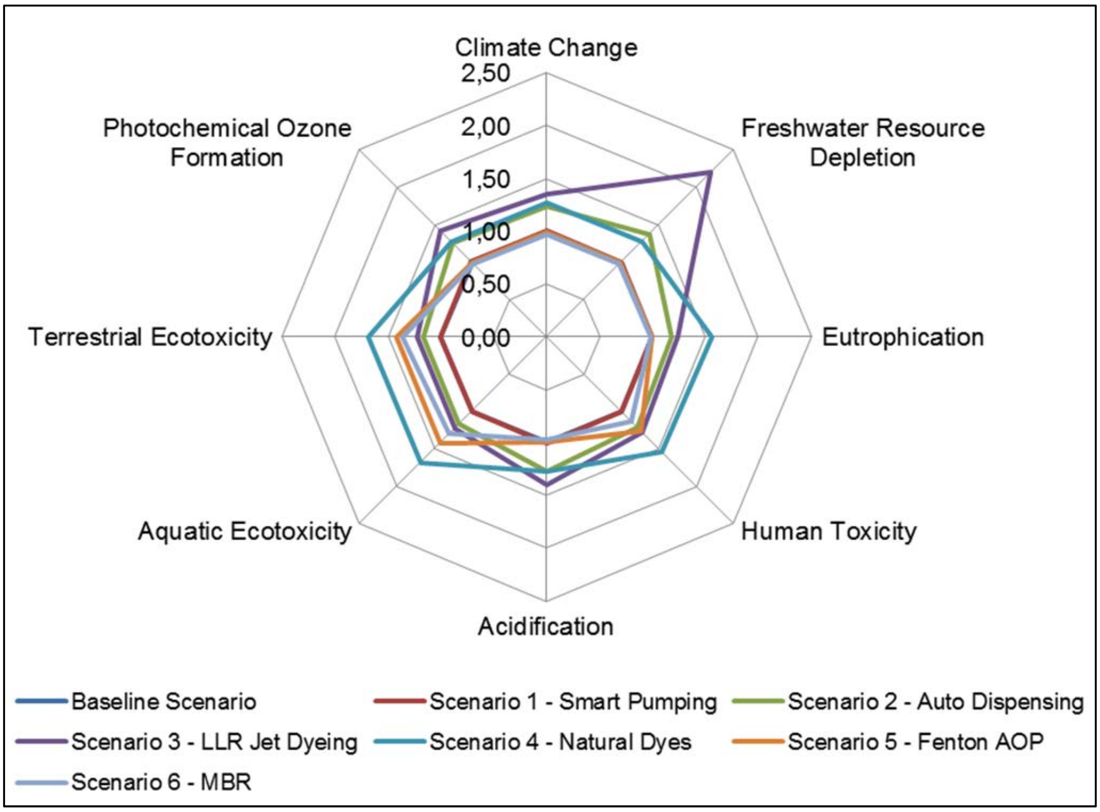

Figure 2-2. Individual eco-efficiency assessment of the six selected technologies

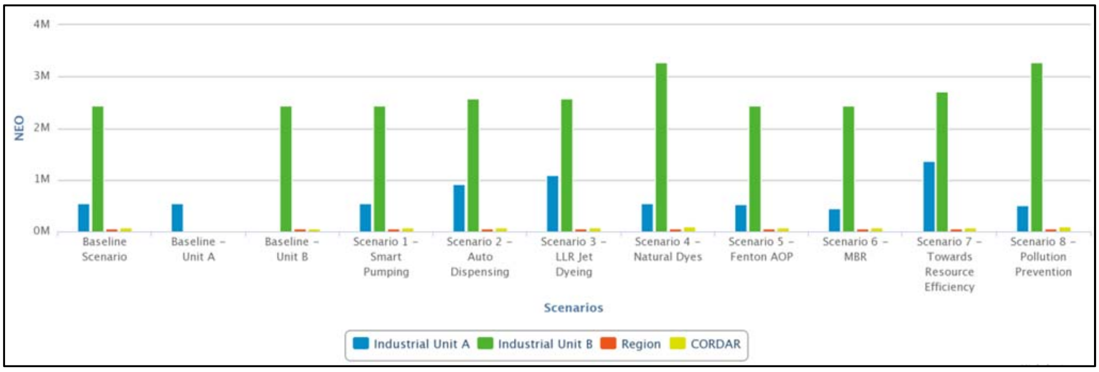

Figure 2-3. Economic performance assessement of technologies per actor

2.3 Assessment of Technology Scenarios

As a second step in the process of upgrading the value chain, two alternative technology scenarios are examined and assessed. The first one is characterised by the application of a set of technologies focusing on resource efficiency, while the second scenario includes technologies, which are oriented towards water pollution prevention. The combination of technologies used in each scenario is presented in Table 2-23. More specifically, the first scenario towards resource efficiency (RE Scenario) includes the implementation of the technologies that reduce the consumption of water and supplementary resources. The smart pumping system is applied to water abstraction process, while the LLR jet dyeing machines and automatic dye and chemical dispensing system are applied to the chemical dyeing process. The second scenario towards pollution prevention (PP Scenario), which is pollution prevention oriented, investigates the implementation of two technologies at the stage of wastewater treatment, and the partial replacement of chemical dyeing processes with natural dyeing.

Table 2-23. Alternative technology scenarios

Technology Scenario	Technologies Included
…towards Resource Efficiency	Smart Pumping Systems
	Automatic Dye and Chemical Dispensing
	Low-Liquor-Ratio Jet Dyeing Machines
…towards Pollution Prevention	Use of Natural Dyes
	Advanced Oxidation Process (Fenton’s Reagent)
	Membrane Bioreactor

2.3.1 Technology scenario focusing on resource efficiency

The technology scenario towards resource efficiency significantly improves freshwater resource depletion (reduction by 52.8%) and slightly improves energy related indicators (acidification by 12.4%, climate change by 9.3% and photochemical ozone formation by 15.9%). Table 2-24 shows the results of environmental performance assessment for the technology scenario towards resource efficiency.

Table 2-24. Environmental performance assessment of RE Scenario

Midpoint Impact Category	Unit	Baseline	RE Scenario
Climate change	€/kgCO_{2eq}	2,311	2,097
Freshwater Resource Depletion	€/m^3	25,500	12,049
Eutrophication	€/kg$PO_4^{3-}{}_{,eq}$	3,047	2,988
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	436,638
Acidification	€/kg$SO^{2-}{}_{,eq}$	8,527	7,468
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	3,816,622
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	330,349
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	449	377

2.3.2 Technology scenario focusing on pollution prevention

All toxicity related indicators are significantly improved through the implementation of the technology scenario towards pollution prevention (reduction in aquatic ecotoxicity by 50.1%, terrestrial ecotoxicity by 53.4%, and human toxicity by 32.7%). Eutrophication is also slightly improved but all other indicators are not positively affected. Table 2-25 presents the outcomes from the environmental performance assessment of the second technology scenario.

Table 2-25. Environmental performance assessment of PP Scenario

Midpoint Impact Category	Unit	Baseline	RE Scenario
Climate change	€/kgCO$_{2eq}$	2,311	2,307
Freshwater Resource Depletion	€/m^3	25,500	25,500
Eutrophication	€/kgPO$_4^{3}{}_{-,eq}$	3,047	2,420
Human toxicity	€/kg1,4DCB$_{,eq}$	455,971	248,274
Acidification	€/kgSO$^{2-}{}_{,eq}$	8,527	8,501
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	3,817,041	1,329,205
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	330,541	111,254
Photochemical Ozone Formation	€/kg C$_2$H$_{4,eq}$	449	447

2.3.3 Overall eco-efficiency assessment

Figure 2-4 presents the eco-efficiency indicators for the two technology scenarios, confirming that both scenarios improve all eight eco-efficiency indicators. Furthermore, the total value added to the product due to water use is increased in both cases (49.52 €/m^3 in the RE scenario, 23.12 €/m^3 in the PP scenario).

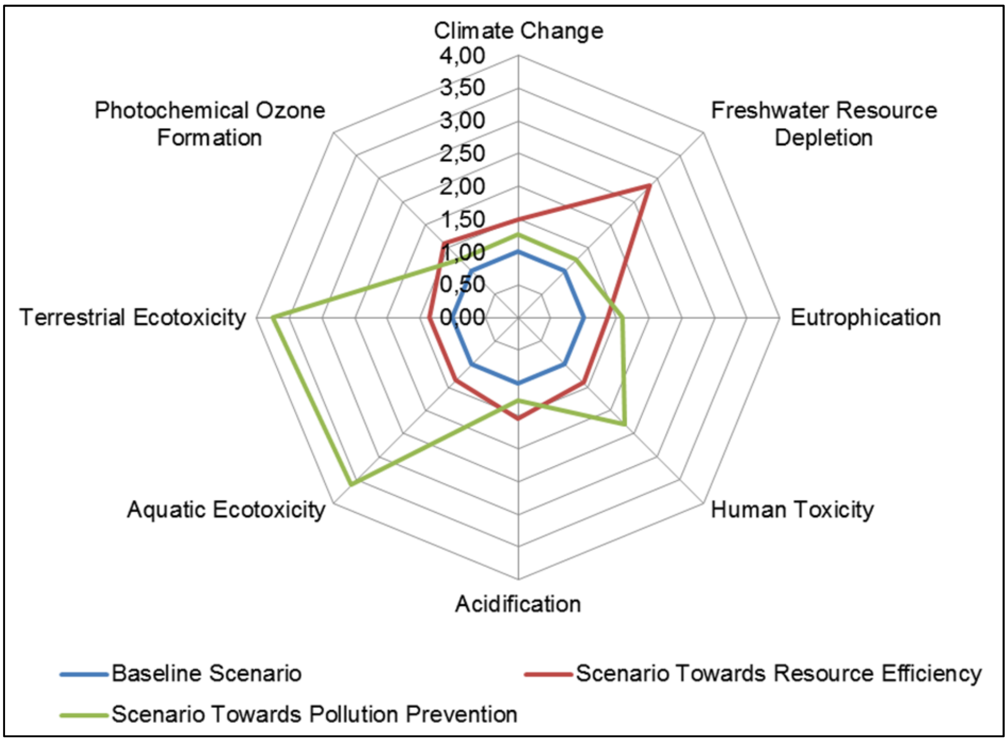

Figure 2-4. Eco-efficiency assessment of the alternative technology scenarios

The net economic output (NEO) of all the actors increases or, in the worst case, remains constant, with the exception of the NEO of the Industrial Unit A in the technology towards pollution prevention (Table 2-26). This observation may be critical for the feasibility of the scenario, since the industrial unit A is the actor responsible for the implementation of two of the technologies. The decrease in the NEO indicates that the economic profit from the installation of an advanced oxidation process and the MBR is not high enough to counterbalance the high investment cost.

Table 2-26. Net economic output (NEO) of all the involved actors and the total valued added of the system

Actor	Baseline	RE Scenario	PP Scenario
Industrial Unit A	548,946 €	1,365,876 €	512,832 €
Industrial Unit B	2,434,621 €	2,704,712 €	3,273,878 €
CORDAR	86,365 €	86,365 €	92,145 €
Region	52,200 €	52,200 €	52,200 €
Total Value Added	3,122,132 €	4,209,153 €	3,931,055 €

2.4 Policy Recommendations

In order to develop policy recomendation for the Case Study of Biella, the socio-technical dynamics (acting either as barriers or as drivers for the technology uptake), which have been identified through local workshops, should be also considered together with the results of the eco-efficiency assessment.

For the specific system, the eco-efficiency analysis has showed that there is a lot of room for improvement, concerning the main environmental problems of the area; namely (a) the freshwater resource depletion and (b) the toxicity of the effluents. However, given the economic conditions of the textile industry in Biella, both scenarios may not be realistic and additional policies are required to promote their uptake.

The scenario towards pollution prevention improves all eight eco-efficiency indicators and increases the TVA of the entire system; however, the NEO of the Industrial Unit A decreases since the economic profit from the installation of new technologies does not counterbalance the high investment cost. Thus, certain economic incentives are required to make its implementation feasible, such as environmental taxes or subsidies. Besides that, similar alternative scenarios could be examined, such as the joint implementation of the WWTP upgrade by more than one actor.

The scenario towards Resource Efficiency can be implemented more easily since it improves all 9 eco-efficiency indicators, increases the TVA of the system and increases (or in the wost case does not affect) the NEO of all the involved actors. Its main disadvantage is that requires a very high investment cost (~400,000 €) from the industrial units. Given the economic conditions of the textile industry in Biella, this scenario may not be realistic. This certain economic incentives may be required to make its implementation feasible, such as environmental taxes or subsidies.

3 Case Study #6 Cogeneration of electricity and heat

3.1 Introduction

This case study consists of a water system, which provides supply and discharge of cooling water used by local energy plants for electricity and thermal energy production. It also consists of the local energy plant and the storage and distribution network and finally the houses and industries where the energy is used.

The case study assesses the wider environmental impacts and improvements and the added economic (service/product) value that will arise from the implementation of technologies and strategies.

The main objectives of this case study are:

1. Finding the most effective ways to **improve the water quality of the “IJmeer” (IJ-lake)** by reducing (the impact of) thermal discharges. In the current case study the ecological impact of the energy production depends on the volume and of residual heat discharged into the surface water system and peak temperatures (temperature difference between of discharged cooling water and the receiving water.
2. Finding the most effective ways to **improve sustainability in the energy sector** by better accommodating electrical and thermal demands, leading to reduction of fossil fuel based heating. The sustainability can be defined as the efficiency of energy production and as the effectiveness of the energy produced. The efficiency is estimated by the ratio between intrinsic energy content of the natural gas (energy source of the power plants) and the supplied energy content of the distributed electrical and thermal energy. The effectiveness can be estimated by the ratio between the electrical and thermal energy produced and the electrical and thermal energy demand.
3. Finding the best sustainable ways to improve the **robustness of the energy sector**, by reducing dependence on availability of cooling water. Dutch legislation limits the allowed (relative) temperature rise due to cooling water discharges; it also limits the maximum allowed absolute temperature and the maximum temperature that may be discharged. This, in combination with potential climate-depending increasing receiving water temperature, it sets constraints to the allowed thermal discharges. The robustness of the energy sector can be improved when the dependency of energy plants on cooling water is reduced.

During the course of the EcoWater project, it became clear that:

- The key technological option, which concerned using higher temperatures for industry purposes was not considered feasible by the key stakeholder, as it implied major adaptations in the combined heat and power plant, and required high temperature clients to be in the vincinity.
- The baseline scenario required significant adaptations to achieve more meaningful results:

- o Implementation of time dependence – in this case allowing monthly input data and computing annual eco-efficiencies based on these varying data.
- o Representation of the four main components of the cogeneration plant: two cogeneration units, heat-only boilers and thermal energy storage.

As a result the delieverables leading to this chapter should be disregarded, and all relevant information is included in this chapter.

3.2 Background

3.2.1 Case study description

The assessed river water system is the system used for abstracting cooling water for power plants in Diemen, a suburb / industrial area situated to the east of Amsterdam (see Figure 3-1).

Figure 3-1. Case study area

As this study comprises only indicative results, the electrical and thermal energy provider is named EHEP. Close to Amsterdam, EHEP operates gas-powered Combined Heat and Power plants (CHP-plants). Since 2006 the facility includes heat-only boilers. A thermal storage is being constructed in 2014. The CHP plants deliver electricity to the Dutch electricity grid and thermal energy (“heat”) to Amsterdam’s thermal energy network. In times of high thermal energy demands and/or low electricity wholesale prices, the heat-only boilers are used. The thermal heat storage is used for peak shaving, i.e. delivering heat during those periods when peak thermal energy demand can be most efficiently met by using stored thermal energy. Production of electricity and thermal energy requires cooling. Cooling water is predominantly extracted and discharged to the IJmeer, which is a large shallow lake. Occasionally water may be abstracted from the Amsterdam-Rhine Channel (ARC) which is a 72 km long man-made connection between the Rhine River and the IJ-bay near Amsterdam. The water then flows into the North Sea Channel, where it is discharged near IJmuiden into the North Sea.

Cooling water availability in the ARC is limited, as also other thermal discharges take place further upstream. This was one of the drivers to change the cooling water abstraction point. The design of the current cooling water inlet/outlet system also takes account of the new suburban area “IJburg West”. This man made area includes some beaches – higher water temperatures may increase the risk of water borne public health issues and deteriorated ecological water quality.

3.2.2 Combined Heat Power generating systems

The gas-powered combined heat-power (CHP) plants consist of a gas turbine, in which gas combustion is used to drive a turbine delivering electricity. Exhaust heat is used to power a steam engine, adding to the electricity output of the plant. Additionally, thermal energy, de facto hot water, is produced at requested temperatures.

In the processes, air is used during combustion and emitted into the atmosphere. The exhaust gases contains carbon dioxide (CO_2) and several other substances (CO, NO_X, SO_2), while their quantity depends on the technology applied. The produced electricity is provided to the electricity grid.

In addition, cooling water is used and discharged into surface water. In the EHEP – Diemen case no chemicals are used to maintain the cooling water system free from algae and shellfish. Instead hot water is used to keep the system clean and efficient. The amount of hot cooling water used is dependent on the electricity demand, the heat demand and regulations.

It should be noted that the cooling water system is not connected to any other water or steam network within a plant, hence neither to the water used in the steam turbine nor to any sanitary water use. Figure 3-2 shows a schematic of a CHP plant.

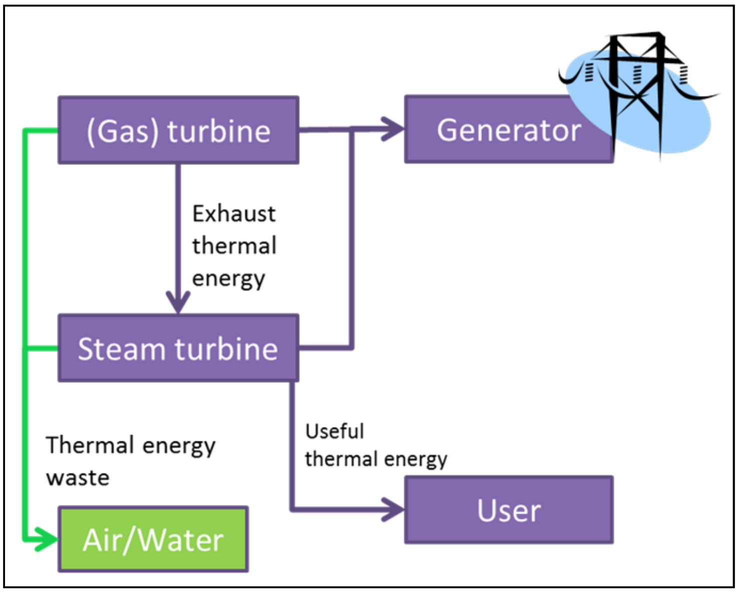

Figure 3-2. Combined Heat Power plat schematics.

3.3 District heating systems

The thermal energy of the CHP plants can be used for many purposes, district heating being one of the most important ones.

In the Netherlands, a typical household is connected to the electricity and natural gas grid. Natural gas is used for heating, hot water and cooking. Occasionally, households choose for cooking based on electricity, or add an electric boiler for comfort.

In a typical district heating system, the demand for heating and for hot water is served by the thermal energy grid. District heating is so far almost exclusively implemented during district construction. In this case households connected to the thermal energy grid will not be connected to the natural gas grid. The implication is that electricity is used for cooking.

Retrofitting existing buildings is challenging. In such cases houses could be connected to all three grids: electricity, natural gas and thermal energy.

In the thermal energy grid, thermal energy is transported by water. It is important to realize that the system contains multiple closed loop systems, interconnected via heat exchangers. There is no water exchange with the environment.

In the primary heat network the entry temperature is at the highest 120 °C. In the secondary networks, delivering the thermal energy to homes, typical incoming temperature in the case study area is 70°C, and outgoing 40°C (http://www.ce.nl/art/uploads/file/08_3613_13.pdf).

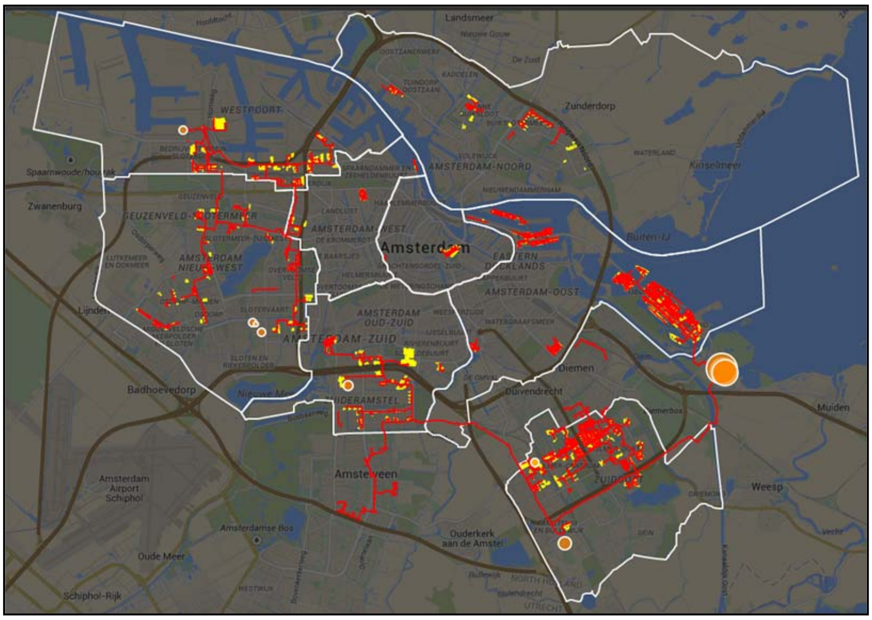

Figure 3-3. City thermal energy network Amsterdam.

Figure 3-3 depicts the thermal energy network of the city of Amsterdam. Only the South-eastern part, which is connected to the EHEP energy plant, is included in this case study. These power plants also deliver heat to the city of Almere, outside the map boundaries to the North-East. (http://maps.amsterdam.nl/energie_restafval/?LANG=nl)

The red lines depict the network; the yellow depicts buildings connected to the thermal energy grid. The orange circles depict the thermal energy producers.

3.4 Finalized baseline scenario assessment

3.4.1 System and Boundaries

Schematically the water use system and the air use system are included in Figure 3-4. The products of this meso-level system are the production, storage and distribution of thermal and electrical energy for usage in households and industries.

For simplicity, the natural gas grid and delivery to households are not included here. This information is included in Figure 3-5 which depicts the resulting system stage-decomposition. The table explains the different stages.

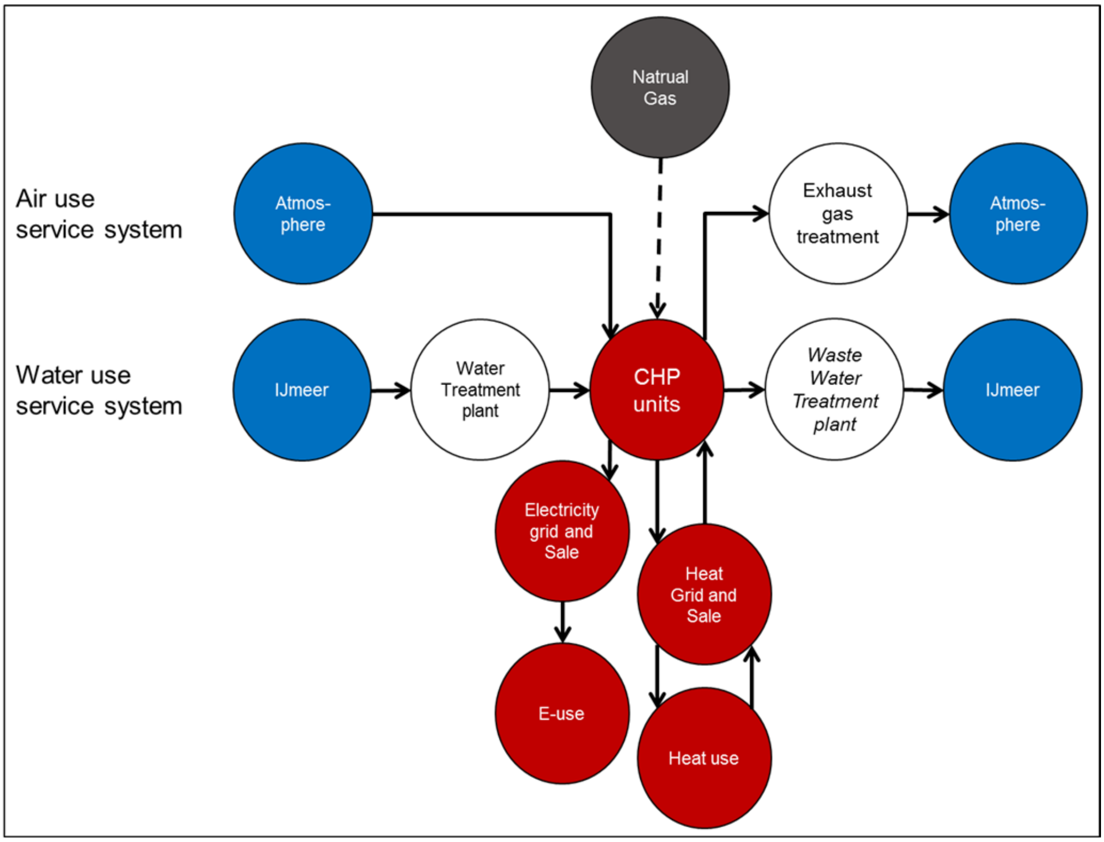

Figure 3-4. Water use service system of the case study.

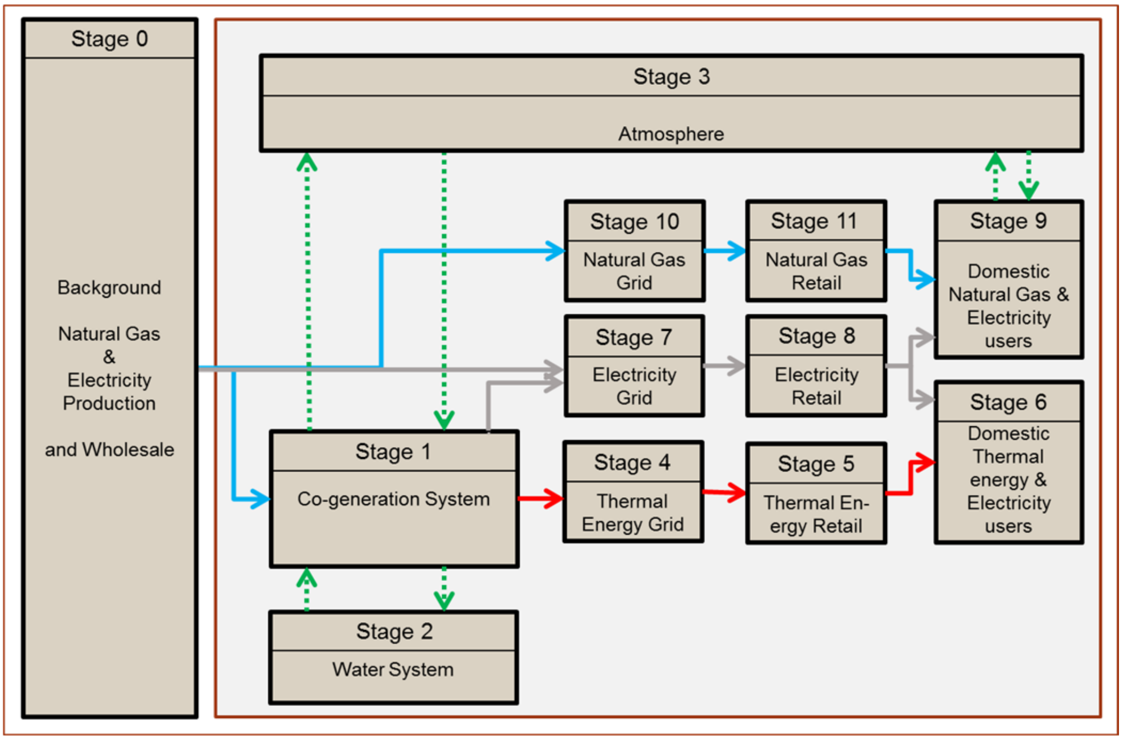

Figure 3-5. Stages in the Cogeneration Case Study (Focus on business as usual).

Table 3-1. Stages description in the Cogeneration Case Study

#	Stage	Description
0	Background	This stage predominantly consists of Natural Gas and Electricity production not resulting from D33 and D34. Natural Gas is typically used in the domestic sector for heating and hot water.
1	Electricity and thermal power generation plant	In this stage the electricity and thermal energy is produced and fed into the electricity grid (stage 7) and the head grid (stage 4). It consists of: 1. Combined Heat-Power Plant D33 2. Combined Heat-Power Plant D34 3. Heat-only boilers 4. Thermal energy storage All are operated by EHEP energy production.
2	Water System	The water system delivers cooling water and is used as a receiving body for the heated water. The regulatory authority is a key actor.
3	Atmosphere	The air used for combustion evidently originates from the atmosphere, to which also the exhaust gases of the CHP plant (stage 1) are emitted. The regulatory authority is a key actor.
4	Thermal energy grid	The thermal energy grid is the infrastructure that transports the thermal energy to the consumers through the district network. The thermal energy network can receive thermal energy from multiple sources, not depicted in this figure. The grid is owned by EHEP. EHEP is the thermal energy retailer for all households connected to the district heating system.
5	Thermal energy retail	The thermal energy retail is not a very tangible stage. It is included as the owner of the grid may be a different organization than the company delivering and invoicing thermal energy delivery to clients.
6	Domestic thermal	In this stage the domestic consumers are respresented. They use

#	Stage	Description
	energy and electricity users	and pay for electricity and thermal energy.
7	Electricity grid	The electricity grid is the infrastructure that transports electricity. The electricity grid is national with many international connections, implying it is fed by uncountable electricity producers. This is not depicted in this figure. The grid is owned by a grid operator that does not play a role in the case study. While the electricity market is free, in this case study we assumed that EHEP is the electricity retailer for all households.
8	Electricity retail	The electricity retail is a not very tangible stage. It is included as the owner of the grid is not the same as the company actually delivering and invoicing the electricity.
9	Domestic natural gas and electricity users	The electricity retail (Stage 8) delivers and invoices electricity both to the households connected to a district heating scheme and to households using natural gas for heating, hot water and cooking.
10	Natural gas grid	The natural gas grid is the infrastructure that transports gas. The grid is national with some international wholesale connections. The grid is mainly fed by natural gas from the north of the Netherlands. This is not depicted in this figure. The grid is owned by a grid operator that does not play a role in the case study. While the natural gas market is free, in this case study we assumed that EHEP is the natural gas retailer for all households.
11	Natural gas retail	The natural gas retail is a not very tangible stage. It is included as the owner of the grid is not the same as the company actually delivering and invoicing the natural gas.

Figure 3-6 depicts the detailed SEAT model and is followed by the table explaining all stages in detail.

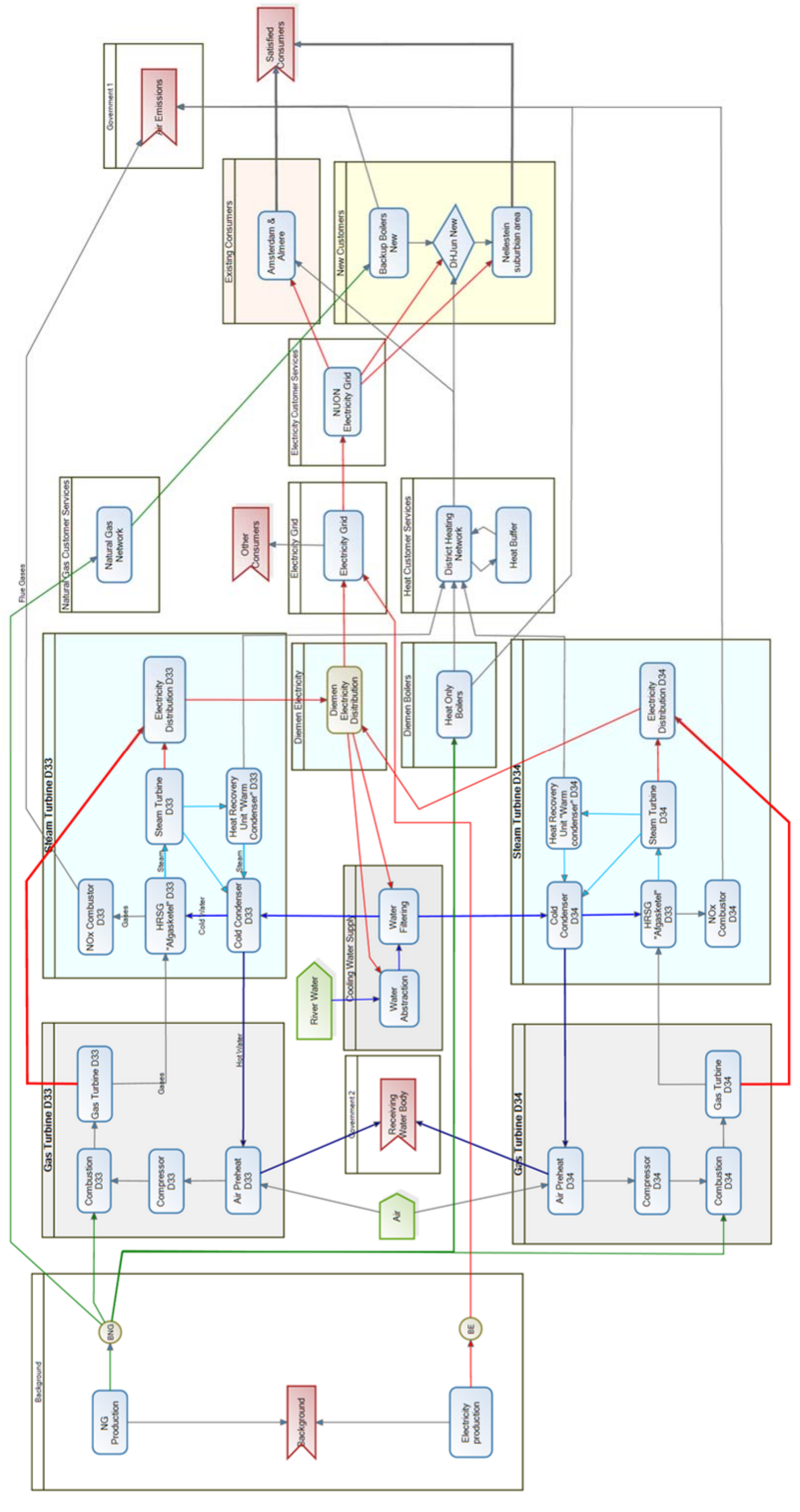

Figure 3-6. SEAT model of the cogeneration case study.

Table 3-2. Stages and processes of the SEAT model.

Stage	Processes
Background (outside the system boundaries)	1. Natural gas production 2. Electricity production
Gas Turbine D33	This stage contains the relevant process in in the gas turbine of Diemen 33 CHP plant, delivering electricity and exhaust heat. 3. Air preheater D33 4. Compressor D33 5. Combustion D33 6. Gas Turbine D33
Steam Turbine D33	This stage contains the relevant process in the steam turbine of Diemen 33 CHP plant, delivering electricity and useful thermal energy. 7. Cold Condenser D33 8. Heat recovery steam generator D33 9. NOx Combustor D33 10. Steam Turbine D33 11. Heat Recovery Unit (Warm condenser) D33 12. Electricity Distribution D33
Gas Turbine D34	This stage contains the relevant process in in the gas turbine of Diemen 34 CHP plant, delivering electricity and exhaust heat. 13. Air preheater D34 14. Compressor D34 15. Combustion D34 16. Gas Turbine D34
Steam Turbine D34	This stage contains the relevant process in in the steam turbine of Diemen 34 CHP plant, delivering electricity and useful thermal energy. 17. Cold Condenser D34 18. Heat recovery steam generator D34 19. NOx Combustor D34 20. Steam Turbine D34 21. Heat Recovery Unit (Warm condenser) D34 22. Electricity Distribution D34
Government 1	This stage contains the emissions to air.
Government 2	This stage contains the emissions to water.
Cooling Water Supply	This stage concerns the cooling water supply system. 23. Water abstraction 24. Water filtering
Diemen Electricity	This stage concerns the collection and distribution node of all electricity. 25. Diemen electricity distribution
Diemen Boilers	This stage concerns the heat-only boilers optionally used for peak shaving. 26. Diemen heat-only boilers
Natural Gas Customer service	This stage includes both the natural gas grid and the sales of natural gas. 27. Natural Gas network
Electricity Junction	This stage includes both the electricity grid and the sales of electricity. 28. Electricity network
Heat Customer service	This stage includes both the thermal energy grid and the sales of thermal

Stage	Processes
	energy. 29. Thermal energy network
Existing Consumers	This stage concerns existing consumers of the thermal energy network. 30. Amsterdam and Almere
New Consumers	31. This stage concerns 50000 potential new thermal energy consumers.
Other consumers	Any other consumers using a surplus of electricity.
Satisfied Consumers	We have to define one manual flow, to allow SEAT to solve the model. This flow has estimated as the total amount of consumers in the scenario BAU without heat-only boilers and without thermal buffer, a scenario which is described later on.

3.4.2 Baseline Scenario Assessment

The baseline scenario consists of the following main items:

1. CHP plant D33
2. CHP plant D34
3. Heat-only boilers (HOB)
4. Thermal energy buffer (BUF)
5. Households already connected to the district heating system
6. Households connected to the natural gas system

As it has been pointed out previously, the energy demand, be it natural gas, electricity or heat, varies throughout the year and day. This implies that at certain moments in time, mainly heat is required.

Electricity prices vary in time. They can be economically not favorable, meaning that a plant owner at such times will aim to reduce electricity production. When producing more than agreed upon, the plant owner in fact gets fined.

In this case study we decided to analyse the system on a monthly basis and combine the results in order to calculate the annual eco-efficiency. For each month the following question was answered: **Given the thermal energy demand and the electricity wholesale price, how can D33, D34, HOB and BUF operate most efficiently?**

Table 3-3. Key input data and assumptions

D33 data		Unit	Value
Maximum electricity output		MW$_e$	255
Maximum thermal output		MW$_{th}$	180
Equivalent to		GJ$_{th}$ /h	648
For emissions see “Emissions to air”			
D34 data			
Maximum electricity output		MW$_e$	435
Maximum thermal output		MW$_{th}$	260
Equivalent to		GJ$_{th}$ /h	936
For emissions see “Emissions to air”			
Heat on boilers data			
Thermal efficiency (assumption)		%	90
Maximum thermal output		MW$_{th}$	175
Equivalent to		GJ$_{th}$ /h	535
For emissions see “Emissions to air”			
Thermal energy buffer			
Maximum capacity when full and used for 8 hours		MW$_{th}$	225
Equivalent to		GJ$_{th}$ /h	810
Households connected to district heating			
Number of households (NUON 2014a,b)		N	89930
Average demand of hot water (value based on NG use in ordinary houses and an efficiency of 90%)		GJ$_{Th}$/yr	10.68
Average demand of heating (dito)		GJ$_{Th}$/yr	25.18
Total heat demand (dito)		GJ$_{Th}$/yr	35.86
According to (NUON 2014b) a significant amount of thermal energy has been delivered to non-domestic clients, or large scale clients. If one computes the overall thermal energy production, only ~400 000 GJ would be available for non-domestic purposes.			
Households connected to natural gas heating			
Number of households (boundary condition)		N	50000
Average annual NG consumption per household in the Province of North Holland is 1.324 m3 (ING 2013)		Nm^3/yr	1.324
Equivalent to		GJ$_{Th}$/yr	41,9
Average use of hot water (Menkveld, 2009)		Nm^3/yr	375
Average use for cooking (Menkveld, 2009)		Nm^3/yr	65
Average use for heating (computed)		Nm^3/yr	884
In house boilers thermal efficiency (assumption)		%	90
In the aforementioned data significant assumptions were made. The urban Amsterdam Area consists of smaller, but often older, less insulated houses. The			

average used here, is higher than an average listed in “Energie in beeld” (Energie in Beeld, 2014) for the specific region: However, the individual district data in “Energie in Beeld” appear to be not consistent with the overall suburbean area of Amsterdam South East. Furthermore, Almere city consists of larger, more modern housing.			
For emissions see “Emissions to air”			
Monthly heat demand and peak demand computation			
		Degree days per months	Peak number of degree days
The total annual heat demand was distributed over the different months weighting the total over te degree days per months. The monthly peak was subsequently determined by using daily degree days, and assuming that 50% of this peak day demand was used in 8 hours, further enhancing the peak. (KWA 2014a,b)	Jan-13	541.6	25.6
	Feb-13	498.4	21.6
	Mar-13	480.1	20.0
	Apr-13	242.2	12.2
	May-13	165.8	8.5
	Jun-13	79.2	6.2
	Jul-13	13.0	2.4
	Aug-13	12.6	2.0
	Sep-13	84.2	5.6
	Oct-13	177.7	9.5
	Nov-13	359.4	16.7
	Dec-13	408.0	18.3
Economic data			
Operational costs per months per unit (D33, D34)	Assumption	€/month	666 667
Operational costs when not operating per unit	Assumption	€/month	600 000
Operational costs boilers per months when operating	Assumption	€/month	40 000
Operational costs boilers per months when not operating	Assumption	€/month	30 000
Operational costs buffer per months when operating	Assumption	€/month	30 000
Operational costs buffer per months when not operating	Assumption	€/month	30 000
Monthly wholesale prices (APXgroup, 2014)	Jan-13	€/kWh	52.67
	Feb-13	€/kWh	52.54
	Mar-13	€/kWh	*58.52*
	Apr-13	€/kWh	*56.87*
	May-13	€/KWh	52.23
	Jun-13	€/kWh	48.80
	Jul-13	€/kWh	47.76
	Aug-13	€/kWh	47.58
	Sep-13	€/kWh	50.57
	Oct-13	€/kWh	49.84
	Nov-13	€/kWh	*53.50*

	Dec-13	€/kWh	52.65
Electricity price per kWh (excluding VAT)	2014	€/kWh	0,064
Electricity tax reduction: Not considered			
Electricity standing charge Maintenance cost of and transport costs by of the local network, by the electricity retailer.		€/yr	32,23
Grid costs Maintenance of main grid, by the grid operator		€/yr	212,63
NG price wholesale The price EHEP pays for natural gas		€/Nm^3	0,27
NG Environment Tax		€/Nm^3	0,1862
Natural Gas Retail (excluding VAT, 2013)		€/Nm^3	0,32
Natural Gas Profit Margin		€/Nm^3	0,0543
Thermal energy price (Excluding VAT)		€/GJ$_{Th}$	19,86
For the energy producer (assumption)		€/GJ$_{Th}$	6,62
For the energy producer (assumption)		€/GJ$_{Th}$	13,24
Fixed costs electricity, annually excluding VAT: Based on 'Vastrecht'(€3,25/month) and grid costs (€21,44/month), including VAT		€/yr	244,86
Fixed costs natural gas, annually excluding VAT: Based on 'Vastrecht'(€3,75/month) and grid costs (€14,69/month), including VAT		€/yr	182,88
Fixed costs thermal energy annual excluding VAT		€/yr	396,60
Emissions to air (NUON, 2014c)			
Note: Italic values in the heat-only boiler column denote those values which are lower than the values in the D34 column..	D33 kg/Nm^3	D34 kg/Nm^3	Heat-only Boiler; in-house boilers kg/Nm^3
Carbon Dioxide (CO$_2$ total)	1.7882250	1.7882250	1.7882250
Carbon Monoxide (CO)	0.0001594	0.0000399	0.0000153
Ethene	0.0000125	0.0000122	0.0000057
Formaldehyde (Methanal)	0.0000051	0.0000051	0.0000031
Micro-pollutants (<10 micrometer)	0.0000063	0.0000063	0.0000063
N2O	0.0000555	0.0000541	0.0000223
NOx	0.0014444	0.0003155	0.0005867
Other data			
Conversion factor Nm^3 to GJ		GJ/Nm^3	0.03165
Water Heat Capacity		kJ/kgK	4.18
Ambient Temperature		oC	24.2
Temperature change		K	7

Water Temperature		oC	25
Water Density		kg/m3	1.000.00

The potential key environmental indictors of the system are:

1. Climate change potential
2. Acidification potential
3. Particulate matter formation
4. Human Toxicity
5. Eutrophication
6. Fossil resource depletion
7. Water abstraction
8. Photochemical ozone formation
9. Total waste heat to water

A closer look to the emission reveals that the heat only boilers provide the least pollution to air.

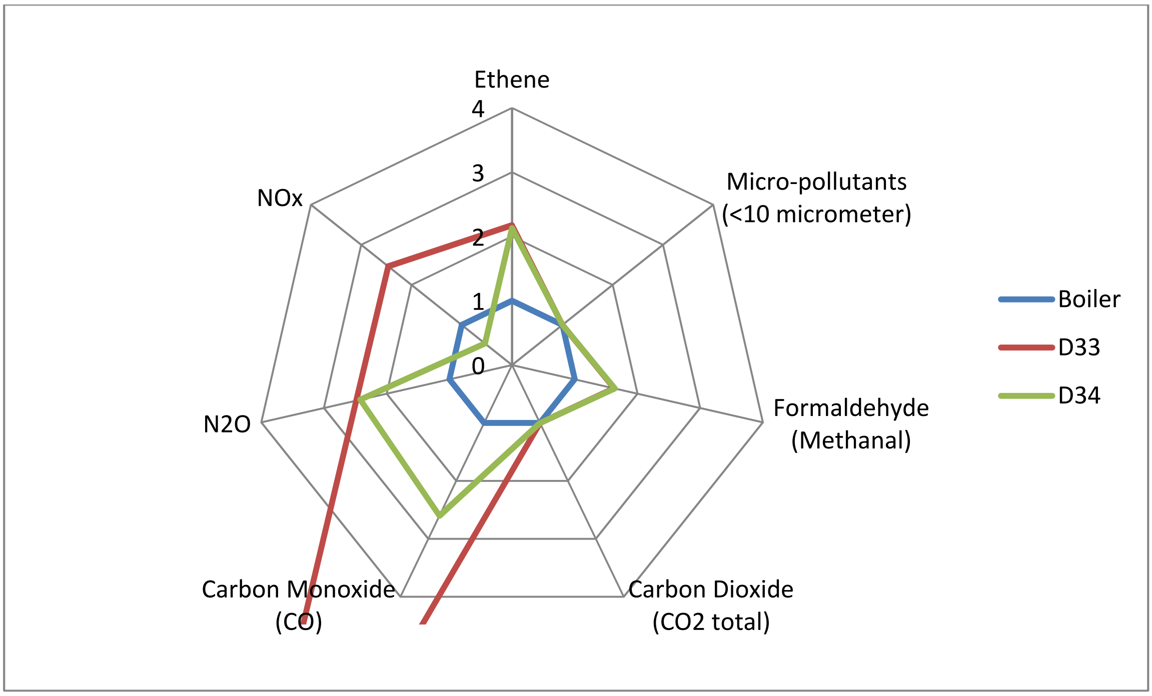

Figure 3-7. Spider diagram of the relative athmospheric pollution (unit circle concerns the heat only boiler).

Based on Figure 3-7 it is expected that a higher use of the boiler will result in positive effects on the environmental performance of scenarios.

perational input data BAU

Table 3-5 provides the input data for the model specific to the BAU scenario. It contains the data types presented in Table 3-4.

Table 3-4. Explanation to the operational data tables

Average heat	The average heat demand per months
Peak	The highest peak demand, based on 50% of the energy being used in 8 hours of the day with the highest weighted degree days.
Target - min E	Implying that the electricity price is too low, and electricity production should be minimized
Target - max E	Implying that the electricity price is high, and electricity production should be maximized
Heat-only boiler	Represents the average thermal output of the heat-only boiler
D33/D34 […]	The two different CHP units with: • Average thermal output • Electrical efficiency of the gas turbine • Electrical efficiency of the steam turbine • Thermal efficiency of the steam turbine • 'Off' indicating that the CHP is not operating

Table 3-5. SEAT input data for the business as usual scenario

	Avg heat	Peak		Heat Only Boiler		D33					D34			
							Efficiencies (%)					Efficiencies (%)		
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimeny	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimeny	ST (e)	ST (th)
1	646	1346	Min E	0						646	35.0	18.0	12.9	87.1
2	668	1175	Min E	0						668	35.0	18.0	12.0	88.0
3	585	1086	Max E	0	0	35.0	14.0	37.0		585	40.0	13.0	35.5	47.6
4	360	729	Max E	0	0	35.0	14.0	37.0		360	40.0	13.0	38.0	29.3
5	272	553	Min E	272						0				
6	193	451	Min E	193						0				
7	120	272	Min E	120						0				
8	120	254	Min E	120						0				
9	198	426	Min E	198						0				
10	284	600	Min E	0						284	33.0	34.0	25.9	74.1
11	480	940	Max E	0	0	35.0	14.0	37.0		480	40.0	13.0	36.7	39.1
12	513	1005	Min E	513										
Total				1416	0					3023				

3.4.2.1 Environmental assessment

Table 3-6 provides the numerical values of the environmental impact of the business as usual (BAU) is presented. Evidently, for a case study mainly dealing with energy production burning fossil fuels, climate change and fossil fuel depletion are very high.

Table 3-6. Environmental Impacts BAU

Indicator	**Unit**	**Total Value (Unit)**	**Foreground Value**	**Background Value**
Climate Change	tCO_2,eq	845951399	845627660	323738
Fossil Fuels Depletion	MJ	19114391985	19114391985	0
Freshwater Resource Depletion	m^3	7308492	7308492	0
Human Toxicity	kg1,4-Dbeq	13681247	4736	13676510
Acidification	$kgSO_2^-$,eq	2599453	113279	2486174
Aquatic Ecotoxicity	kg1,4-Dbeq	7383	7383	0
Terrestrial Ecotoxicity	kg1,4-Dbeq	515261	840	514421
Respiratory Inorganics	PM_{10}eq	3114	3114	0
Photochemical Ozone Formation	kgC_2H_4,eq	161156	2471	158685
Thermal Pollution	MJ	2034598	2034598	0

Figure 3-8 shows the distribution over foreground and background. Human Toxicity, Acidification and Photochemical Ozone Formation indicators are strongly depending on background processes, i.e. the pollution due to background natural gas and electricity production. Figure 3-9 vizualizes the impact per stage. It is evident from these figures that the stages associated with energy production concern the highest environmental impact.

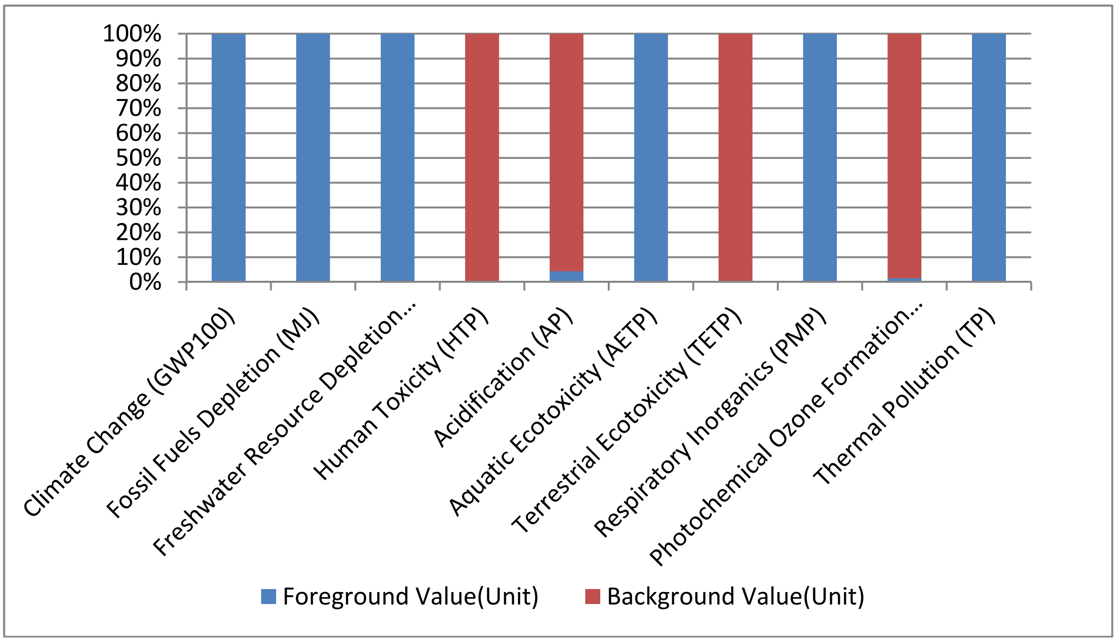

Figure 3-8. Distribution of environmental impact over foreground and background (BAU)

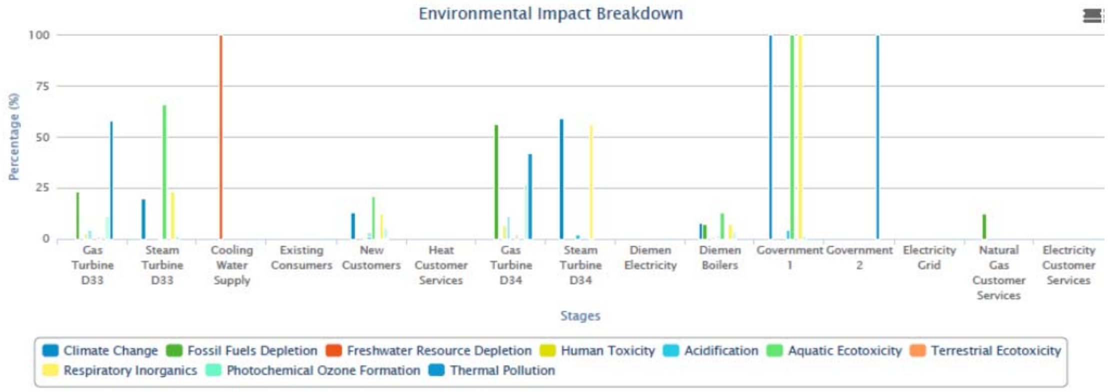

Figure 3-9. Distribution of environmental impact over stages

3.4.2.2 Value assessment

Figure 3-10 provides insight in the costs and benefits per actor. It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential. One should note that the main week points in the economic assessment are:

1. The operational costs of the different plants;
2. The distribution of the income of thermal energy delivery over the retailer and the producer;
3. The price at which electricity production becomes economically interesting.

The income of the consumers has been set equal to the costs for consumers, and hence the values cancel each other out. EHEP Producer, Retailer and Grid Operator are within the same holding, which means the overall NEO for EHEP is the sum of the different bars. However, energy tax for electricity has been considered an income to EHEP in this case study, which is not correct. ‘Wholesale’ depicts the natural gas income on the wholesale market.

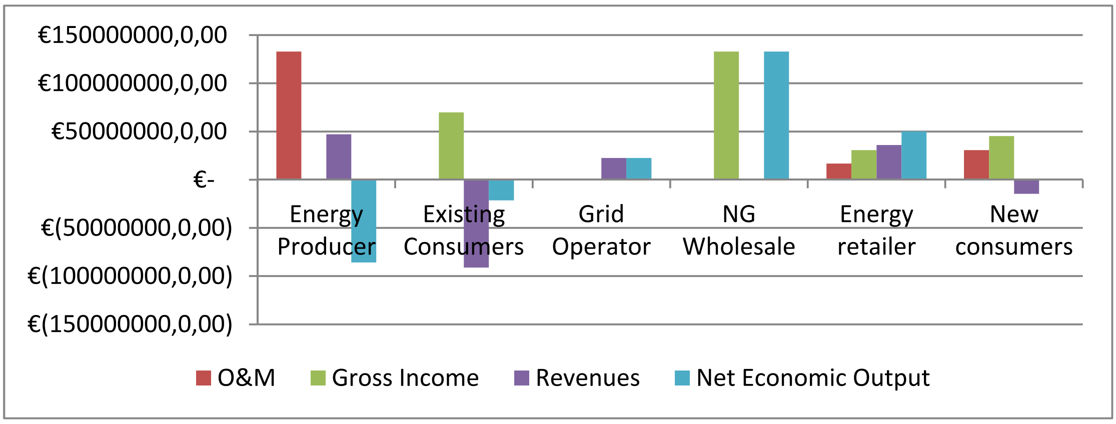

Figure 3-10. Distributional effects of costs and benefits (BAU)

3.4.2.3 Eco-efficiency assessment

Table 3-7 provides insight in the eco-efficiency, the total added value divided by the environmental impact. As one can clearly see very little added value per unit of environmental impact relates to Climate Change and Fossil Fuel Depletion, in other words, the environmental impact is very large compared to the value added. It is not surprising, given that the case study concerns burning fossil fuel.

Table 3-7. Eco-efficiency per midpoint indicator. (*) denotes midpoint indicators predominantly determined by background processes.

Midpoint Indicator	**Unit**	**Value**
Climate Change	€/t$CO_{2,eq}$	0.12
Fossil Fuels Depletion	€/MJ	0.01
Freshwater Resource Depletion (FEI)	€/m3	13.46
Human Toxicity (*)	*€/kg1,4-Db*$_{eq}$	7.19
Acidification (*)	*€/kg*$SO_{2^{-},eq}$	37.85
Aquatic Ecotoxicity	€/kg1,4-Db$_{eq}$	13324.73
Terrestrial Ecotoxicity (*)	*€/kg1,4-Db*$_{eq}$	190.94
Respiratory Inorganics	€/PM10$_{eq}$	31590.33
Photochemical Ozone Formation (*)	*€/kg*$C_2H_{4,eq}$	610.50
Water Thermal Pollution	€/MJ	48.36

3.4.3 Objectives for the introduction of innovative technologies

The objectives of the introduction of ‘innovative technologies’ is twofold:

1. Assess the effects of already implemented technologies
    a. What is the effect of the thermal energy buffer?
    b. What is the effect of the thermal energy and heat-only buffers?
2. Assess the effect of new technologies.
    a. What effect will be achieved by retrofitting 50000 other households for district heating?
    b. What effect will insulating these 50000 households have?
    c. What will be the effect of preheating potable water?
    d. What will be the effect if 25000 houses are retrofitted for district heating, and 25000 households install a micro-CHP?

3.5 Individual assessment of innovative technologies

3.5.1 BAU without heat buffer

3.5.1.1 *Main assumptions*

The BAU without heat buffer implies that peaks cannot be shaved by using stored thermal energy. This again implies that there is a chance that more thermal energy units need to operate in order to meet peak demands. Table 3-8 shows the dynamic input data. Both average heat demand and peak demand are the same as in Table 3-5. However, in order to be able to meet peak demands, the heat-only boilers are operating in more months, as is D34. Because the boilers are operating in more months, the average thermal output and efficiencies of D34 are different.

Table 3-8. SEAT input data for the BAU without heat buffer scenario.

	Avg heat	Peak		Heat Only Boiler		D33					D34			
							Efficiencies (%)					Efficiencies (%)		
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimeny	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimeny	ST (e)	ST (th)
1	646	1346	Min E	100	0	31.0	17.0	24.0	0.0	546	35.0	18.0	6.6	93.4 %
2	668	1175	Min E	100	0	31.0	17.0	24.0	0.0	568	35.0	18.0	5.0	95.0 %
3	585	1086	Max E	0	100	35.0	14.0	35.3	11.7	485	40.0	13.0	36.6	39.5 %
4	360	729	Max E	0	0	35.0	14.0	37.0		360	40.0	13.0	38.0	29.3 %
5	272	553	Min E	172						100	33.0	34.0	39.6	27.2 %
6	193	451	Min E	193										
7	120	272	Min E	120										
8	120	254	Min E	120										
9	198	426	Min E	198										
10	284	600	Min E	0						284	33.0	34.0	25.9	74.1 %
11	480	940	Max E	0	100	35.0	14.0	35.3	11.7	380	40.0	13.0	37.8	31.0 %
12	513	1005	Min E	100						413	35.0	18.0	21.9	63.5 %
Total				1103	200					3136				

3.5.1.2 Technology Assessment

The eco-efficiency values are presented in Table 3-9. In this configuration, the heat-only boilers are used at lower capacity, while the D33 and D34 are running at higher capacity. As the thermal energy production remains the same compared to the Business as Usual scenario, the difference is mainly due to the difference in exhaust air quality. As presented in Table 3-3, the exhaust of D34 is for some compounds worse than for the heat-only boilers.

According to expectation, the table also shows no major change in the parameters predominantly depending on background processes. While fossil fuel depletion goes up one could expect this to impact these background indicators, but it is compensated by other electricity production in the background.

Figure 3-11 shows the changes in economics. As D33 and D34 are operating more, the amount of natural gas use increases, resulting in a higher economic output for the natural gas wholesale market. As more electricity is produced against low prices, the EHEP producer's net economic output further decreases. The total value added increases from B€ 98.4 (BAU) to B€ 99.1.

It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential.

Table 3-9. Environmental comparison between BAU and BAU without the thermal energy buffer. (*) denotes midpoint indicators predominantly determined by background processes.

Midpoint Indicator	Unit	BAU	BAU minus thermal buffer	Difference
Climate Change	$tCO_{2,eq}$	845951399	915878707	8.27%
Fossil Fuels Depletion	MJ	19114391985	20708503455	8.34%
Freshwater Resource Depletion	m3	7308492	8305912	13.65%
Human Toxicity (*)	$kg1,4\text{-}Db_{eq}$	13681247	3660094	-73.25%
Acidification (*)	$kgSO_{2^-,eq}$	2599453	962543	-62.97%
Aquatic Ecotoxicity	$kg1,4\text{-}Db_{eq}$	7383	7107	-3.74%
Terrestrial Ecotoxicity (*)	$kg1,4\text{-}Db_{eq}$	515261	182597	-64.56%
Respiratory Inorganics	$PM10_{eq}$	3114	3360	7.89%
Photochemical Ozone Formation (*)	$kgC_2H_{4,eq}$	161156	105801	-34.35%
Water Thermal Pollution	MJ	2034598	2312268	13.65%

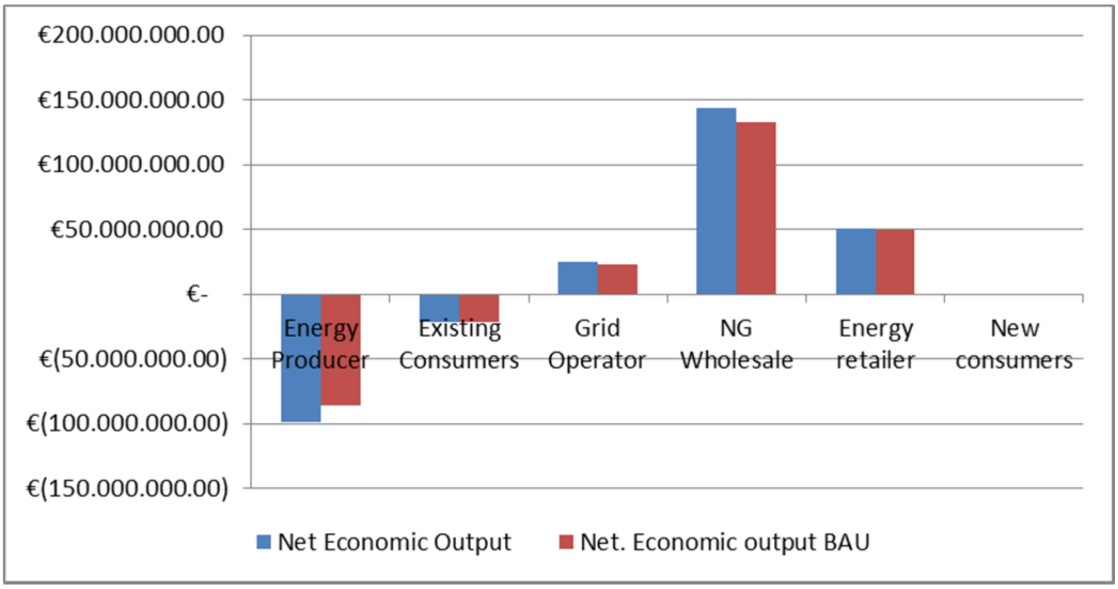

Figure 3-11. Distributional effects of costs and benefits: BAU and BAU without heat buffer.

Figure 3-12 presents the relative comparison of the eco-efficiency performance between the current scenario and BAU. For most midpoint indicators leaving the heat buffer out of the system results in decreasing eco-efficiency. As one can see the parameters that are negatively influenced concern those which are dominated by background processes. The rational behind this is that in BAU both combined heat power plants are shut off and all heat demand is covered by the heat only boiler and buffer system. This results in an electricity demand from the background system, as is shown in Table 3-10 for the scenario BAU minus heat buffer.

For illustrative purposes Figure 3-13 provides the results for April and May for the two scenarios. April depicts a month in which in both scenarios D33 and D34 are operating. In May the BAU scenario works on heat only boilers, requiring electricity from the background. The figure shows that the environmental pressures are very different if no electricity produced to meet the within system demand.

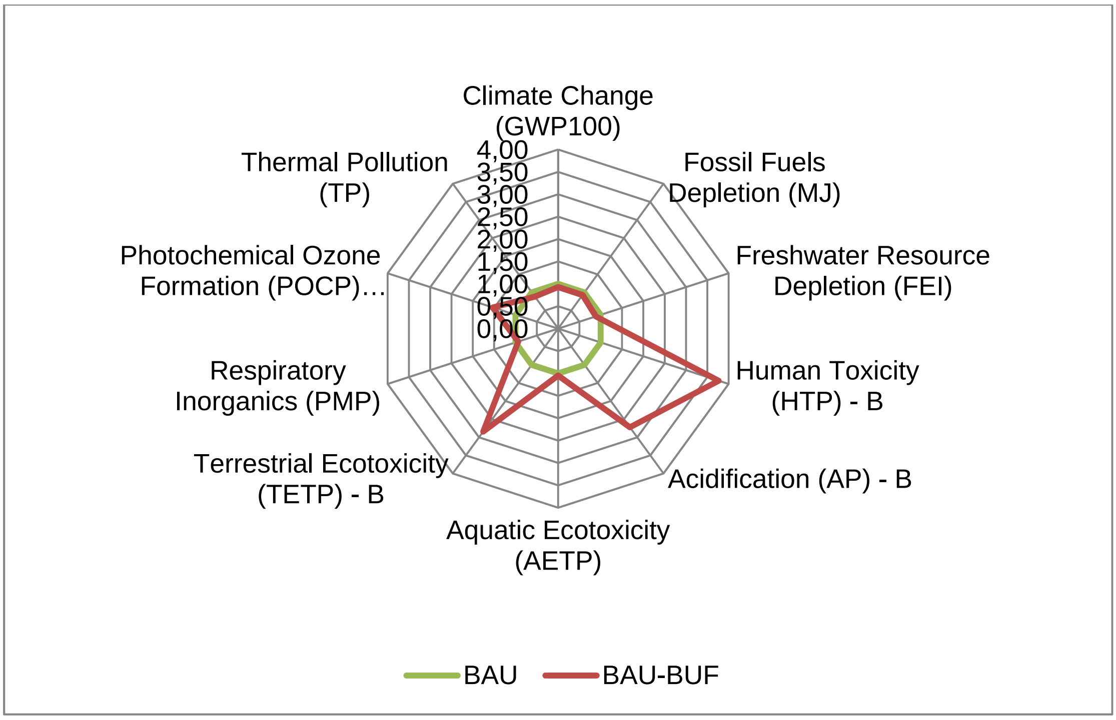

Figure 3-12. Graphical representation of the eco-efficiency of BAU and BAU without the thermal energy buffer eco-efficiency. "- B" depicts environmental pressures resulting from background processes.

Table 3-10. Background electricity demand (GJ).

Months	BAU-HOB-BUF	New BAU
1	0	0
2	0	0
3	0	0
4	0	0
5	0	148836.75
6	0	138522.75
7	0	138522.75
8	0	138522.75
9	0	148836.75
10	0	0
11	0	0
12	0	169464.75

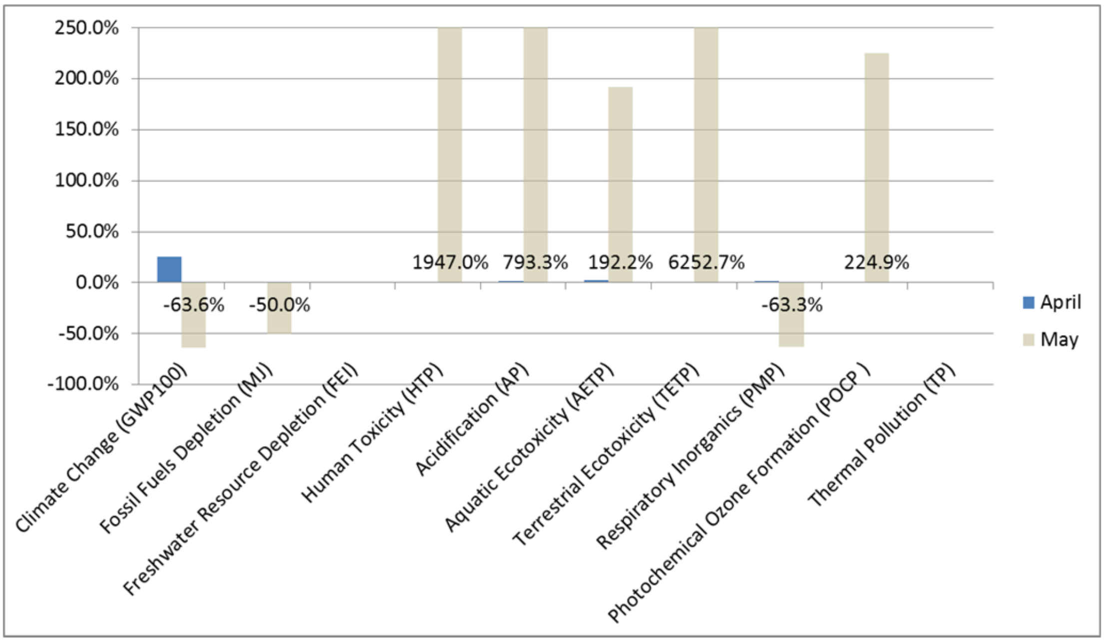

Figure 3-13. Relative difference in environmental performance for two months for the BAU and the BAU minus Heat only boilers minus buffer scenario.

3.5.2 BAU without heat buffer and without heat-only boilers

3.5.2.1 Main assumptions

The BAU without heat buffer and without heat-only boilers implies that peaks cannot be shaved by using stored thermal energy and that there is no possibility to produce only heat. It also means that electricity is always produced when thermal energy is required, even if electricity production is not economically interesting. Table 3-11 shows the dynamic input data. Both average heat demand and peak demand are the same as in Table 3-5. However, in order to be able to meet peak demands D33 is operating in more months, and D34 in all months.

3.5.2.2 Technology Assessment

The eco-efficiency values are presented in Table 3-12. As the boilers are not used, the exhausts to air follow the D33 and D34 values in Table 3-3. As the thermal energy production remains the same compared to the Business as usual scenario, the very significant difference is mainly due to the difference in exhaust air quality.

Ommitting the heat only boilers and the buffer, results in significant import of electricity from the background. As the environmental footprint of this background energy is worse than of the foreground system, the BAU performs for background related envirnmenal pressures much worse than in the scenario BAU minus boilers minus buffer. According to expectation, BAU is performing much better concering forground pressures such as fossil fuel depletion and climate change.

Table 3-11. SEAT input data for the BAU without heat buffer and without heat-only boilers scenario

				Heat Only Boiler		D33					D34			
	Avg heat	Peak				Efficiencies (%)					Efficiencies (%)			
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimey	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimey	ST (e)	ST (th)
1	646	1346	Min E	0	100	31.0	17.0	18.4	24.4	546	35.0	18.0	16.8	83.2
2	668	1175	Min E	0	100	31.0	17.0	18.4	24.4	568	35.0	18.0	15.9	84.1
3	585	1086	Max E	0	100	35.0	14.0	35.3	11.7	485	40.0	13.0	36.6	39.5
4	360	729	Max E	0		35.0	14.0	37.0		360	40.0	13.0	38.0	29.3
5	272	553	Min E	0						272	33.0	34.0	26.8	73.2
6	193	451	Min E	0						193	33.0	34.0	32.7	52.1
7	120	272	Min E	0						120	33.0	34.0	38.1	32.6
8	120	254	Min E	0						120	33.0	34.0	38.1	32.5
9	198	426	Min E	0						198	33.0	34.0	32.4	53.4
10	284	600	Min E	0						284	33.0	34.0	25.9	74.1
11	480	940	Max E	0	100	35.0	14.0	35.3	11.7	380	40.0	13.0	37.8	31.0
12	513	1005	Min E	0	100	31.0	17.0	18.4	24.4	413	35.0	18.0	21.9	63.5
Total					500					3939				

Table 3-12. Environmental comparison between BAU and BAU without the thermal energy buffer. (*) denotes midpoint indicators predominantly determined by background processes.

Midpoint Indicator	**Unit**	**BAU**	**BAU without buffers and boilers**	**Difference**
Climate Change	tCO$_{2,eq}$	845951399	1029823149	21.74%
Fossil Fuels Depletion	MJ	19114391986	23387844209	22.36%
Freshwater Resource Depletion (FEI)	m3	7308492	11900731	62.83%
Human Toxicity (*)	kg1,4-Db$_{eq}$	13681247	2042878	-85.07%
Acidification (*)	kgSO$_{2-,eq}$	2599453	777178	-70.10%
Aquatic Ecotoxicity	kg1,4-Db$_{eq}$	7383	8766	18.72%
Terrestrial Ecotoxicity (*)	kg1,4-Db$_{eq}$	515261	27424	-94.68%
Respiratory Inorganics	PM10$_{eq}$	3114	4211	35.21%
Photochemical Ozone Formation (*)	kgC$_2$H$_{4,eq}$	161156	98532	-38.86%
Water Thermal Pollution	MJ	2034598	3313024	62.83%

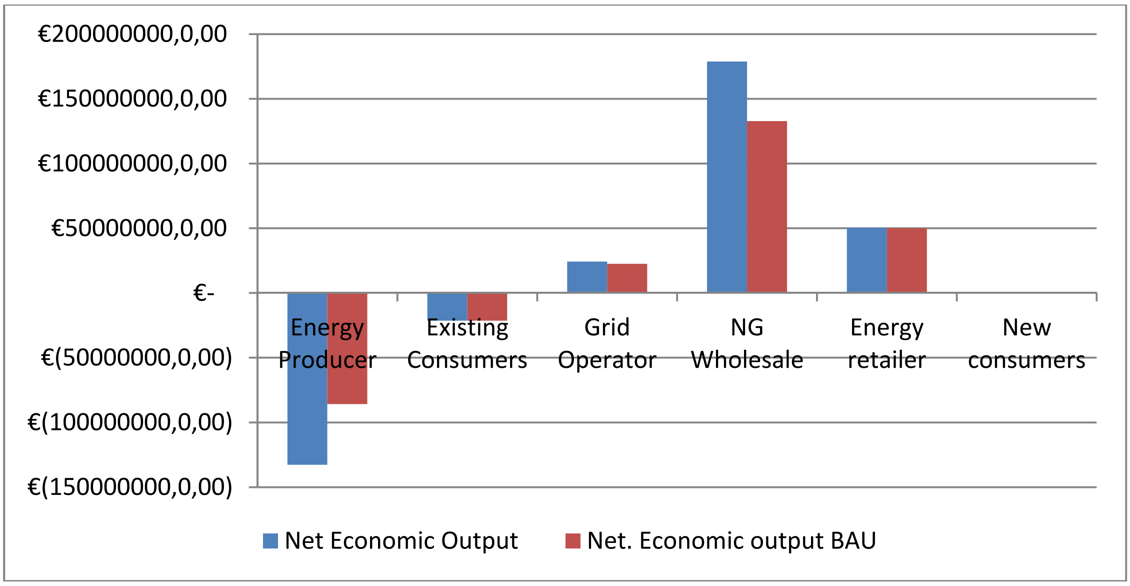

Figure 3-14. Distributional effects of costs and benefits: BAU, BAU without thermal buffer and BAU without thermal buffer and without heat-only boilers.

Consistent with the previous scenario (BAU minus buffer), higher use of D33 and D34, due to the missing heat-only boilers, results in even higher benefits for the wholesale market and less economic output for the heat producer. The energy producer has a significant higher loss. The total value added increases from B€98.4 (BAU) to B€99.5. It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential.

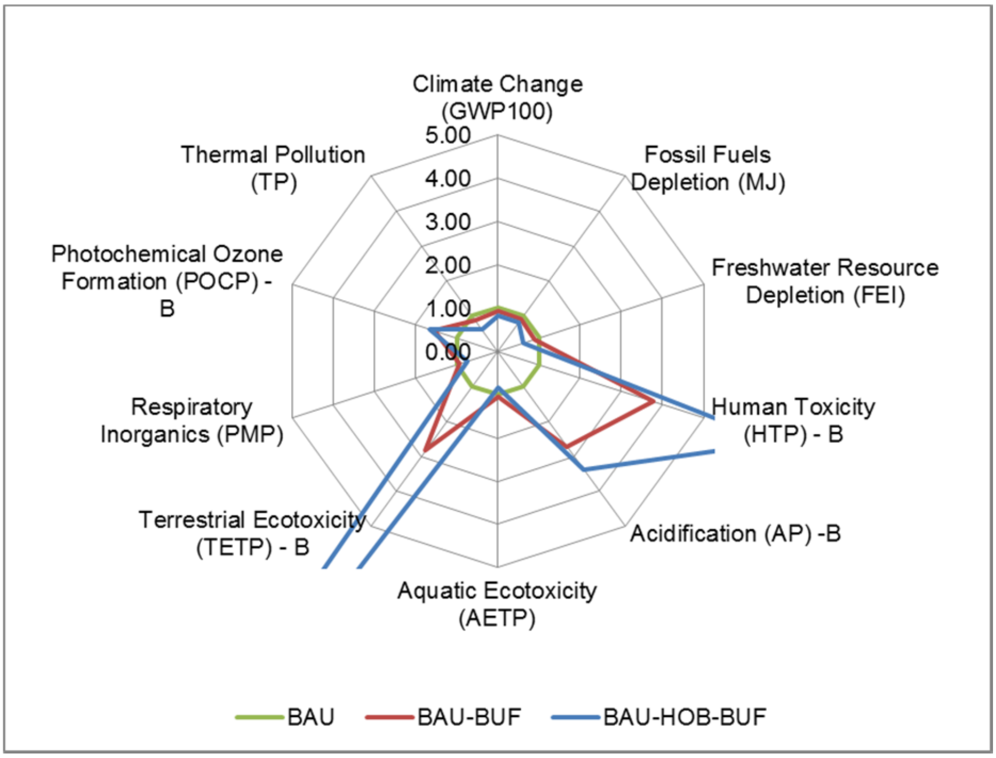

Figure 3-15. Graphical representation of the eco-efficiency of BAU and BAU without the thermal energy buffer eco-efficiency and without the heat-only buffer. "- B" depicts environmental pressures resulting from background processes.

It is evident from Figure 3-15 that the eco-efficiency for several environmental pressures is overall higher if both buffer and heat-only boiler are not installed. However, as in the previous case this is due to the electricity demand from the background. For almost all other environmental pressures the eco-efficiency of the BAU is higher.

3.5.3 Retrofitting 50000 homes

3.5.3.1 *Main assumptions*

In this scenario 50000 existing homes are retrofitted for district heating. The average energy demand per household in terms of natural gas use was used to compute thermal energy demand for heating and hot water. The values are included in Table 3-3. A calibration was made to correct for electricity use for cooking. Table 3-13 shows the dynamic input data. Both average heat demand and peak demand are much higher than in Table 3-5, as the number of connected houses rises by almost 50%. Consequently the installations are operating more often. However, it is striking that the demand can still easily be met, showing again the added value of the heat-only boilers and thermal energy storage.

Table 3-13. SEAT input data for the BAU with 50000 retrofitted houses

	Avg heat	Peak		Heat Only Boiler		D33					D34			
						Efficiencies (%)					Efficiencies (%)			
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimey	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimey	ST (e)	ST (th)
1	1005	2094	Min E	105						900	40.0	13.0	24.7	73.1
2	1039	1829	Min E	139						900	40.0	13.0	24.7	73.1
3	910	1689	Max E	0	100	35.0	14.0	35.3	11.7	810	40.0	13.0	26.4	65.8
4	560	1134	Max E	0	0	35.0	14.0	37.0		560	40.0	13.0	35.8	45.6
5	424	861	Min E	424										
6	300	702	Min E	300										
7	187	424	Min E	187										
8	187	395	Min E	187										
9	307	662	Min E	307										
10	442	934	Min E	442										
11	747	1462	Max E	0	0	35.0	14.0	37.0		747	40.0	13.0	27.6	60.7
12	798	1564	Min E	0						798	40.0	13.0	26.6	64.8
Total		6907		2091	100					4716				

3.5.3.2 *Technology Assessment*

The eco-efficiency values are presented in Table 3-14. Since the in-house boilers are not used anymore, the overall exhausts to air follow relatively more the D33 and D34 values in Table 3-3. The thermal energy provided by D34 increases from 3023 to

4716 GJ/h(th). The thermal energy production of the plant is much higher compared to the Business as usual scenario.

Table 3-14. Environmental comparison between BAU and BAU plus 50000 retrofitted houses. (*) denotes midpoint indicators predominantly determined by background processes.

Midpoint Indicator	**Unit**	**BAU**	**BAU plus 50000 retrofitted houses**	**Difference**
Climate Change	$tCO_{2,eq}$	845951399	898007495	6.15%
Fossil Fuels Depletion	MJ	19114391986	20257583762	5.98%
Freshwater Resource Depletion	m3	7308492	5512303	-24.58%
Human Toxicity (*)	$kg1,4\text{-}Db_{eq}$	13681247	13796190	0.84%
Acidification (*)	$kgSO_{2}\text{-}_{,eq}$	2599453	2631136	1.22%
Aquatic Ecotoxicity	$kg1,4\text{-}Db_{eq}$	7383	6236	-15.53%
Terrestrial Ecotoxicity (*)	$kg1,4\text{-}Db_{eq}$	515261	517059	0.35%
Respiratory Inorganics	$PM10_{eq}$	3114	3296	5.84%
Photochemical Ozone Formation (*)	$kgC_2H_{4,eq}$	161156	165600	2.76%
Water Thermal Pollution	MJ	2034598	1534560	-24.58%

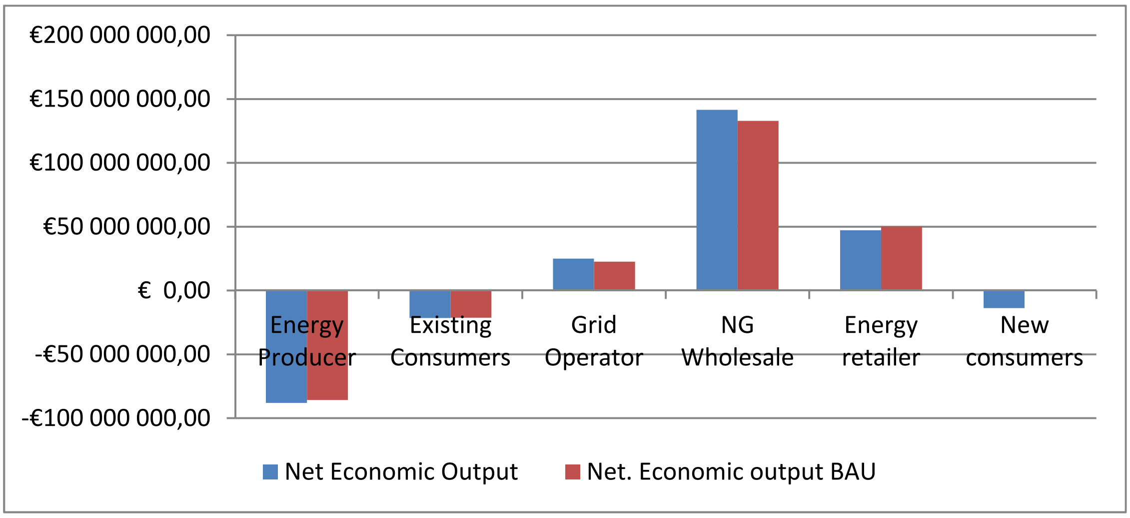

Figure 3-16. Distributional effects of costs and benefits: BAU and 50000 retrofitted houses

Consistent with the previous scenario, the higher use of D34, resulting in increased electricity production at a low price and increased natural gas consumption, results in an increase in the economic output of the natural gas wholesale market and a lower economic output for the producer. The new thermal energy consumers have a marginal lower economic output due to small differences in consumer prices and taxes. The electricity grid operator has a marginal higher income due to a higher electricity output. It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential.

Figure 3-17 shows that the overall eco-efficiency is not changing very much. A reason for the that is the decrease of the total value added from B€98.4 to €Eco-efficiency Retrofitting existing houses B€ 90.2, compensating the gains in environmental benefits depicted in Table 3-14.

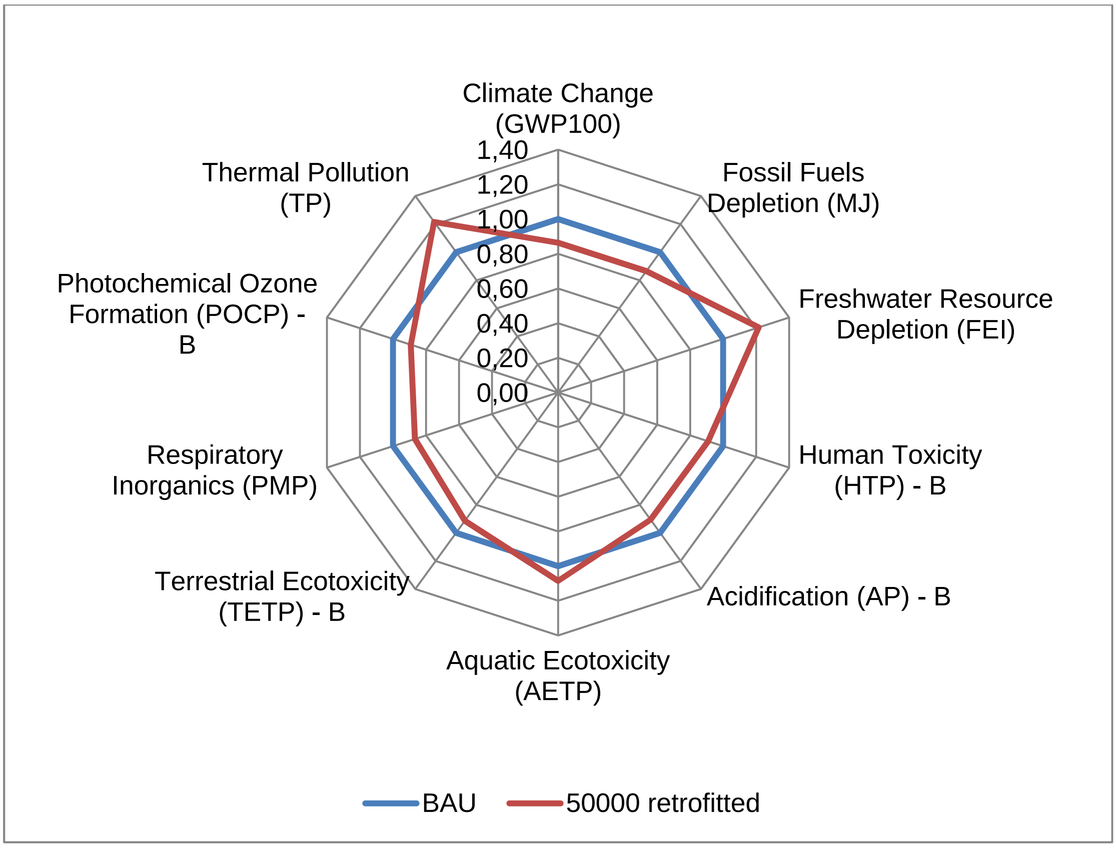

Figure 3-17. Graphical representation of the eco-efficiency of BAU and 50000 retrofitted houses. "- B" depicts environmental pressures resulting from background processes.

3.5.4 Insulating 50000 retrofitted homes

3.5.4.1 *Main assumptions*

Like in the previous scenario 50000 existing homes are retrofitted for district heating but in addition they are insulated, reducing the energy demand for heating by 22%. Both average heat demand and peak demand (Table 3-15) are much higher than in Table 3-5, but evidently they are significantly lower than in Table 3-13.

3.5.4.2 *Technology Assessment*

Table 3-16 provides insight in the environmental performance of the scenario. If one compares the values to the values without insulation (Table 3-14), it is clear that the reduction is lower. This is the effect of a different distribution of thermal energy production in the two scenario's, resulting in different values for air pollution.

Table 3-15. SEAT input data for the BAU with 50000 retrofitted and insulated houses

	Avg heat	Peak		Heat Only Boiler		D33					D34			
						Efficiencies (%)					Efficiencies (%)			
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimey	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimey	ST (e)	ST (th)
1	939	1949	Min E	39	0					900	40.0	13.0	24.7	73.1
2	972	1707	Min E	72	0					900	40.0	13.0	24.7	73.1
3	852	1576	Max E	0	0	35.0	14.0	37.0		852	40.0	13.0	25.6	69.1
4	530	1065	Max E	0	0	35.0	14.0	37.0		530	40.0	13.0	36.1	43.2
5	404	813	Min E	404										
6	290	668	Min E	290										
7	186	410	Min E	186										
8	185	384	Min E	185										
9	297	631	Min E	297										
10	421	881	Min E	421										
11	702	1367	Max E	0	0	35.0	14.0	37.0		702	35.0	18.0	10.7	89.3
12	749	1461	Min E	0	0					749	35.0	18.0	8.9	91.1
Total				1893	0					4632				

Table 3-16. Environmental comparison between BAU and BAU plus 50000 retrofitted and insulated homes.

Midpoint Indicator	**Unit**	**BAU**	**BAU plus 50000 retrofitted and insulated houses**	**Difference**
Climate Change	$tCO_{2,eq}$	845951399	886327427	4.77%
Fossil Fuels Depletion	MJ	19114391986	19973466894	4.49%
Freshwater Resource Depletion	m^3	7308492	5821274	-20.35%
Human Toxicity (*)	$kg1,4\text{-}Db_{eq}$	13681247	13770825	0.65%
Acidification (*)	$kgSO_{2^-,eq}$	2599453	2621054	0.83%
Aquatic Ecotoxicity	$kg1,4\text{-}Db_{eq}$	7383	6129	-16.99%
Terrestrial Ecotoxicity (*)	$kg1,4\text{-}Db_{eq}$	515261	516703	0.28%
Respiratory Inorganics	$PM10_{eq}$	3114	3255	4.52%
Photochemical Ozone Formation (*)	$kgC_2H_{4,eq}$	161156	164406	2.02%
Water Thermal Pollution	MJ	2034598	1620574	-20.35%

Figure 3-18 shows that only marginal changes occur in the value added. The insulated houses require less thermal energy and hence the value added is slightly lower compared to the non-insulated houses (B€ 90.2 without insulation, B€ 88.8 with insulation).

It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential.

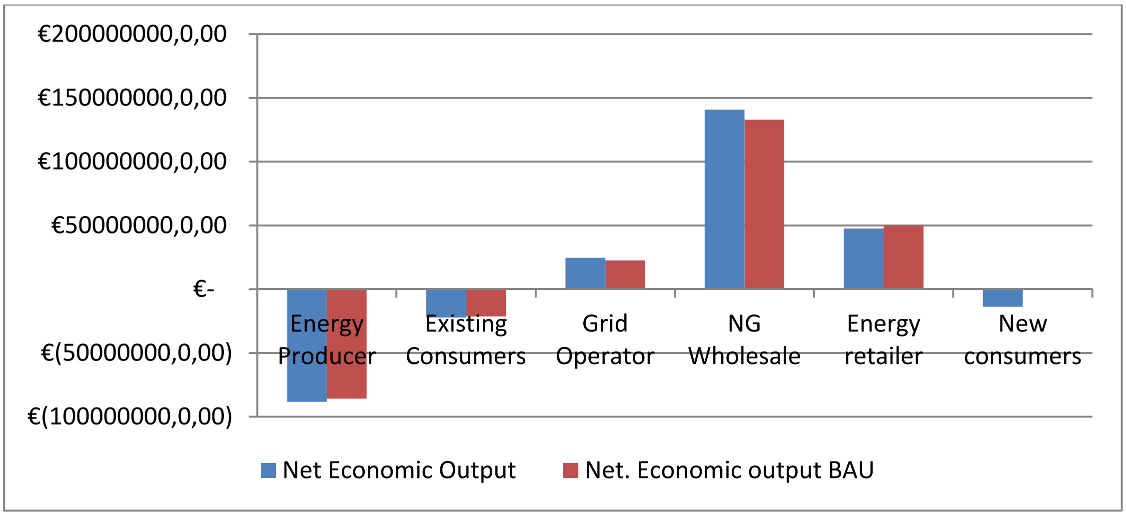

Figure 3-18. Distributional effects over actors of BAU and BAU plus 50000 retrofitted and insulated homes.

Finally, Figure 3-19 provides insight in the eco-efficiency of the scenario. Insulation improves the eco-efficiency concerning thermal pollution and freshwater depletion beyond the improvements of the retrofitting scenario. Like in the retrofitting scenario, the explanation of the lower eco-efficiency is mainly due to a significant reduction in total value added, from B€ 98.4 to B€ 88.8.

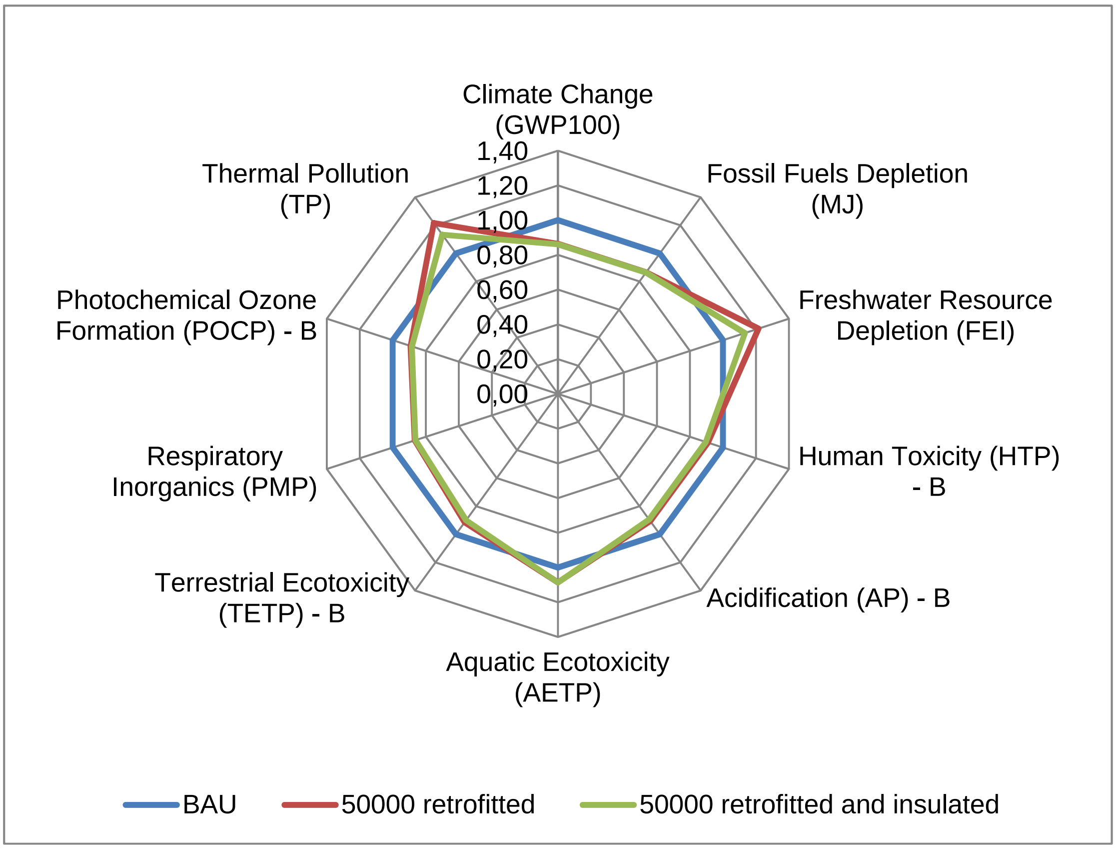

Figure 3-19. Graphical representation of the eco-efficiency of BAU, 50000 retrofitted houses, and 50000 retrofitted and insulated houses. "- B" depicts environmental pressures resulting from background processes.

3.5.5 Pre-heating potable water

3.5.5.1 Main assumptions

In this case heat is used to preheat potable water. The energy used for hot water is lower if the incoming water is of higher temperature. As this incoming water is usually significantly below 15°C and regulations allow incoming water up to 25°C, using residual heat results in lower natural gas use at the domestic level. The overall heat demand for heating houses is identical to the BAU plus 50000 retrofitted houses. As the retrofitted houses have a backup natural gas system, potable water-preheating can be discontinued when a shortage of access heat exists. The houses are not additionally insulated.

We assumed that soil is a sufficient insulator to neglect heat losses to the environment. Of course, when the system becomes operational due to warming the soil some heat loss will occur.

In this scenario investment costs were not considered. The financial benefit lies with the consumers, who require less natural gas. The dynamic input data are included in Table 3-17.

Table 3-17. SEAT input data for the BAU with potable water preheating scenario

	Avg heat	Peak		Heat Only Boiler		D33					D34			
						Efficiencies (%)					Efficiencies (%)			
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimey	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimey	ST (e)	ST (th)
1	980	2057	Min E	80	0					900	40.0	13.0	24.7	73.1
2	1011	1787	Min E	111	0					900	40.0	13.0	24.7	73.1
3	885	1652	Max E	0	0	35.0	14.0	37.0		885	40.0	13.0	25.0	71.8
4	534	1095	Max E	0	0	35.0	14.0	37.0		534	40.0	13.0	36.1	43.5
5	399	823	Min E	399	0									
6	274	664	Min E	274	0									
7	162	386	Min E	162	0									
8	162	357	Min E	162	0									
9	282	623	Min E	282	0									
10	417	897	Min E	417	0									
11	721	1423	Max E	0	0	35.0	14.0	37.0		721	40.0	13.0	28.1	58.6
12	773	1527	Min E	0	0					773	40.0	13.0	27.1	62.8
Total				1886	0					4714				

3.5.5.1 Technology Assessment

Table 3-18 provides insight in the environmental performance of the scenario. In contrast to what should be expected, and similar to insulation, many environmental indicators change to the worse. This is amongst others the effect of a different distribution of thermal energy production in the two scenario's, resulting in different values for air pollution.

Table 3-18. Environmental comparison between BAU and BAU plus potable water preheating.

Midpoint Indicator	**Unit**	**BAU**	**BAU plus potable water preheating**	**Difference**
Climate Change	$tCO_{2,eq}$	845951399	893134863	5.58%
Fossil Fuels Depletion	MJ	19114391986	20120483379	5.26%
Freshwater Resource Depletion	m3	7308492	5985734	-18.10%
Human Toxicity (*)	$kg1,4\text{-}Db_{eq}$	13681247	13782939	0.74%
Acidification (*)	$kgSO_{2}\text{-}_{,eq}$	2599453	2626263	1.03%
Aquatic Ecotoxicity	$kg1,4\text{-}Db_{eq}$	7383	6193	-16.12%
Terrestrial Ecotoxicity (*)	$kg1,4\text{-}Db_{eq}$	515261	516846	0.31%
Respiratory Inorganics	$PM10_{eq}$	3114	3279	5.29%
Photochemical Ozone Formation (*)	$kgC_2H_{4,eq}$	161156	165020	2.40%
Water Thermal Pollution	MJ	2034598	1666358	-18.10%

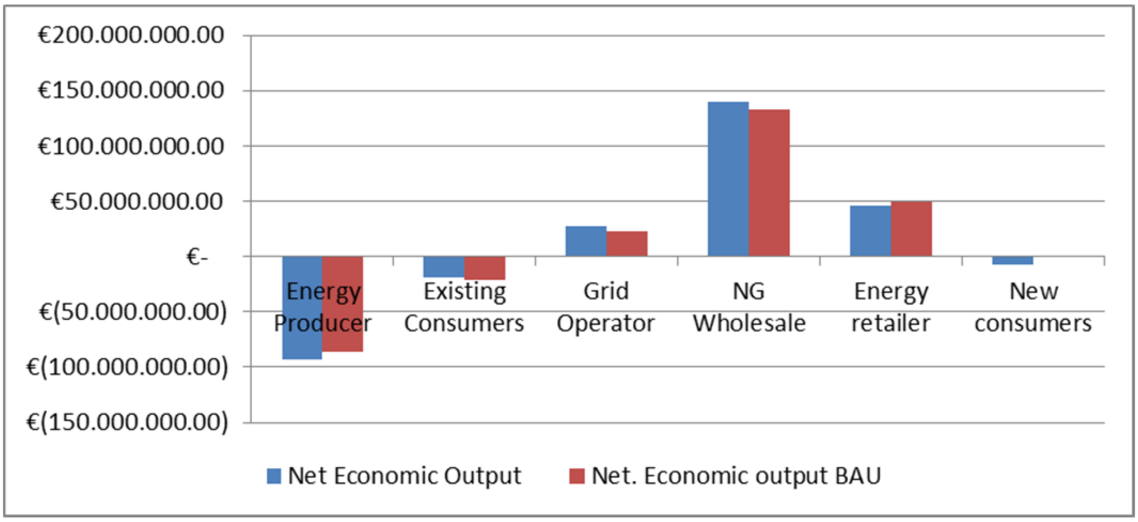

Figure 3-20. Distributional effects over actors of BAU and BAU plus potable water preheating.

Figure 3-20 shows that only marginal changes occur in the distribution of the value added. Evidently, the consumers require less thermal energy: Both existing thermal energy users and the traditional consumers require have a higher (less negative) value added.

It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential.

Overall, the total value added is significantly lower than in BAU but higher compared to insulation or retrofitting:

BAU	B€ 98.4
Retrofitting existing houses	B€ 90.2
Insulation	B€ 88.7
Potable Water Preheating	B€ 93.6

In the end, the minor improvements in environmental aspects and the increase in total value added result in mariginal changes in the eco-efficiency of the overall system (Figure 3-21).

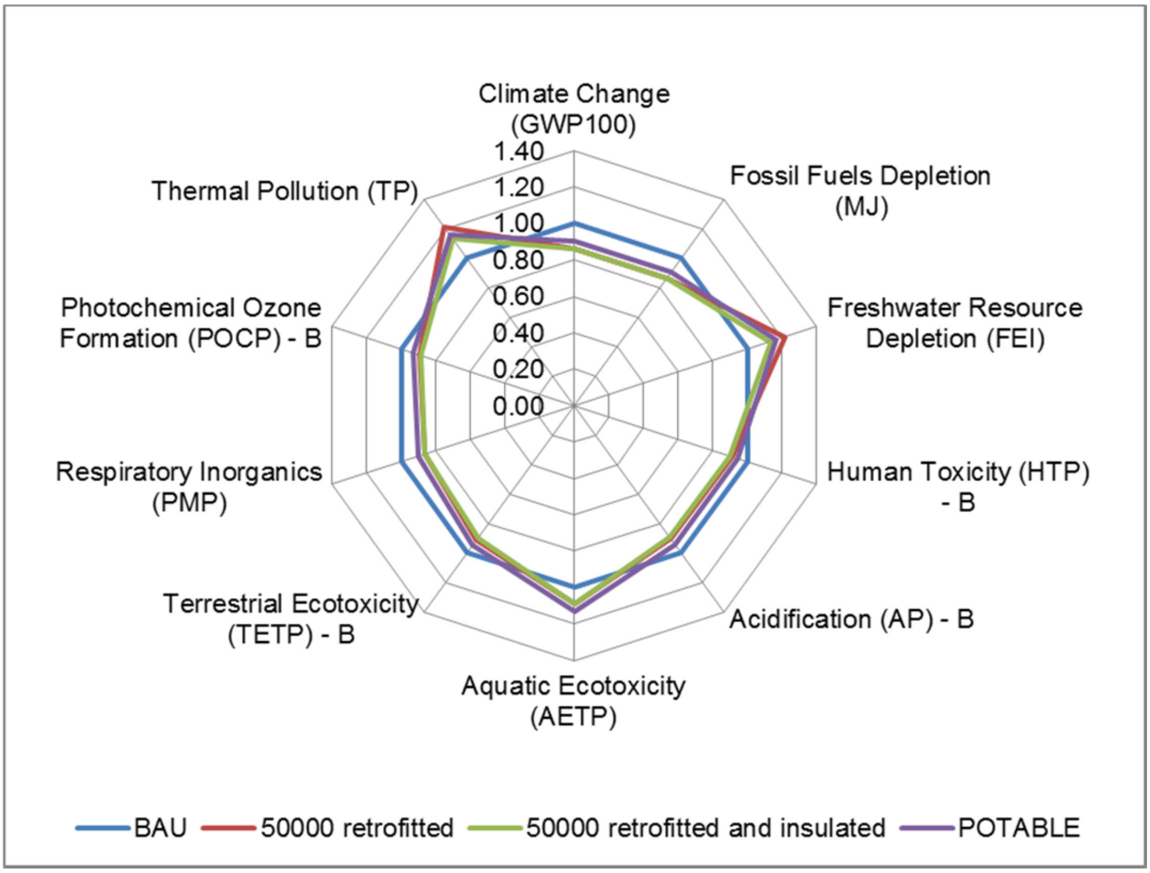

Figure 3-21. Graphical representation of the eco-efficiency of BAU and potable water preheating. "- B" depicts environmental pressures resulting from background processes.

3.5.6 Implementing micro-CHP

3.5.6.1 Main assumptions

In this case study, 25000 houses are retrofitted for district heating while the remaining 25000 homes are retrofitted to have micro-CHPs. Micro-CHP's are installations at domestic level, allowing production of both electricity and heat.

The current regulation is that consumers receive the same price per kWh for electricity delivered to the grid than taken from the grid. This implies that during thermal peak demands the houses with CHP deliver electricity to the grid, while the other producers need to produce less electricity.

In this case study we assume that the atmospheric pollution of micro-CHP follows the exhaust of boilers.

We also assumed the following data for the micro CHP:

Thermal efficiency	90%
Electrical efficiency	35%

Via some computation considering degree days the following data have been developed:

NG use of a micro-CHP homes:	Nm^3	1937
Total electricity production	kWh	5960
Own electricity consumption	kWh	3270
Sales to grid	kWh	2690
Factor		1.8

Table 3-19 provides the dynamic input data for this scenario.

Table 3-19. SEAT input data for the BAU with 25000 retrofitted and 25000 micro CHP houses

	Avg heat	Peak		Heat Only Boiler		D33					D34			
						Efficiencies (%)					Efficiencies (%)			
Month	GJ/h	GJ/h	Target	GJ/h (th)	GJ/h (th)	GT (e)	Chimey	ST (e)	ST (th)	GJ/h (Th)	GT (e)	Chimey	ST (e)	ST (th)
1	826	1720	Min E	15						811	40.0	13.0	26.4	65.8
2	853	1502	Min E							853	40.0	13.0	25.6	69.3
3	747	1388	Max E		100	35.0	14.0	35.3	11.7	647	40.0	13.0	34.8	52.7
4	460	931	Max E			35.0	14.0	37.0		460	40.0	13.0	36.9	37.5
5	348	707	Min E	348										
6	246	577	Min E	246										
7	154	348	Min E	154										
8	154	324	Min E	154										
9	253	544	Min E	253										
10	363	767	Min E	363										
11	614	1201	Max E			35.0	14.0	37.0		614	40.0	13.0	35.2	50.0
12	656	1285	Min E							656	35.0	18.0	12.5	87.5
Total				1533	100									

3.5.6.2 Technology Assessment

Table 3-20 provides insight in the environmental performance of the scenario. In contrast to what was to be expected, many environmental indicators change to the better. This must be due to the background electricity production, which decreases due to the surplus of electricity produced by the micro-CHP. In other words, the environmental effects of the background electricity production are worse than the foreground effects of electricity production, which is unreasonable, but still a logical effect of the background parameters from the LCID database. Of course, the change in total heat demand, the different thermal energy production per plant and differences in efficiencies contribute, too.

Figure 3-22 shows that only marginal changes occur in the distribution of the value added. As the micro-CHP clients produce electricity which they are able to sell for the same price as they would buy, these 25000 homes have a positive added value. Evidently the grid operator has less income from electricity. New consumers now have a zero net economic output. This is due to the fact that the 25000 micro CHP owners compensate exactely the 25000 ordinary retrofitted house, and new consumers combine both retrofitted and micro-CHP users.

It should be noted that the economic values on the Y-axis are based on a significant number of assumptions, and are likely far off from the reality. The relative values are essential. Overall, the total value added is comparable to the BAU resulting in a reasonable increase in eco-efficiency, as can be seen in Figure 3-23.

Finally, Figure 3-23 provides insight in the eco-efficiency of the scenario. Interestingly, for many indicators the eco-efficiency is worse than the BAU. This demonstrates the sensitivity of the results for changes in the distribution of thermal energy production over D34 and the heat-only boilers.

Table 3-20. Environmental comparison between BAU and BAU 25000 retrofitted house and 25000 micro-CHP (mCHP) houses.

Midpoint Indicator	**Unit**	**BAU**	**BAU plus mCHP**	**Difference**
Climate Change	$tCO_{2,eq}$	845951399	917646674	8.48%
Fossil Fuels Depletion	MJ	19114391986	21475420442	12.35%
Freshwater Resource Depletion	m3	7308492	6557830	-10.27%
Human Toxicity (*)	$kg1,4\text{-}Db_{eq}$	13681247	9694456	-29.14%
Acidification (*)	$kgSO_{2^-,eq}$	2599453	1981003	-23.79%
Aquatic Ecotoxicity	$kg1,4\text{-}Db_{eq}$	7383	6509	-11.84%
Terrestrial Ecotoxicity (*)	$kg1,4\text{-}Db_{eq}$	515261	345814	-32.89%
Respiratory Inorganics	$PM10_{eq}$	3114	3365	8.06%
Photochemical Ozone Formation (*)	$kgC_2H_{4,eq}$	161156	142399	-11.64%
Water Thermal Pollution	MJ	2034598	1825623	-10.27%

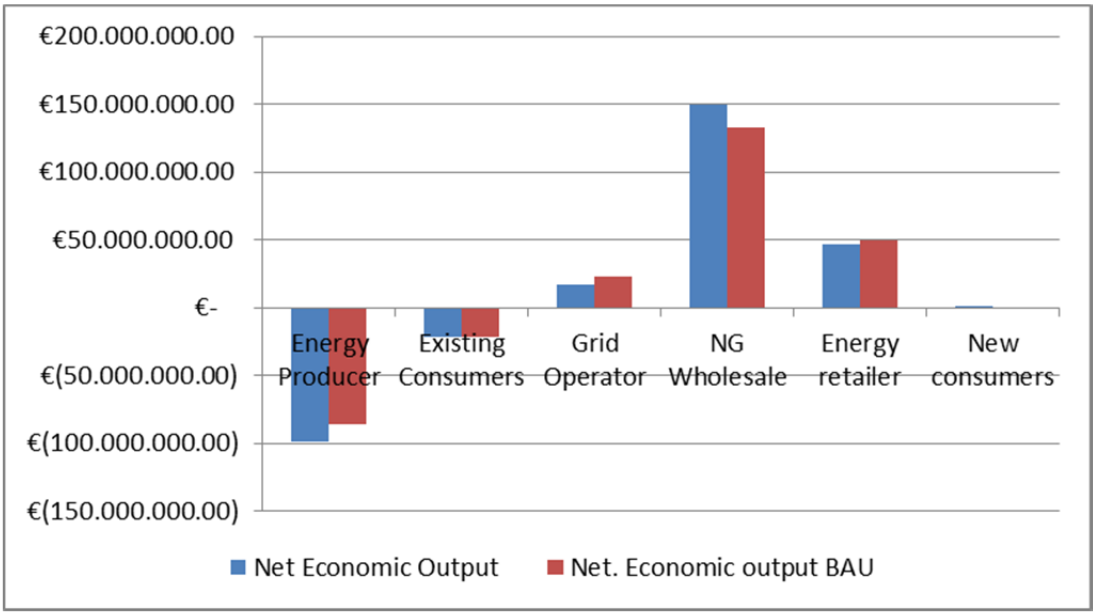

Figure 3-22. Distributional effects over actors of BAU and BAU plus 25000 retrofitted houses and 25000 mCHP.

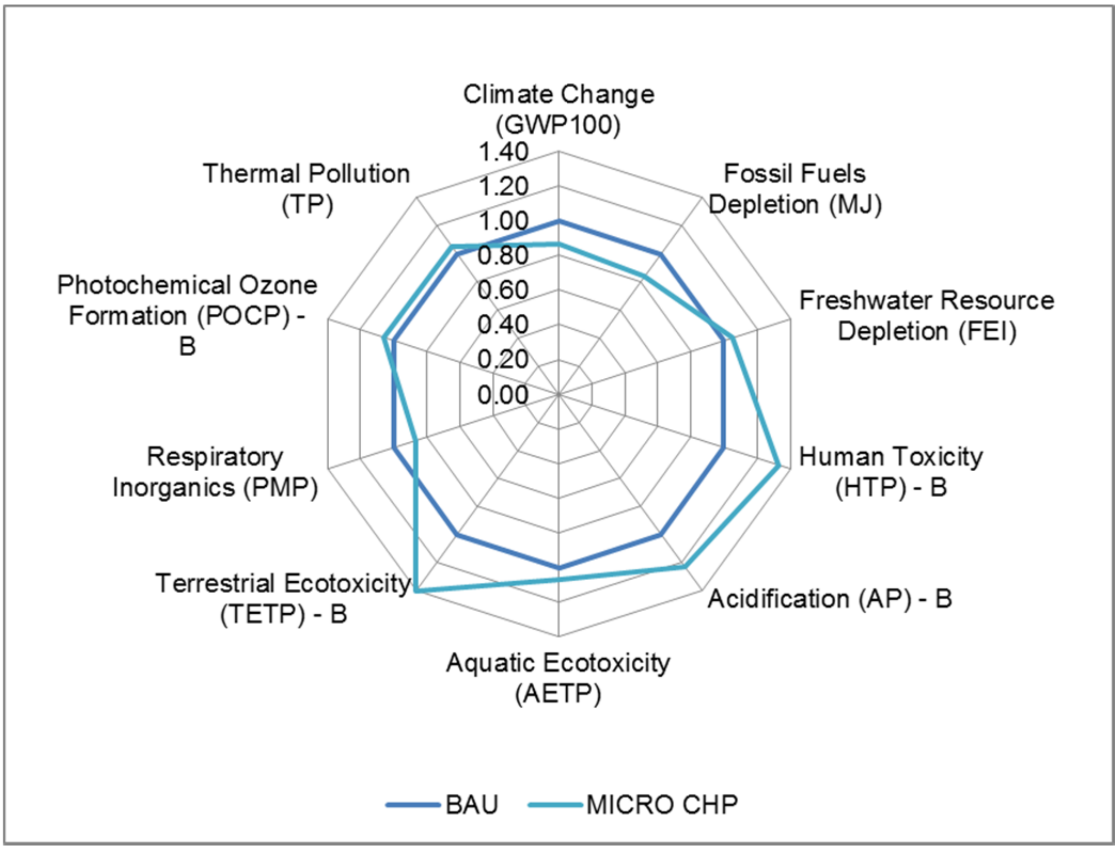

Figure 3-23. Graphical representation of the eco-efficiency of BAU and potable water preheating. "- B" depicts environmental pressures resulting from background processes.

3.6 Assessment of Technology Scenarios

Before entering discussing joint scenarios, Table 3-21, provides an overall view on the operations of D33 and D34, summarizing some essential issues concerning the eco-efficiency peculiarities. D33 is operating mainly when electricity prices are profitable (month 3, 4, 11). Changes only occur in a few months when thermal energy demand can not be met as there is no buffer and/or heat only boiler installed. D34 provides a different picture. In December this plant is operating in all scenario's against a poor electricity price, causing reduction in total value added.

Table 3-21. Operations of the energy plants D33 and D34.

	D33							D34						
	BAU	BAU-BUF	BAU-BUF-HOB	Retrofitting	Insulation	Potable	m-CHP	BAU	BAU-BUF	BAU-BUF-HOB	Retrofitting	Insulation	Potable	m-CHP
1		Y	Y					Y	Y	Y	Y	Y	Y	Y
2		Y	Y					Y	Y	Y	Y	Y	Y	Y
3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5									Y	Y				
6										Y				
7										Y				
8										Y				
9										Y				
10								Y	Y	Y				
11	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
12			Y						Y	Y	Y	Y	Y	Y

3.6.1 Technology scenario focusing on resource efficiency

The BAU scenario is the main scenario focusing on resource efficiency. While the heat-only boilers have already been installed, the thermal heat storage is currently being constructed. In this case study, the two scenario's "BAU without heat buffer" and "BAU without heat buffer and without heat-only boilers" are the two scenarios that are compared to the BAU, as if they can be removed from the system.

The figure below (Figure 3-24) shows all environmental indicators charted against the economic performance fo the scenario BAU-HOB-BUF. The figure does not provide details (see relevant sections). The important conclusion is that the economic performance is hardly changing, while the environmental performance is decreasing for many environmental indicators due to the importing of electricity from the background system.

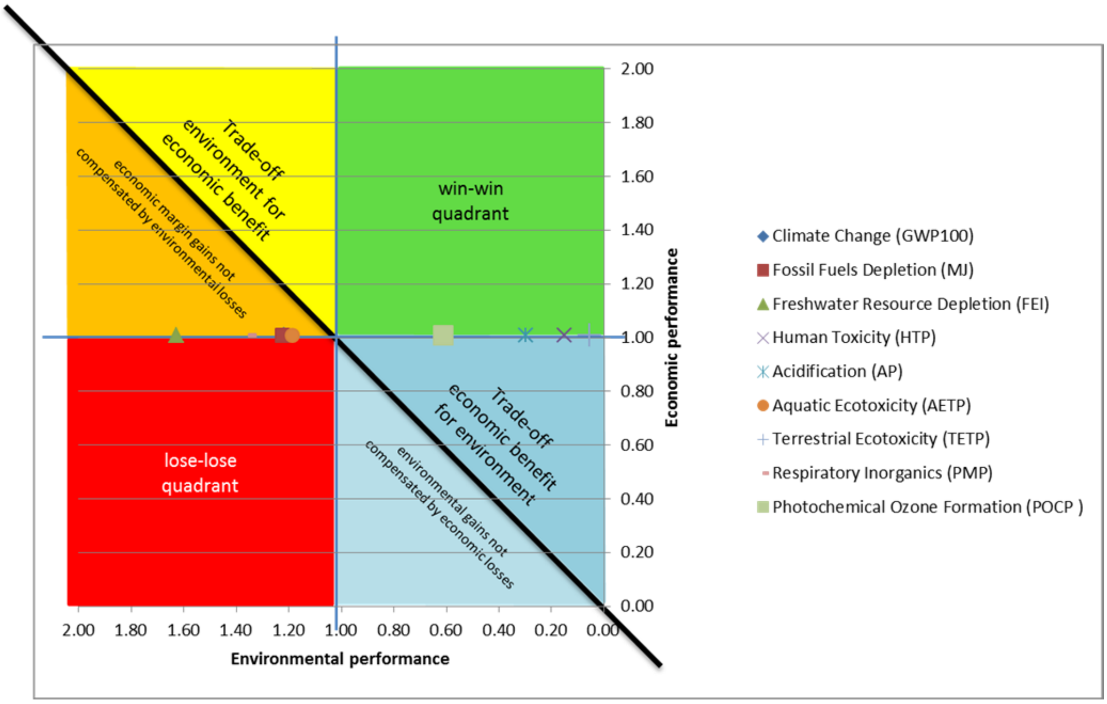

Figure 3-24. Environmental performance versus economic performance for BAU without thermal buffer and heat only boilers, compared to the BAU which is the origin.

3.6.2 Technology scenario focusing on pollution prevention

The scenarios focusing on pollution prevention can be considered all the other scenarios discussed in the previous sections. For illustrative purposes only the scenario of retrofitted and insolated houses is included in Figure 3-25.

It is evident that for all scenarios there are some environmental parameters that do not show reduced environmental burden, but the majority of indicators seems to improve. With respect to the economic performance, the total added value is reduced. Hence, given the study at hand, eco-efficiency is not improved.

However, considering several features of the scenarios, the results are too uncertain to be able to draw firm conclusions. This will be debated in the next chapter.

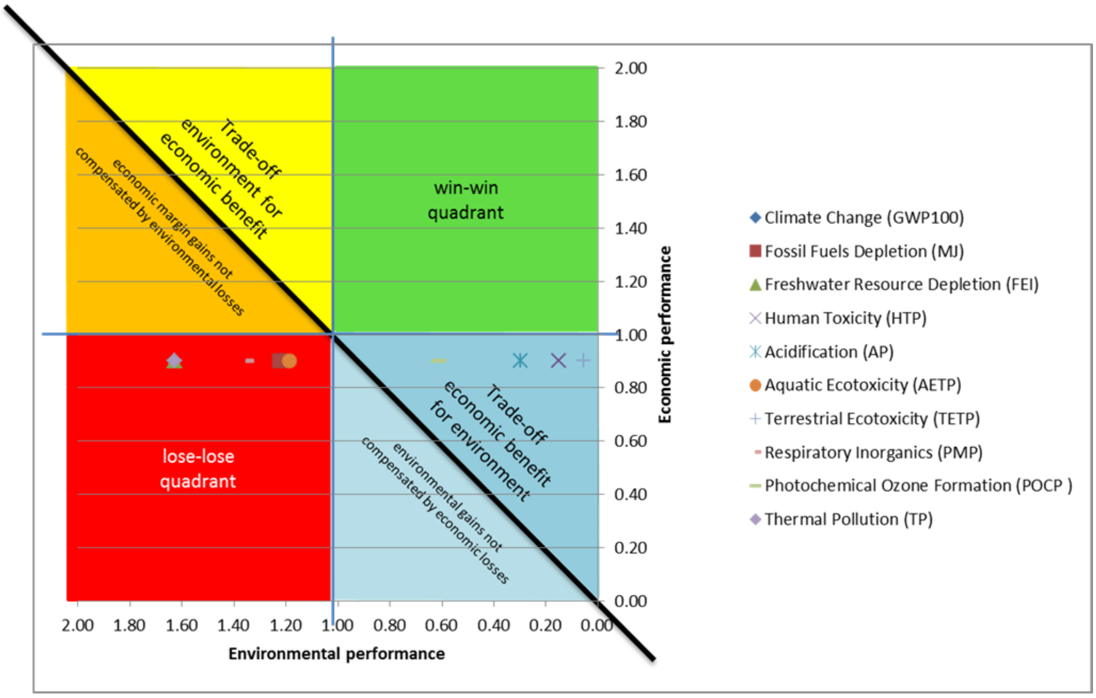

Figure 3-25. Environmental performance versus economic performance for 50000 retrofitted and insulated houses compared to the BAU which is the origin.

3.6.3 Overall eco-efficiency assessment discussion

This case study has developed into a very complex case study due to three main reasons:

1. The inclusion of temporal variation;
2. The varying and uncertain efficiencies of the D33 and D34 plants at different thermal energy demands; the variation in use of both D33 and D34.
3. The general assumptions about economic data.

Temporal variation

Table 3-3 provides insight in ‘degree days’ per month and peaks per months. These data have been used to determine monthly total demand and monthly peaks. Several assumptions about the distribution of daily heat demand needed to be made. In particular the peak demand is important as it determines which installations (D33, D34, heat-only boilers) need to be operational. While initializing a plant takes time, they can be operated in a more flexible way than on a monthly basis. If a lower temporal variation would be used, it could turn out that D33 and D34 can be used less or more. As has been demonstrated, turning the installations off results in electricity import, adversely affecting the environmental pressure due to background processes. An improvement to consider is to operate D33 and D34 in such a way that a net electricity production is achieved, avoiding the effects of background electricity imports.

Varying and uncertain efficiencies

The thermal energy production from the different installations varies significantly. As the different installations all vary, analysing results is already challenging. It becomes almost impossible if the variation in efficiencies is considered. The operating efficiencies have been included in the table for each scenario. In hindsight it could have been advisable to distribute the heat demand differently over the CHP plants and the heat only boiler, maximizing the boiler use given constraints on minimum efficiency the plants.

While the computation of the efficiencies for the CHP plants is considered reliable, the assumptions about the efficiencies of in-house boilers, micro-CHP and heat-only boilers are likely not reflecting the situation in the field. While the true values may not differ too much, small changes have an immediate impact on the eco-efficiency.

Furthermore, as Table 3-21 indicates, plants are not turned on/off consistently. This has a major impact n results which can only be discussed by analysing the detailed monthly data.

Economic data

The operational costs of the different installations have been guessed. In particular the operational costs at times when the plants are not operated may have been set too high, implying very significant costs included in the net economic output even if plants are not operating.

The profitable electricity price, has been set almost arbitrarily based and monthly averages have been used to determine if electricity is profitable. However, temporal variation in the period of one month can be significant, and also the plants can be operated with more operational variability, as has been pointed out in section ‘temporal variation’. If the profitable price would have been set lower, the net economic output for producers change drastically. More importantly, it may result that some months in which plants are not operating become economically relevant, solving the issue of importing electricity from the background.

It should also be noted that investment costs and some taxes have been omitted from the analysis.

Background effects

As metioned several times before, the background electricity production has an adverse impact on the results. The effect of this needs closer inspection: Small adjustments in the electricity production could result in background electricity being replaced by foreground electricity.

Exhaust gas quality – exhaust cleaning

The assumption was made that in-house boilers and the heat-only boilers have identical exhausts per normalized natural gas volume. We could not verify this assumption. In addition, technologies for further washing exhaust gases of the different installations, mainly D34 and heat-only boilers were not looked into.

3.7 Conclusions and policy Recommendations

The previous section has brought up a number of issues which render the results questionable. The results nevertheless demonstrate the relevance of a systemic approach to analyse the energy system. It has become evident that in particular in the environmental part of eco-efficiency, improvements can be achieved. The energy demand and supply market is changing significantly. Thermal energy storage is implemented, but also electrical energy could be stored: As (car) batteries are improving constantly, installing such batteries in houses may be a viable way forward to reduce problems resulting from irregular small scale energy production, mainly in the fields of wind and solar power. With small-scale energy producers on the rise, the main power installations are additionally challenged to be able to fill the gaps in times of peak demands or low production by small-scale energy producers.

The liberalisation of the energy market makes it more challenging to coordinate production required to minimize environmental burden and maximize societal added value, while keeping a resilient and robust energy system.

The EcoWater methodology allows to analyse the energy system and assess both the economic and environmental aspects. While several actions can be taken to improve the results, it remains to be seen if the level of detail required to make operational or strategy decisions can be reached. Nevertheless, the results can be used as discussion starters between various stakeholders, including policy makers, to discuss steps to improve the eco-efficiency on a systemic level.

4 Case Study #7 Dairy industry

The case study implementation area includes the total Danish Dairy sector. Figure 4-1 shows the distribution of dairies in Denmark. As can be seen the dairies are located mainly in Jutland and Funen. Circles indicate co-operatively owned dairies and triangular symbols indicate private owned dairies. The circle shows the location of the milk powder producing dairy HOCO in Holstebro which participated in the project.(Arla, 2011 and 2013).

Figure 4-1. Location of dairies in Denmark showing also the dairy studies

HOCO has already reduced its water and energy use significantly over the last decade and is striving to reduce its use further. HOCO is part of the Arla Group which has as environmental target to reduce its emissions of greenhouse gases and water use by 3% each year up to 2020. The Arla Group target is also a target for the individual dairies. (Arla, 2010 and 2013). As it can be seen HOCO has managed to increase its production significantly and reduced the use of water, energy and waste water discharge (Figure 4-2).

This has been achieved through the installation of more efficient process technology, more efficient cleaning in place technologies and better management and lean implementation. HOCO has also installed larger tanks to which reuse water can be returned and used for a purpose which fits the quality of the reuse water. As a safeguard measure the reuse water is treated with UV light prior to its use in the dairy. The management of HOCO has started looking also at possibilities to increase efficiency by cooperating with other actors in the water value chain.

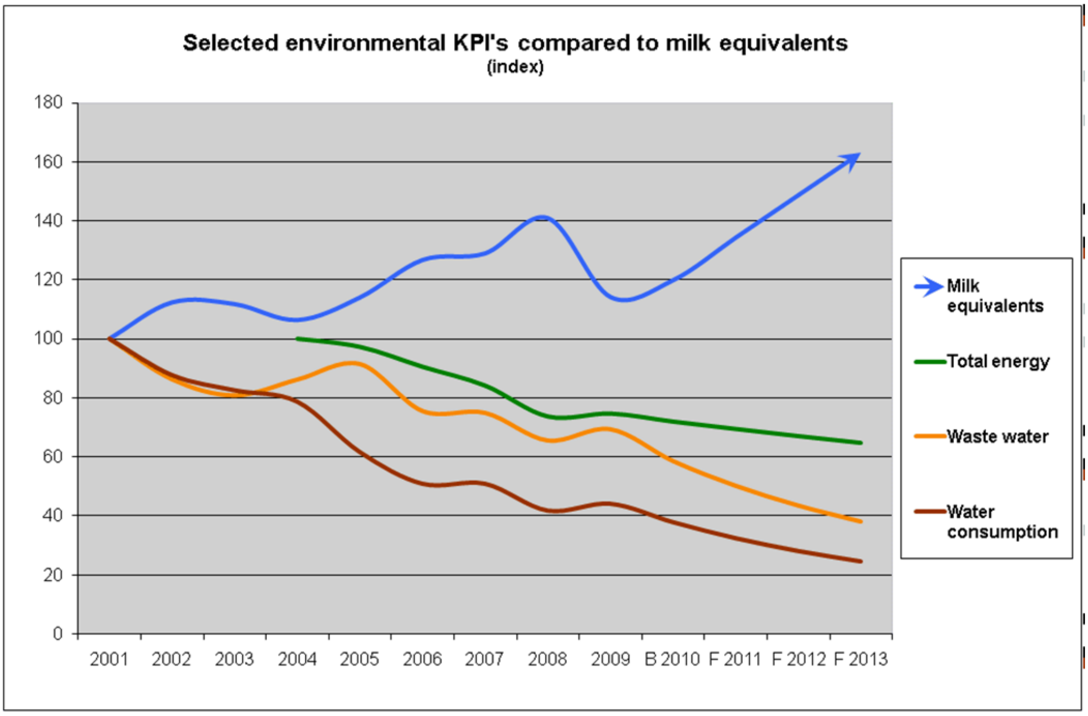

Figure 4-2. Water, energy and waste water discharge and milk equivalents

Prospects for improving the system's overall eco-efficiency are investigated. Through the identification of the environmentally weak stages of the system, as well as the selection and implementation of innovative technologies that would upgrade the value chain, two alternative technology scenarios are formulated and compared to the baseline scenario. The analysis that follows is mainly focused on the study of the potential to improve water and energy efficiency through an increased use of the water in the milk water, but also on reuse of water which today leaves the dairy as water vapour. Other solutions analysed are anaerobic pre-treatment of the waste water discharged to the waste water treatment

4.1 Finalized baseline scenario assessment

4.1.1 Systems boundaries and functional unit

The studied system is divided into the foreground and the background sub-systems. The foreground system contains the water supply, the water use chain (the dairy), the waste water treatment plant, the biogas plant and transport. The latter stage has been included at transport by lorries of raw milk, milk powder is a substantial energy user in dairy operations. These stages enclose the relevant actors involved in the system and the interactions among them. The actors of the system, both directly and indirectly involved, are the following:

- The Water Utility- Vestforsyning A/S operating both the water supply and the waste water treatment system
- The dairy plant- HOCO being part Arla Foods in Denmark
- The biogas plant (Maarberg Biorefinery)
- Private companies transporting milk, milk powder and other milk ingredients under contract with the dairy.

The background system consists of the production processes for the supplementary resources (electricity and natural gas), raw materials and chemicals. However, only the electricity and natural gas production processes are taken into consideration for the eco-efficiency assessment- as data on chemical uses has not been made available for the study.

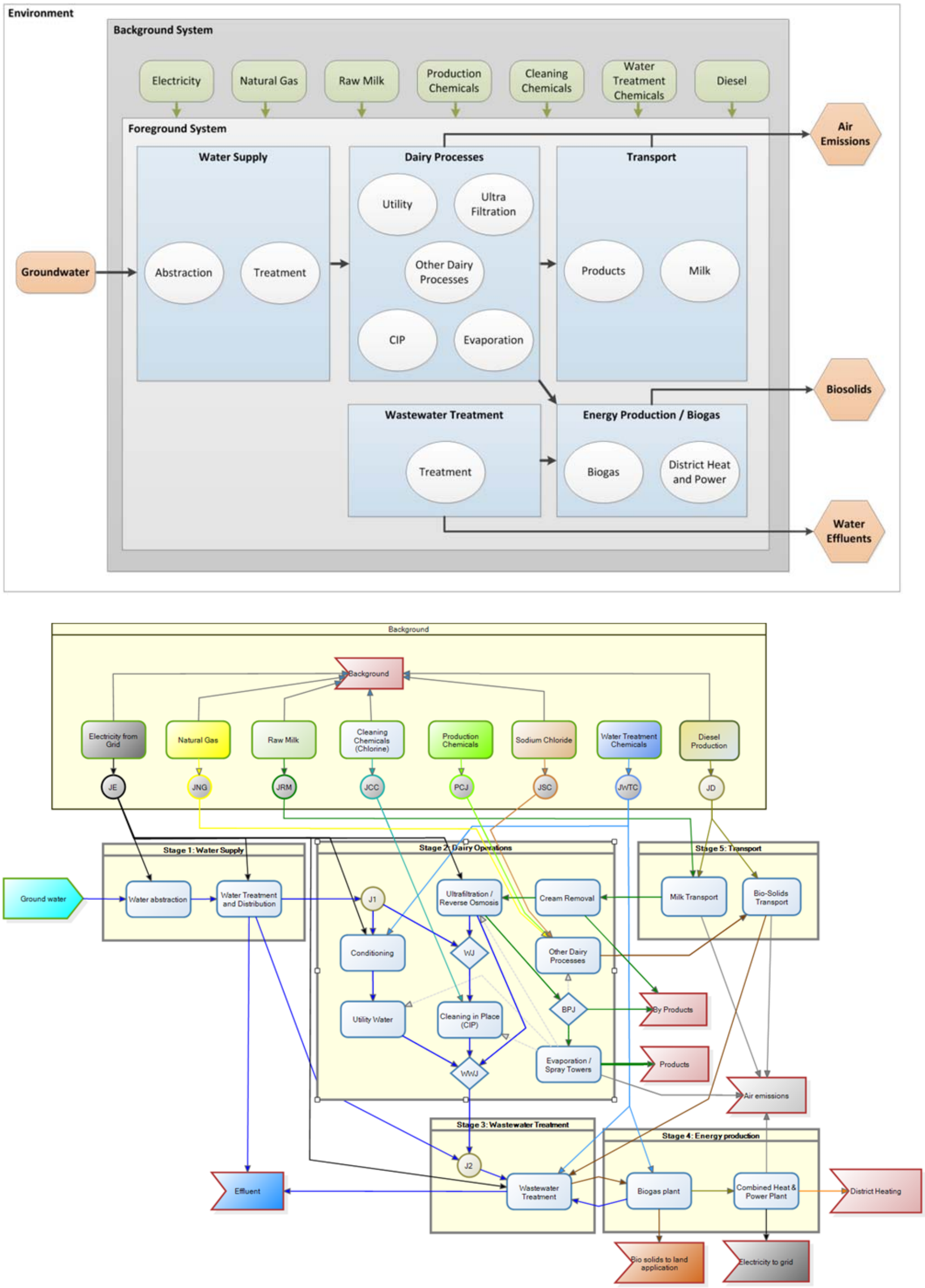

Figure 4-3. (a + b) Schematic representation of the foreground and background systems including the processes and the involved actors of the water-use-system.

The functional unit used is defined as 1 kg of milk powder produced. As there is an almost fixed relation between milk powder produced and milk taken into the dairy the results can also be expressed per kg of milk taken into the dairy.

4.1.2 Baseline scenario assessment

The dairy had an output of 17165 ton milk powder in 2012. For the dairy processes it is estimated that in 2012 1 kg of milk powder required 31 liter of groundwater, 2560 kWh of electricity and energy from natural gas equivalent to 7676 kWh. The input of raw milk in 2012 was 524236 ton giving a groundwater intake to milk ratio of about 1 liter per kg of raw milk. This is below the average 1.5 litre of water per kg of raw milk reported for milk powder production (Weeks, 2010).

In the calculations of the baseline scenario it has been taken into account that the waste water treatment plant as well as the biogas plant also receive inputs from other waste water and sludge and bio solid sources. The resource use, emissions and value added therefore only refer to the amounts from the dairy plant.

4.1.2.1 Environmental assessment

The environmental performance of the system is assessed through eight environmental midpoint indicators, representative for the specific system and relevant to the dairy industry. The background processes that are taken into account for the assessment of the environmental impacts are electricity and natural gas production, as it was not possible to collect data for the other background processes. The characterisation factors included in the CML-IA database are used for the calculation of the environmental impacts of the foreground system, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (JRC, 2011).

Table 4-1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario

Midpoint Impact Category	**Environmental Performance Indicator per kg of milk powder produced**	**Foreground Contribution**	**Background Contribution**
Climate change	58 $kgCO_{2eq}$/ kg	45%	55%
Freshwater Resource Depletion	0,008 m^3/kg	100%	0%
Eutrophication	1.7 $kgPO_4^{3}{}_{-,eq}$/kg	0.3%	99.7%
Human toxicity	0.06 $kg1,4DCB_{,eq}$/kg	14%	86%
Acidification	0.56 $kgSO_2^{-}{}_{,eq}$/kg	0.8%	99.2%
Aquatic Ecotoxicity	0.002 $kg1,4DCB_{,eq}$/kg	0%	100%
Terrestrial Ecotoxicity	0.003 $kg1,4DCB_{,eq}$/kg	0%	100%
Photochemical Ozone Formation	0.0005 kg $C_2H_{4,eq}$/ kg	35%	65%

Table 4-1 presents the normalized values of environmental indicators per kg of milk powder produced for the entire system and the contribution of the foreground and the background system separately. The most significant environmental foreground problems are freshwater depletion and climate change impact. The freshwater use in the background (the water used in agriculture to produce the milk) is not included in the figures in Table 4-1. If included the background would account for more than 99% and the Freshwater Resource Depletion would increase by a factor of 64 to 0,5 m^3/kg of milk powder produced.

4.1.2.2 Value assessment

Calculated value assessment of the value chain per actor is shown in Table 4-2. The total net economic output is 30.201.664 € - equivalent to 1.7 € per kg of milk powder produced. As this figure refers to the specific value chain this figure cannot be compared with other dairy plants.

The net economic output of the value chain is completely dominated by the dairy industry and the value of the milk powder produced. For the dairy the main cost is the raw milk and the net economic output is highly influenced by this price.

Table 4-2. Economic evaluation of the value chain

Actor	**Annual O&M costs (€/yr)**	**Gross income (€/yr)**	**Revenues from services (€/yr)**	**Net economic output (€/yr)**
Water supply operator	52,731	0	953,300	882,569
Dairy industry	213,154,418	249,642,370	-9,668,941	26,819,011
WWT operator	294,049	0	2,428,019	2,133,970
Biogas plant	19,618	102,627	0	83,008
Transport companies	6,022.515	0	6,305,620	283,105

4.1.2.3 Eco-efficiency assessment

Table 4-3 presents the results of the baseline eco-efficiency assessment for the overall system. It is confirmed that the major environmental impacts of the studied system (including both foreground and background) are eutrophication, acidification, human toxicity, climate change and freshwater resource depletion which are characterised by the lowest eco-efficiency indicator value and thus the worst performance. Focussing only on the foreground climate change and freshwater resource depletion had the lowest eco-efficiency value and thus the lowest performance.

Table 4-3. Baseline eco-efficiency assessment

Midpoint Impact Category	**Unit**	**Total for the value chain**
Climate change	€/kgCO_{2eq}	0.03
Freshwater Resource Depletion	€/m^3	203
Eutrophication	€/kgPO_4^{3}-$_{,eq}$	0.99
Human toxicity	€/kg1,4DCB$_{,eq}$	28.5
Acidification	€/kg$SO^{2-}{}_{,eq}$	3.14
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	737
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	630
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	3271

4.1.3 Objectives for the introduction of innovative technologies

The baseline eco-efficiency assessment and the identification of the environmental weaknesses of the system can lead to the selection of innovative technologies, which can upgrade the examined value chain. With the focus on the foreground technologies which could upgrade eco-efficiency should focus on reduction of climate change and freshwater resource depletion.

Thus, three main objectives are set for the upgrading of the studied system: (a) increase of resource efficiency, focusing on freshwater and energy optimisation (b) energy pollution prevention and c) circular technologies where the water in the milk is treated to enable an increased reuse. After discussing with the directly involved actors in the system and reviewing the relevant literature, four alternative technologies were selected for implementation in the dairy and one in the waste water treatment plant. These technologies are described in the following paragraphs.

Table 4-4. Alternative technologies to upgrade the dairy value chain

Technology Scenario	Technologies Included
Resource Efficiency	Anaerobic pre-treatment of dairy waste water
	Product and water recovery from the Cleaning in Place Systems
	Cleaning and reuse of condensate of water vapor
	Increased efficiency of diffusors in the waste water treatment plant
	Increased loading capacity of trucks transporting milk and intermediates
Pollution Prevention	Anaerobic pre-treatment of dairy waste water
Circular economy/ressource efficiency	Advanced oxidation and UV treatment

4.2 Individual assessment of innovative technologies

4.2.1 Anaerobic digestion

Anaerobic digestion (AD) is a technology that can transform organic waste products into energy through production of biogas (methane), which can be used to substitute natural gas consumption in the dairy – or be used for power and heat production. The AD system converts organic substances in the dairy wastewater (mainly fats, proteins and sugars) into mainly methane and carbon dioxide (biogas). The biogas can be burned and used to substitute natural gas or produce electricity and heat, and the methane will be converted to CO_2. The energy consumption of the downstream WWTP will be reduced – as will the energy production from sludge treatment following the WWTP. However, the reduced biogas production from sludge treatment is more than compensated from the energy production in the pre-treatment stage.

Through the application of anaerobic digestion the natural gas consumption can be reduced by 2% in the dairy dye to biogas production. At the same tide the electricity used in the Wastewater treatment plant can be reduced by 61% due to reduced pollution load in the waste water. The investment costs is 2,500,000 € and the lifetime of the equipment is estimated to be 20 years.

Main Assumptions: Anaerobic Digestion for pre-treatment of wastewater from Arla HOCO aims to reduce the organic load on the municipal WWTP, while producing energy instead of using energy for aeration requirements in the WWTP.

4.2.1.1 Technology assessment

The installation of Anaerobic Digestion for pre-treatment of wastewater from the dairy has a significant positive impact on the climate change indicator and and positive effects on all other indicators. The overall eco-efficiency is positively affected in particular also for climate change. This technology can be a part of an overall technology scenario focusing on pollution prevention. The environmental, economic and eco-efficiency assessment in for the implementation of the anaerobic digester is presented in Table 4-5 to Table 4-7.

Table 4-5. Environmental impact of baseline and anaerobic digestion (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Anaerobic digestion
Climate change	kgCO$_{2eq}$/kg	58	52
Freshwater Resource Depletion	m^3/kg	0.008	0.008
Eutrophication	kgPO$_4^{3}{}_{-,eq}$/kg	1.7	1.7
Human toxicity	kg1,4DCB$_{,eq}$/kg	0.06	0.06
Acidification	kgSO$^{2-}{}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.002	0.002
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	kg C$_2$H$_{4,eq}$/kg	0.0005	0.0005

Table 4-6. Net economic output of baseline and anaerobic digestion

Net Economic Output	Baseline	Anaerobic Digestion
Water supply operator	882,569	902,218
Dairy	26,819,011	29,285,840
WWT operator	2,133,970	2,163,295
Biogas plant	83,008	62,242
Transport company	283,05	283,105
Total Value Added	30,202,000	32,696,702

Table 4-7. Eco-efficiency of baseline and anaerobic digestion

Midpoint Impact Category	Baseline	Anaerobic digestion
Climate change	0,030 €/kgCO$_{2eq}$	0,036 €/kgCO$_{2eq}$
Freshwater Resource Depletion	203 €/m^3	219 €/m^3
Eutrophication	0,99 €/kgPO$_4^{3}{}_{-,eq}$	1,07 €/kgPO$_4^{3}{}_{-,eq}$
Human toxicity	28,5 €/kg1,4DCB$_{,eq}$	31,0 €/kg1,4DCB$_{,eq}$
Acidification	3,1 €/kgSO$^{2-}{}_{,eq}$	3,4 €/kgSO$^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	801 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	683 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3271 €/kg C$_2$H$_{4,eq}$	3563 €/kg C$_2$H$_{4,eq}$

4.2.2 Advanced oxidation and UV treatment

The HOCO production process utilizes different degrees of membrane filters to separate and concentrate valuable products in the milk. Reverse Osmosis (RO) filters are used as a final step in this process to separate and concentrate different products. The permeation from the RO filters is a high quality water stream, however with some small molecular organic and nitrogen compounds still remaining – such as urea. The challenge is that these substances cause the otherwise clean water to be highly microbiologically unstable. These compounds are very difficult to separate by physicochemical processes and the most efficient way to remove these compounds cay be to use *chemical oxidation and UV treatment* to remove the organic material and also remove the growth potential in the treated “milk water”

The advanced oxidation of urea in the RO permeate in the dairy requires an additional use of energy (7.35 kWh/m3 of waste water) and addition of hydrogen peroxide (0.123 kg/m3 of waste water) and activated carbon (0.017 kg/m3 of waste water). The reduction of freshwater intake is 44%. The investment cost is 400,000 €, and the estimated lifetime is 10 years. The additional operating cost is 36,000 €/year.

Main assumptions: It is assumed that the use of chemical oxidation followed by UV treatment and polishing with activated carbon will remove the growth potential of microorganisms in the “milk-water” and that the treated milk-water can replace freshwater in some dairy operations.

4.2.2.1 Technology assessment

The installation of advanced oxidation and UV light treatment has a positive effect in in two of the indicators, expressing the environmental performance of the system (climate change and freshwater resource depletion) , while the other six indicators are not affected. The overall eco-efficiency is increased by 131% for freshwater depletion and by 12 percent on climate change. Thus, this technology can be a part of an overall technology scenario focusing on resource efficiency. As the technology enables a recirculation of water into the dairy processes and replaces freshwater it can also part of a technology scenario on circular economy. The environmental performance (Table 4-8), the economic performance (Table 4-9) and the eco-efficiency of the implementation of the technology implementation (Table 4-10) is presented below.

Table 4-8. Environmental impact of baseline and advanced oxidation and UV (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Advanced oxidation and UV
Climate change	$kgCO_{2eq}$/kg	58	55
Freshwater Resource Depletion	m^3/kg	0.008	0.004
Eutrophication	$kgPO_4^{3-}{}_{,eq}$/kg	1.7	1.7
Human toxicity	$kg1,4DCB_{,eq}$/kg	0.06	0.06
Acidification	$kgSO^{2-}{}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	$kg1,4DCB_{,eq}$/kg	0.002	0.002
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	kg $C_2H_{4,eq}$/kg	0.0005	0.0005

Table 4-9. Net economic output of baseline and advanced oxidation and UV

Net Economic Output	Baseline	Advanced oxidation and UV Treatment
Water supply operator	882,569	404,928
Dairy	26,819,011	29,352,707
WWT operator	2,133,970	1,276,334
Biogas plant	83,008	69,326
Transport company	283,105	283,105
Total Value Added	30,202,000	31,386,402

Table 4-10. Eco-efficiency of baseline and advanced oxidation and UV

Midpoint Impact Category	Baseline	Advanced oxidation and UV Treatment
Climate change	0.030 €/kgCO_{2eq}	0.033 €/kgCO_{2eq}
Freshwater Resource Depletion	203 €/m^3	470 €/m^3
Eutrophication	0.99 €/kg$PO_4{}^{3}{}_{-,eq}$	1.03 €/kg$PO_4{}^{3}{}_{-,eq}$
Human toxicity	28.5 €/kg1,4$DCB_{,eq}$	28.8 €/kg1,4$DCB_{,eq}$
Acidification	3.1 €/kg$SO^{2-}{}_{,eq}$	3.2 €/kg$SO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4$DCB_{,eq}$	748 €/kg1,4$DCB_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4$DCB_{,eq}$	646 €/kg1,4$DCB_{,eq}$
Photochemical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	3364 €/kg $C_2H_{4,eq}$

4.2.3 Product and water recovery in Cleaning in Place system

Cleaning-In-Place is essential in HOCO's production for keeping a high hygienic quality of production equipment. A typical CIP sequence could be: Product recovery, Pre-rinse, Alkaline solution wash, Intermediate Rinse, Acid solution wash, Final Rinse.

The chemical baths are of interest here, as these contain water as well as chemicals and heat that can be recovered by installation of a nano-filtration membrane in a by-pass on the chemical CIP tanks. Water and chemicals will be able to pass through the membrane while contaminants in the CIP baths are rejected as wastewater. In this way it is possible to extend the lifetime of the chemical CIP solutions and as such save water, chemicals and product.

The product and water recovery from CIP in the dairy requires an increased use of electricity and natural gas. (4.1 kWh and 0.55 m^3 per m^3 of recovered water respectively). The recovery of water is estimated to 5% of the intake of freshwater. Due to higher product recovery the organic load from the dairy to the wastewater is reduced by 20%. The increase quantity of product recovered is estimated to be 3.3 kg per m^3 of recovered water. The annual investment cost is 270,000 € with a lifetime of the equipment of 5 years. The additional O&M cost is estimated to 7,000 €/year.

Main assumption: It is assumed that the water recovered can preplace the use of freshwater in some dairy operation and the quality of the product recovered (and thus also the value of the product) is the same as any milkpowder produced in the dairy.

4.2.3.1 Technology assessment

The installation of equipment to increase the water and product recovery has a positive impact in freshwater resource depletion, while the other indicators are not affected. However, due to the fairly low investment cost and the additional product recovered the overall eco-efficiency is positively affected in particular for freshwater ressource depletion. This technology can be a part of an overall technology scenario focusing on ressource efficiency.

The environmental, economic and eco-efficiency assessment in for the implementation of the anaerobic digester is presented in Table 4-11 to Table 4-13.

Table 4-11. Environmental impact of baseline and product and water recovery (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Cleaning in Place system
Climate change	$kgCO_{2eq}$ /kg	58	58
Freshwater Resource Depletion	m^3 /kg	0.008	0.007
Eutrophication	$kgPO_4{}^{3}{}_{-,eq}$ /kg	1.7	1.7
Human toxicity	$kg1{,}4DCB_{,eq}$ /kg	0.06	0.06
Acidification	$kgSO^{2-}{}_{,eq}$ /kg	0.56	0.56
Aquatic Ecotoxicity	$kg1{,}4DCB_{,eq}$ /kg	0.002	0.002
Terrestrial Ecotoxicity	$kg1{,}4DCB_{,eq}$ /kg	0.003	0.003
Photochemical Ozone Formation	$kg\ C_2H_{4,eq}$ /kg	0.0005	0.0005

Table 4-12. Net economic output of baseline and product and water recovery

Net Economic Output	Baseline	Product and water recovery in Cleaning in Place system
Water supply operator	882,569	840,162
Dairy	26,819,011	29,330,901
WWT operator	2,133,970	2,026,947
Biogas plant	83,008	81,300
Transport company	283,105	283,105
Total Value Added	30,202,000	32,562,418

Table 4-13. Eco-efficiency of baseline and product and water recovery

Midpoint Impact Category	Baseline	Product and water recovery in Cleaning in Place system
Climate change	0.030 €/$kgCO_{2eq}$	0.033 €/$kgCO_{2eq}$
Freshwater Resource Depletion	203 €/m^3	234 €/m^3
Eutrophication	0.99 €/$kgPO_4{}^{3}{}_{-,eq}$	1.07 €/$kgPO_4{}^{3}{}_{-,eq}$
Human toxicity	28.5 €/$kg1{,}4DCB_{,eq}$	30.7 €/$kg1{,}4DCB_{,eq}$
Acidification	3.1 €/$kgSO^{2-}{}_{,eq}$	3.4 €/$kgSO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/$kg1{,}4DCB_{,eq}$	794 €/$kg1{,}4DCB_{,eq}$
Terrestrial Ecotoxicity	630 €/$kg1{,}4DCB_{,eq}$	679 €/$kg1{,}4DCB_{,eq}$
Photochemical Ozone Formation	3271 €/$kg\ C_2H_{4,eq}$	3526 €/$kg\ C_2H_{4,eq}$

4.2.4 Cleaning and reuse of condensate

Large amounts of water evaporate in the spray dryers – water also containing significant bound energy. The total amount is approximately 3 kg of water per kg of product. This water comprises the most significant opportunity for separation of a very clean water stream for reuse.

The *condensation* could be achieved by using the vapor used to preheat the drying air for the spray towers. This could be done in an air-air heat exchanger or in air-liquid-air double heat exchanger – with a recirculating medium in between.

Direct savings in natural gas consumption will be achieved, and significant amounts of water will be recovered and could potentially be reused. There will be an increase in electricity consumption to drive fans and pumps for this solution - however, a side effect may be better air pollution control of dust from the spray dryers.

Reuse of condensate reduces the intake of freshwater by 20%. The additional use of electricity is 4kWh/m^3 of reclaimed condensate. The annual investment cost is 270.000 € with a lifetime of 5 years. The additional O&M cost is estimated to 7.000 €

Main assumption: It is assumed that the condensate can replace freshwater use in some dairy operations.

4.2.4.1 Technology assessment

Cleaning and reuse of condensate has a positive impact in the climate change, freshwater ressource depletion and aquatic ecotoxicology, while the other five indicators are not affected. The overall eco-efficiency positively affected for all parameters in particular for freshwater depletion. Thus, this technology can be a part of an overall technology scenario focusing on ressource efficiency.

The environmental, economic and eco-efficiency assessment for the implementation of the anaerobic digester is presented in Table 4-14 to Table 4-16.

Table 4-14. Environmental impact of baseline and cleaning and reuse of condensate (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	**Unit**	**Baseline**	**Cleaning and reuse of condensate**
Climate change	kgCO_{2eq}/kg	58	59
Freshwater Resource Depletion	m^3/kg	0.008	0.007
Eutrophication	kg$PO_4{}^{3}{}_{-,eq}$/kg	1.7	1.7
Human toxicity	kg1,4DCB$_{,eq}$/kg	0.06	0.06
Acidification	kg$SO^{2-}{}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.002	0.002
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	kg $C_2H_{4,eq}$/kg	0.0005	0.0005

Table 4-15. Net economic output of baseline and cleaning and reuse of condensate

Net Economic Output	**Baseline**	**Cleaning and reuse of condensate**
Water supply operator	882,569	722,107
Dairy	26,819,011	29,300,400
WWT operator	2,133,970	2,130,522
Biogas plant	83,008	82,593
Transport company	283,105	283,105
Total Value Added	30,202,000	32,519,089

Table 4-16. Eco-efficiency of baseline and cleaning and reuse of condensate

Midpoint Impact Category	**Baseline**	**Cleaning and reuse of condensate**
Climate change	0.030 €/kgCO$_{2eq}$	0.032 €/kgCO$_{2eq}$
Freshwater Resource Depletion	203 €/m^3	273 €/m^3
Eutrophication	0.99 €/kgPO$_4^{3}{}_{-,eq}$	1.07 €/kgPO$_4^{3}{}_{-,eq}$
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	30.6 €/kg1,4DCB$_{,eq}$
Acidification	3.1 €/kgSO$^{2-}_{,eq}$	3.4 €/kgSO$^{2-}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	790 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	676 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3271 €/kg C$_2$H$_{4,eq}$	3516€/kg C$_2$H$_{4,eq}$

4.2.5 More efficient diffusors in the waste water treatment plant

Installation of *more efficient diffusors* and aeration systems in the waste water treatment system will improve the energy efficiency of the biological waste water treatment and thus also the total waste water treatment system (Jette Fleng Rasmussen, personal communication). The electricity use will be reduced by 6%. The investment cost is 330,000 €. The lifetime is 10 years.

4.2.5.1 Technology assessment

The installation more efficient diffusers in the municipal wastewater treatment plans only has minor effects on the overall impact and eco-efficiency of the system. The environmental, economic and eco-efficiency assessment in for the implementation of the anaerobic digester is presented in Table 4-17 to Table 4-19.

Table 4-17. Environmental impact of baseline and efficient diffusors

Midpoint Impact Category	**Unit**	**Baseline**	**Efficient diffusors**
Climate change	kgCO$_{2eq}$/kg	58	59
Freshwater Resource Depletion	m^3/kg	0.008	0.009
Eutrophication	kgPO$_4^{3}{}_{-,eq}$/kg	1.7	1.8
Human toxicity	kg1,4DCB$_{,eq}$/kg	0.06	0.06
Acidification	kgSO$^{2-}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.002	0.002
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	kg C$_2$H$_{4,eq}$/kg	0.0005	0.0005

Table 4-18. Net economic output of baseline and efficient diffusors

Net Economic Output	Baseline	Efficient diffusors
Water supply operator	882,569	882,569
Dairy	26,819,011	26,819,011
WWT operator	2,133,970	2,070,854
Biogas plant	83,008	83,008
Transport company	283,105	283,105
Total Value Added	30,202,000	30,138,548

Table 4-19. Eco-efficiency of baseline and efficient diffusors

Midpoint Impact Category	Baseline	Efficient diffusors
Climate change	0.0300 €/kgCO_{2eq}	0.0297 €/kgCO_{2eq}
Freshwater Resource Depletion	203 €/m^3	202 €/m^3
Eutrophication	0.99 €/kg$PO_4^{3}$$_{-,eq}$	0.99 €/kg$PO_4^{3}$$_{-,eq}$
Human toxicity	28.5 €/kg1,4$DCB_{,eq}$	28.5 €/kg1,4$DCB_{,eq}$
Acidification	3.1 €/kg$SO^{2-}$$_{,eq}$	3.1 €/kg$SO^{2-}$$_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4$DCB_{,eq}$	736 €/kg1,4$DCB_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4$DCB_{,eq}$	630 €/kg1,4$DCB_{,eq}$
Photochemical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	3265 €/kg $C_2H_{4,eq}$

4.2.6 Increased loading capacity of trucks

Milk, by-products, intermediates and products are all transported by trucks. If the loading capacity can be increased for each truck- without increasing the overall weight of the truck, then the overall energy use for transport can be reduced. This may be done by removing some equipment from the truck or replacing equipment with some that has a lower weight.

Based on initial results it is estimated that the loading capacity of milk, by-products, intermediates and products ca be increased by 6% with an investment cost of 100,000 € and a lifetime of 20 years.

Technology assessment

An increased loading capacity in trucks has only minor effects on the overall impact and eco-efficiency of the system.

The environmental, economic and eco-efficiency assessment in for the implementation of the anaerobic digester is presented in Table 4-20 to Table 4-22.

Table 4-20. Environmental impact of baseline and increased loading capacity of trucks (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Increased loading capacity on trucks
Climate change	$kgCO_{2eq}/kg$	58	58
Freshwater Resource Depletion	m^3/kg	0.008	0.009
Eutrophication	$kgPO_4^{3}{}_{-,eq}/kg$	1.7	1.7
Human toxicity	$kg1,4DCB_{,eq}/kg$	0.06	0.06
Acidification	$kgSO^{2-}{}_{,eq}/kg$	0.56	0.56
Aquatic Ecotoxicity	$kg1,4DCB_{,eq}/kg$	0.002	0,002
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}/kg$	0.003	0.003
Photochemical Ozone Formation	$kg\ C_2H_{4,eq}/kg$	0.0005	0.0005

Table 4-21. Net economic output of baseline and increased loading capacity of trucks

Net Economic Output	Baseline	Increased loading capacity of trucks
Water supply operator	882,569	882,569
Dairy	26,819,011	26,819,011
WWT operator	2,133,970	2,133,970
Biogas plant	83,008	83,008
Transport company	283,105	615,554
Total Value Added	30,202,000	30,534.113

Table 4-22. Eco-efficiency of baseline and increased loading capacity of trucks

Midpoint Impact Category	Baseline	Increased loading capacity of trucks
Climate change	0.0300 €/$kgCO_{2eq}$	0.0304 €/$kgCO_{2eq}$
Freshwater Resource Depletion	203 €/m^3	205 €/m^3
Eutrophication	0.99 €/$kgPO_4^{3}{}_{-,eq}$	1.00 €/$kgPO_4^{3}{}_{-,eq}$
Human toxicity	28.5 €/$kg1,4DCB_{,eq}$	29.4 €/$kg1,4DCB_{,eq}$
Acidification	3.1 €/$kgSO^{2-}{}_{,eq}$	3.2 €/$kgSO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/$kg1,4DCB_{,eq}$	762 €/$kg1,4DCB_{,eq}$
Terrestrial Ecotoxicity	630 €/$kg1,4DCB_{,eq}$	641 €/$kg1,4DCB_{,eq}$
Photochemical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	3401 €/kg $C_2H_{4,eq}$

4.2.7 Overall assessment of individual technologies

Table 4-23. Summary of eco-efficiencies of individual technologies

Midpoint Impact Category	Baseline	Anaerobic digestion	Advanced oxication and UV light treatment	Product and water recovery from CIP	Cleaning and reuse of conden-sate	More efficient blowers	Increased loading capacity of trucks
Climate change	0,030 €/kgCO_{2eq}	+21%	+11%	+9%	+8%	+0,3%	+1%
Freshwater Resource Depletion	203 €/m^3	+8%	+131%	+15%	+ 35%	0%	0%
Eutrophi-cation	0,99 €/kg$PO_4^{3}{}_{-,eq}$	7%	+3%	+7%	+7%	0%	+4%
Human toxicity	28,5 €/kg1,4$DCB_{,eq}$	+9%	1%	+8%	+7%	+0%	+0,3%
Acidification	3,1 €/kg$SO^{2-}{}_{,eq}$	+11%	+4%	+8%	+8%	0%	+4%
Aquatic Eco-toxicity	737 €/kg1,4$DCB_{,eq}$	+9%	+1%	+8%	+7%	0%	+1%
Terrestrial Eco-toxicity	630 €/kg1,4$DCB_{,eq}$	+8%	+2%	+8%	+7%	0%	+2%
Photochemical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	+9%	+3%	+8%	+7%	+1%	+2%

As it can be seen the largest improvements in eco-efficiency are achieved for the climate change and freshwater resource depletion indicators. The advanced oxidation and UV light treatment, anaerobic pre-treatment and the reuse of condensate contribute to the largest improvements in eco-efficiency.

Other technologies like more efficient diffusers in the wastewater treatment plant and increased loading capacity of trucks have almost no impact on the overall system, while they can have an impact if only assessing the wastewater treatment and transport stage individually (results not shown).

Combining the technologies with the largest improvements of the eco-efficiency will improve the eco-efficiency of the water value chain. The assessment of combined technologies is further described in the following section.

4.3 Assessment of Technology Scenarios

As a second step in the process of upgrading the value chain, four alternative technology scenarios are examined and assessed. The scenarios combine the most eco-efficient individual technologies with the aim both to improve resource efficiency, reduce pollution load and increase the circular economy. Finally one scenario combines the most water efficient technologies with the aim to analyze how close the dairy can get to closing the water intake through replacement of freshwater with other types of water present in the dairy (Table 4-24). The following sections present the scenario assessment. The information on the individual technologies (technology and values used in the assessment) is available in the previous sections. It is assumed that the technologies can be implemented as individual technologies and that the investment cost and operating cost can be calculated as the sum of the individual technologies.

Table 4-24. Technology scenarios combining individual technologies

Technology Scenarios	Technologies Included
Increased resource efficiency and pollution prevention	Anaerobic digester
	Advanced oxidation
Increased resource efficiency, pollution prevention and circular economy	Anaerobic digester
	Advanced oxidation
	Product and water recovery
Increased water resource efficiency	Product and water recovery
	Cleaning and reuse of condensate
Towards circular economy and closing the water loop	Advanced oxidation
	Cleaning and reuse of condensate

4.3.1 Anaerobic digester combined with advanced oxidation

The installation of Anaerobic Digestion combined with advanced oxidation halves the impact measures for the water resource depletion indicator and also reduces the impact on climate change. Other indicators are not affected. The eco-efficiency is positively affected for all impact categories. The most significant impact is observed for freshwater depletion which more than doubles. The environmental, economic and eco-efficiency assessment for the implementation of the combined technologies are presented in Table 4-25 to Table 4-27.

Table 4-25. Environmental impact of baseline and combined technologies (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Anaerobic digester combined with Advanced Oxidation
Climate change	$kgCO_{2eq}$/kg	58	55
Freshwater Resource Depletion	m^3/kg	0.008	0.004
Eutrophication	$kgPO_4{}^{3}{}_{-,eq}$/kg	1.7	1.7
Human toxicity	$kg1,4DCB_{,eq}$/kg	0.06	0.06
Acidification	$kgSO^{2-}{}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	$kg1,4DCB_{,eq}$/kg	0.002	0.002
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	$kg\ C_2H_{4,eq}$/kg	0.0005	0.0005

Table 4-26. Net economic output of baseline and combined technologies

Net Economic Output	Baseline	Anaerobic digester combined with Advanced Oxidation
Water supply operator	882,569	404,928
Dairy	26,819,011	29,428.735
WWT operator	2,133,970	1,293,874
Biogas plant	83,008	69,326
Transport company	283,105	283,105
Total Value Added	30,202,000	31,479,870

Table 4-27. Eco-efficiency of baseline and combined technologies

Midpoint Impact Category	Baseline	Anaerobic digester combined with Advanced Oxidation
Climate change	0.030 €/kgCO$_{2eq}$	0.034 €/kgCO$_{2eq}$
Fresh-water Resource Depletion	203 €/m^3	471 €/m^3
Eutrophication	0.99 €/kgPO$_4{}^{3}{}_{-,eq}$	1.03 €/kgPO$_4{}^{3}{}_{-,eq}$
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	29.0 €/kg1,4DCB$_{,eq}$
Acidification	3.1 €/kgSO$^{2-}{}_{,eq}$	3.3 €/kgSO$^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	752 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	649 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3271 €/kg C$_2$H$_{4,eq}$	3292 €/kg C$_2$H$_{4,eq}$

4.3.2 Anaerobic digester combined with advanced oxidation and product and water recovery

The installation of Anaerobic Digestion for pre-treatment of wastewater combined with advanced oxidation and product and water recovery has a positive effect on two indicators (freshwater resource depletion and climate change) while the other indicators are not affected. The overall eco-efficiency is positively affected, with the eco-efficiency 2.3 times higher than the baseline for the freshwater resource depletion. The environmental, economic and eco-efficiency assessment for the implementation of the anaerobic digester is presented in Table 4-28 to Table 4-30.

Table 4-28. Environmental impacts of baseline and combined technologies (indicators are expressed per kg of milk powder produced)

Midpoint Impact Category	Unit	Baseline	Anaerobic digester combined with Advanced Oxidation and product and water recovery
Climate change	kgCO$_{2eq}$ /kg	58	54 kgCO$_{2eq}$/ kg
Freshwater Resource Depletion	m^3 /kg	0.008	0.004 m^3/kg
Eutrophication	kgPO$_4{}^{3}{}_{-,eq}$ /kg	1.7	1.7 kgPO$_4{}^{3}{}_{-,eq}$/kg
Human toxicity	kg1,4DCB$_{,eq}$ /kg	0.06	0.06 kg1,4DCB$_{,eq}$/kg
Acidification	kgSO$^{2-}{}_{,eq}$ /kg	0.56	0.56 kgSO$_2{}^{-}{}_{,eq}$/kg
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$ /kg	0.002	0.002 kg1,4DCB$_{,eq}$/kg
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$ /kg	0.003	0.003 kg1,4DCB$_{,eq}$/kg
Photochemical Ozone Formation	kg C$_2$H$_{4,eq}$ /kg	0.0005	0.0005 kg C$_2$H$_{4,eq}$/ kg

Table 4-29. Net economic output of baseline and combined technologies

Net Economic Output	Baseline	Anaerobic digester combined with Advanced Oxidation and product and water recovery
Water supply operator	882,569	404,928
Dairy	26,819,011	29,381,571
WWT operator	2,133,970	1,229,573
Biogas plant	83,008	68,314
Transport company	283,105	283,105
Total Value Added	30,202,000	31,367,493

Table 4-30. Eco-efficiency of baseline and combined technologies

Midpoint Impact Category	Baseline	Anaerobic digester combined with Advanced Oxidation and water and product recovery
Climate change	0.030 €/kgCO_{2eq}	0.034 €/kgCO_{2eq}
Fresh-water Resource Depletion	203 €/m^3	470 €/m^3
Eutrophication	0.99 €/kg$PO_4^{3}{}_{-,eq}$	1.03 €/kg$PO_4^{3}{}_{-,eq}$
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	28.9 €/kg1,4DCB$_{,eq}$
Acidification	3.1 €/kg$SO^{2-}{}_{,eq}$	3.3 €/kg$SO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	749 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	646 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3,271 €/kg $C_2H_{4,eq}$	3,375 €/kg $C_2H_{4,eq}$

4.3.3 Product and water recovery combined with cleaning and reuse of condensate

Product and water recovery in the CIP process combined with cleaning and reuse of condensate has a significant positive impact in two of the indicators (freshwater resource depletion and climate change impact) while the other indicators are not affected. The overall eco-efficiency is positively affected for all impact categories most significantly for freshwater ressource depletion. The environmental, economic and eco-efficiency assessment in for the implementation of the anaerobic digester is presented in Table 4-31 to Table 4-33.

Table 4-31. Environmental impact of baseline and combined technologies

Midpoint Impact Category	Unit	Baseline	Product and water recovery combined with cleaning and reuse of condensate
Climate change	kgCO_{2eq} /kg	58	58
Freshwater Resource Depletion	m^3 /kg	0.008	0.006
Eutrophication	kg$PO_4^{3}{}_{-,eq}$ /kg	1.7	1.7
Human toxicity	kg1,4DCB$_{,eq}$ /kg	0.06	0.06
Acidification	kg$SO^{2-}{}_{,eq}$ /kg	0.56	0.56
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$ /kg	0.002	0.002
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$ /kg	0.003	0.003
Photochemical Ozone Formation	kg $C_2H_{4,eq}$ /kg	0.0005	0.0005

Table 4-32. Net economic output of baseline and combined technologies

Net Economic Output	Baseline	Product and water recovery combined with cleaning and reuse of condensate
Water supply operator	882,569	660,051
Dairy	26,819,011	29,460,539
WWT operator	2,133,970	2,023,500
Biogas plant	83,008	81,245
Transport company	283,105	283,105
Total Value Added	30,202,000	32,508,442

Table 4-33. Eco-efficiency of baseline and combined technologies

Midpoint Impact Category	Baseline	Product and water recovery combined with cleaning and reuse of condensate
Climate change	0.030 €/kgCO_{2eq}	0.033 €/kgCO_{2eq}
Freshwater Resource Depletion	203 €/m^3	299 €/m^3
Eutrophication	0.99 €/kg$PO_4^{3-}{}_{,eq}$	1.07 €/kg$PO_4^{3-}{}_{,eq}$
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	30.5 €/kg1,4DCB$_{,eq}$
Acidification	3.1 €/kg$SO^{2-}{}_{,eq}$	3.4 €/kg$SO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	789 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	676 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3,271 €/kg $C_2H_{4,eq}$	3,512 €/kg $C_2H_{4,eq}$

4.3.4 Advanced oxidation combined with cleaning and reuse of condensate

The advanced oxidation combined with cleaning and reuse of condensate (the individual technologies with the largest impact on water resource depletion indicator) can significantly improve the freshwater depletion indicator (3.7 times lower). Climate change improves by 8%, aquatic ecotoxicity is slightly improved while the other four indicators are not affected. The overall eco-efficiency is more than five times higher for the freshwater depletion impact category and all other impact categories are also positively affected. The environmental, economic and eco-efficiency assessment for this scenario is presented in Table 4-34 to Table 4-36.

Table 4-34. Environmental impact of baseline and combined technologies

Midpoint Impact Category	Unit	Baseline	Product and water recovery combined with cleaning and reuse of condensate
Climate change	kgCO_{2eq}/kg	58	54
Freshwater Resource Depletion	m^3/kg	0.008	0.003
Eutrophication	kg$PO_4^{3-}{}_{,eq}$/kg	1.7	1.7
Human toxicity	kg1,4DCB$_{,eq}$/kg	0.06	0.06
Acidification	kg$SO^{2-}{}_{,eq}$/kg	0.56	0.56
Aquatic Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.002	0.003
Terrestrial Ecotoxicity	kg1,4DCB$_{,eq}$/kg	0.003	0.003
Photochemical Ozone Formation	kg $C_2H_{4,eq}$/kg	0.0005	0.0005

Table 4-35. Net economic output of baseline and combined technologies

Net Economic Output	Baseline	Product and water recovery combined with cleaning and reuse of condensate
Water supply operator	882,569	224,817
Dairy	26,819,011	29,482,346
WWT operator	2,133,970	1,272,886
Biogas plant	83,008	69,271
Transport company	283,105	283,105
Total Value Added	30,202,000	31,332,427

Table 4-36. Eco-efficiency of baseline and combined technologies

Midpoint Impact Category	**Baseline**	**Product and water recovery combined with cleaning and reuse of condensate**
Climate change	0.030 €/kgCO_{2eq}	0.033 €/kgCO_{2eq}
Fresh-water Resource Depletion	203 €/m^3	845 €/m^3
Eutrophication	0.99 €/kg$PO_4^{3}{}_{-,eq}$	1.03 €/kg$PO_4^{3}{}_{-,eq}$
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	28.6 €/kg1,4DCB$_{,eq}$
Acidification	3.1 €/kg$SO^{2-}{}_{,eq}$	3.3 €/kg$SO^{2-}{}_{,eq}$
Aquatic Ecotoxicity	737 €/kg1,4DCB$_{,eq}$	743 €/kg1,4DCB$_{,eq}$
Terrestrial Ecotoxicity	630 €/kg1,4DCB$_{,eq}$	643 €/kg1,4DCB$_{,eq}$
Photochemical Ozone Formation	3,271 €/kg $C_2H_{4,eq}$	3,351 €/kg $C_2H_{4,eq}$

4.3.5 Overall assessment of technology scenarios

Table 4-37. Eco-efficiency assessment of technology scenarios

Midpoint Impact Category	**Baseline**	**Anaerobic digestion and advanced oxidation**	**Anaerobic digestion, advanced oxidation and product and water recovery**	**Product and water recovery and cleaning and reuse of condensate**	**Cleaning and reuse of condensate and advanced oxidation**
		Aim to increase resource efficiency and pollution prevention	**Aim to increase resource efficiency, pollution prevention and circular economy**	**Aim to increase water resource efficiency**	**Aim to move towards circular economy and close the water loop in the dairy**
Climate change	0.030 €/kgCO_{2eq}	+12%	+12%	+2%	+11%
Freshwater Resource Depletion	203 €/m^3	+133%	+131%	+47%	+316%
Eutrophication	0.99 €/kg$PO_4^{3}{}_{-,eq}$	+3%	+3%	+8%	+4%
Human toxicity	28.5 €/kg1,4DCB$_{,eq}$	+2%	+1%	+7%	+0,3%
Acidification	3.1 €/kg$SO^{2-}{}_{,eq}$	+4%	+4%	+8%	+4%
Aquatic Eco-toxicity	737 €/kg1,4DCB$_{,eq}$	+2%	+1%	+7%	+1%
Terrestrial Eco-toxicity	630 €/kg1,4DCB$_{,eq}$	+3%	+2%	+7%	+2%
Photochemical Ozone Formation	3,271 €/kg $C_2H_{4,eq}$	+4%	+3%	+7%	+2%

The implementation of advanced oxidation combined with cleaning and reuse of condensate showed the highest improvements of eco-efficiency for the freshwater resource depletion and climate change. This scenario which reduces the groundwater intake by 64%, resulting in a water use of 0.6 m^3/kg of milk which is among the low figures given in the literature, increases the eco-efficiency by more than four times. Installing technologies in the dairy industry, which aim at using the water coming into the dairy with the milk instead of using freshwater is therefore highly ecoefficient.

Combining advanced oxidation, cleaning and reuse of condensate with anaerobic digestion will further increase the eco-efficiency in particular for the climate change impact category- and this option (not assessed in the case study) may be the best overall choice for a technology scenario for milk powder producing dairies.

The installation of the technologies or combination of technologies increases the total net economic output (NEO) (Table 4-38). For the dairy the NEO increases for all technologies and combinations of technologies- while the NEO only reduces for the waste water treatment operator and is either reduced or kept constant for the other actors in all technologies and combination of technologies. In fact the increased NEO for the dairy is only partly a result of the decreased cost the dairy has to pay for its water supply and waste water treatment services to the water utility, as increases in NEO is also a result of reduced energy costs and other costs related to the operation of the dairy.

Table 4-38. Net economic output of baseline and combined technologies

Net Economic Output	**Baseline**	**Anaerobic digester combined with Advanced Oxidation**	**Anaerobic digester combined with Advanced Oxidation & Product and water recovery**	**Product and water recovery combined with cleaning & reuse of condensate**	**Product and water recovery combined with cleaning & reuse of condensate**
Water supply operator	882,569	404,928	404,928	660,051	224,817
Dairy	26,819,011	29,428.735	29,381,571	29,460,539	29,482,346
WWT operator	2,133,970	1,293.874	1,229.573	2,023,500	1,272,886
Biogas plant	83,008	69,326	68,314	81,245	69,271
Transport company	283,105	283,105	283,105	283,105	283,105
Total	30,202,000	31,479,870	31,367,493	32,508,442	31,332,427

4.4 Policy recommendations

The main policy implications of the scenarios are the following: i) there is a large potential in increasing the eco-efficiency of dairy water value chains if water from the milk can replace freshwater intake. This requires that food authorities accept that the water in milk does not cause any risks to the product. At least in some countries in Europe including Denmark it has been difficult to get this accepted as the authorities refer to the EU requirement to use drinking water. The current ongoing revisions of the BREF documents for the dairy sector must secure that the water in milk can be used to a high degree and replace intake of freshwater. ii) a number of internal water streams in the dairy plant has very low levels of contamination and could be used not only in the dairy plant but also for purposes like agriculture, injection into the groundwater zone etc. Presently the quality criteria and control mechanisms for doing this is discussed as part of the implementation of the “Blueprint for Water Management in EU”, and it is important that the dairy industry is considered as one of the sectors with a larger potential to deliver water for these purposes,

5 Case Study #8: Automotive Industry

5.1 Finalized baseline scenario assessment

The analysed system consists of two separate water value chains, linked together by the industrial actor Volvo Trucks (Figure 5-1), having production sites both in Umeå and Tuve (in Gothenburg). Additional actors in the system are the municipal water providers (UMEVA and Kretslopp & Vatten) and the wastewater treatment company (Stena Recycling).

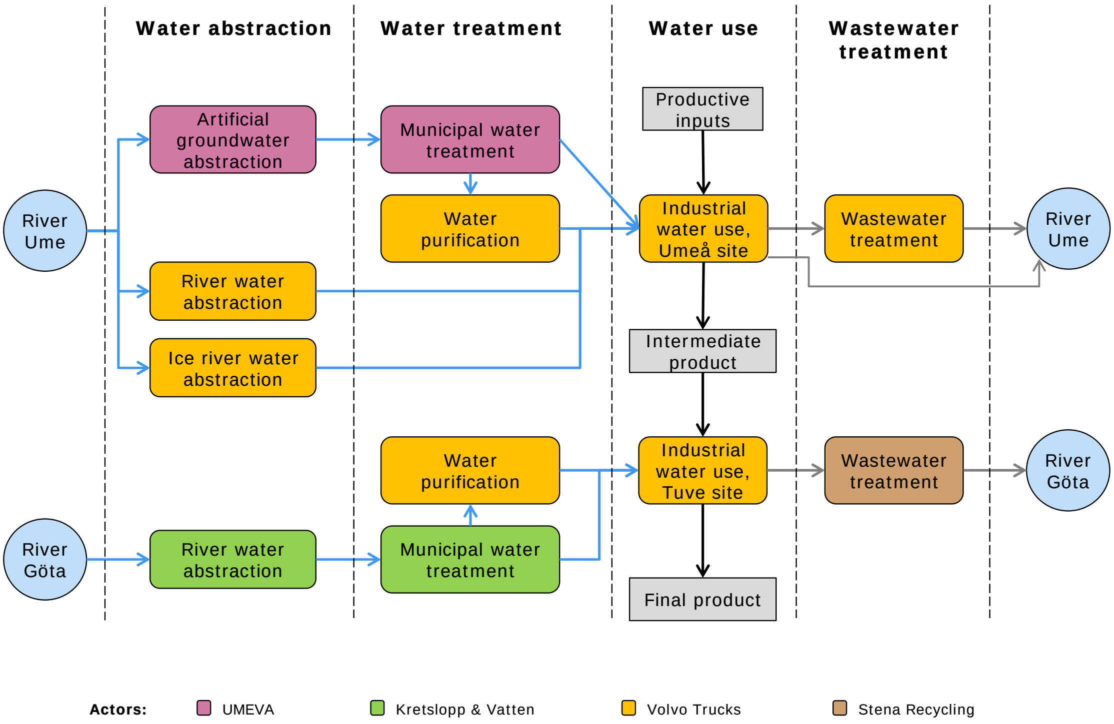

Figure 5-1. System overview, Case Study 8, colour coded by actor.

The resulting environmental performance remains the same as previously reported (EcoWater, 2014a[1]). The environmental performance assessment table (Table 5-1) shows that most of the impact occurs in the background (i.e. emissions are not stemming from the actors but from production of resources used by the actors). It can be noted that the indicators *Eutrophication*, *Human Toxicity* and *Eco-toxicity – Aquatic* partly stems from the foreground (i.e. emissions that occur at one or several actors in the system). The Freshwater Resource Depletion indicator is entirely attributed to the foreground due to its definition (EcoWater, 2014b[2]). It requires

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[1] EcoWater, Deliverables 4.2 Baseline eco-efficiency assessment of water use in industrial sectors - Case Study 5, 6, 7 and 8. January 2014

[2] EcoWater, Upgrading the Water Value Chain - Technology Scenario Assessment, March 2014

knowledge on which specific river basin is used for water extraction. That kind of information is not available for the production of resources used by the actors.

Table 5-1. Baseline environmental performance of the Volvo Trucks Case Study.

Environmental indicator	**Unit**	**Total Value***	**% in foreground**	**% in background**
Climate change	tCO_2,eq	652	0%	100%
Ozone depletion	kgCFC11eq	0.62	0%	100%
Eutrophication	kg PO_4^{-3}	691	44%	56%
Acidification	$kgSO_2^-$,eq	1 910	0%	100%
Human toxicity	kg 1,4-DB,eq	14 500	11%	89%
Ecotoxicity - Aquatic	kg 1,4-DB,eq	16 400	98%	2%
Ecotoxicity - Terrestrial	kg 1,4-DB,eq	228	0%	100%
Photochemical ozone formation	kgC_2H_4,eq	129	0%	100%
Freshwater Resource Depletion	m^3	1 660	100%	0% **
Abiotic Resource Depletion	kgSb,eq	1 010	0%	100%

*Rounded to three digits.

**The indicator Freshwater resource depletion could not be assessed for the background system. An analysis of the total amount of water used results in the share of 2,8% in the foreground and 97,2% in the background, out of 14,57 million m3 total water used.

The economic performance calculations were updated after the previously reported results in D4.2 (EcoWater, 2014a[3]). They now explicitly include an estimate for the collective cost of all raw material to the actor Volvo Trucks, i.e. framebeams, cabins and all other parts for making the complete truck. The other parts are not produced within the modelled system, but some are produced by Volvo and there is no simple way of assigning costs to the internally produced parts. Therefore, individual costs of raw materials are not possible to assign. In our calculations they are grouped as one input of Raw material, under the assumption that the total cost represents 99% of the product value. Product value is 100,000 € and they make 30,000 items per year.

The assumption of 99% is based on discussions with Volvo. We ended up with the assumption that the value of corrosion protection represents 1% of the Total Value of Products, thus indirectly saying that the value of raw materials is 99%. The assumption made for the value of raw materials is just a rough theoretical indication, necessary for the calculations. Some of the components that fall under “raw material“ input to the modelled system are internal products, not available on the market. Their respective value would be an aggregation of actual costs and product refinement.

The same conclusions as before can be drawn from the updated economic performance (Table 5-2), e.g. that the TVA is dominated by the actor Volvo Trucks. The resulting baseline eco-efficiency indicators are presented inTable 5-3.

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[3] EcoWater, Deliverables 4.2 Baseline eco-efficiency assessment of water use in industrial sectors - Case Study 5, 6, 7 and 8. January 2014

Table 5-2. Baseline economic performance (in €) of the Volvo Trucks Case Study.

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
UMEVA	2,081	0.00	22,196	20,114
Kretslopp & Vatten	176	0.00	2 275	2,100
Volvo Trucks	2,971,095,426	3,000,000,000	-197,271	28,707,303
Stena Recycling	12,359	0.00	172,800	160,441
Total Value Added:				28,889,958

Table 5-3. Baseline eco-efficiency of the Volvo Trucks Case Study.

Indicator	Unit	Baseline Scenario
Climate Change	€/tCO2eq	44,316
Freshwater Resource Depletion	€/m3	17,419
Eutrophication	€/kgPO4eq	41,823
Human Toxicity	€/kg1,4-DBeq	1,997
Acidification	€/kgSO2eq	15,099
Abiotic Resource Depletion	€/kgSbeq	28,663
Aquatic Ecotoxicity	€/kg1,4-DBeq	1,761
Stratospheric Ozone Depletion	€/kgCFC-11eq	46,882,457
Terrestrial Ecotoxicity	€/kg1,4-DBeq	126,757
Photochemical Ozone Formation	€/kgC2H4,eq	223,882

In order to identify objectives for the introduction of innovative technologies we look at the environmental impact broken down on the individual stages (Figure 5-2).

The Water use stage is the environmentally week stage of the system, with its large energy consumption and emission of pollutants to wastewater, and where implementation of new technology can result in large environmental improvements.

In addition to Volvo Trucks being the only actor in the water use stage of the system, they are also an actor within the water supply chain, due to their own water abstraction (Abstraction 2 in Figure 5-2), water treatment (Treatment 2 and Treatment 4 in Figure 5-2 and treatment of municipal water to purified water for processes (WW Treatment 1 in Figure 5-2).

From the baseline assessment (summarized above and further detailed in D4.2 (EcoWater, 2014a[4])) it is clear that new technologies of interest are those that can be implemented at Volvo Trucks in order to either

- 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,

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[4] EcoWater, Deliverables 4.2 Baseline eco-efficiency assessment of water use in industrial sectors - Case Study 5, 6, 7 and 8. January 2014

- Reduce the use of elements that become toxic pollutants in the wastewater, or
- Reduce the use of elements that become nutrients in the wastewater, causing eutrophication.

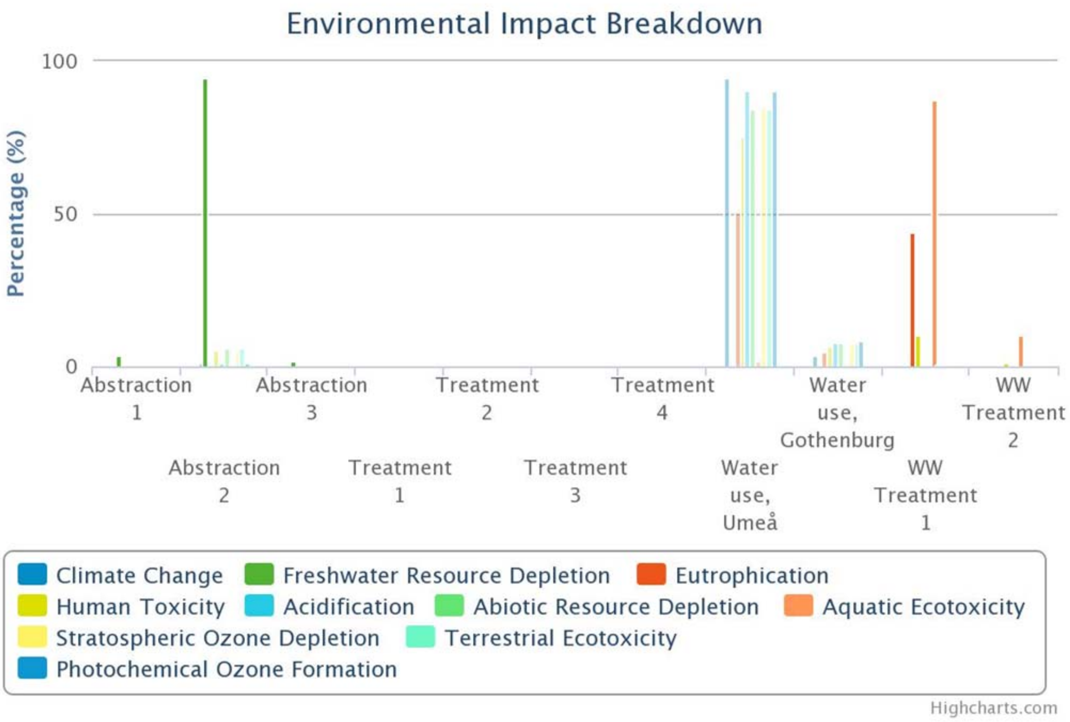

Figure 5-2. Environmental impact breakdown over stages. Transparent bars represent background impact.

5.2 Individual assessment of innovative technologies

Four innovative technologies are included in the analysis of Case Study #8. A short description of each technology and their respective individual assessment follow in the next sections. For a more comprehensive description of the technologies the reader is referred to D4.3 (EcoWater, 2013[5]). The four technologies are:

- Membrane distillation
- Electro-Deionisation
- Silane-based metal surface treatment
- Recirculation of process water and chemicals

The assessment is made under the assumption that technology implementation takes place at one of the Volvo Trucks production sites, in the stages as indicated in Figure 5-3. Anticipated improvements due to new technology in those processes are reduced energy use, reduced water use, reduced use of scarce elements and less pollution to wastewater. Such improvements are expected to have a positive effect in

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[5] EcoWater, Deliverables 4.3 Innovative technologies for enhancing the eco-efficiency of water use in industries - Case Study 5, 6, 7 and 8, October 2013

other parts of the system as well, thus making the whole system better due to technology implementation.

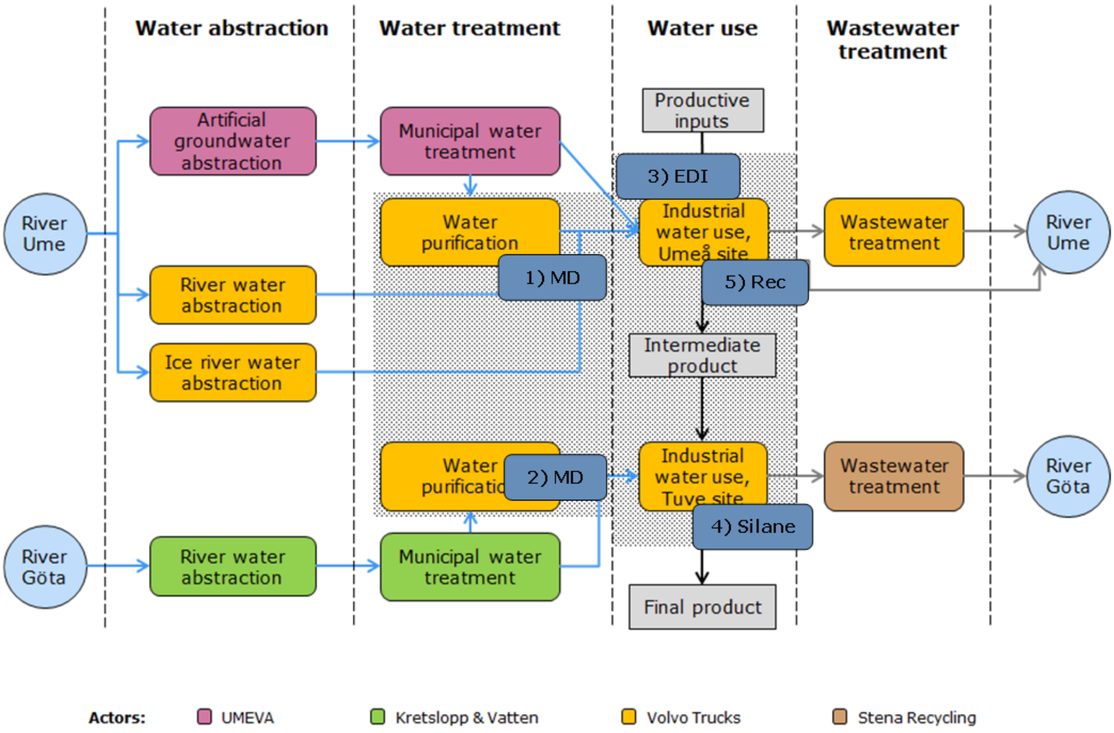

Figure 5-3. Technology implementation overview. Implementation of Membrane distillation is individually assessed at both industrial sites.

5.2.1 Membrane distillation

5.2.1.1 *Short Description*

Membrane distillation (MD) is a chemical unit operation that uses water repellent (hydrophobic) membranes as a barrier for contaminated water. The process takes place at temperatures below 100°C and at ambient pressure. Temperature levels are such that low-grade heat sources may be used to supply the required energy for the process. Unlike other membrane processes, MD does not require a mechanical pressure pump and is not limited by the osmotic pressure.

The objectives of technology implementation are:

- Resource efficiency (saving energy and reduced use of chemicals)
- Reduced operating costs (as a result of the first bullet)

This technology can potentially replace the use of reverse osmosis as a water purifying technology before water use in the processes. It could be installed at either of the two Volvo Trucks sites in the Case Study. An individual assessment has been made for both sites.

5.2.1.2 *Main Assumptions*

Membrane distillation is assumed to be implemented as an alternative to reverse osmosis in the water treatment stage. It is individually assessed at each of the two

Volvo Trucks sites. The values used in the technology assessment are summarized in Table 5-4.

Table 5-4. Values used for assessment of Membrane distillation.

	Baseline using RO	Membrane distillation, Umeå	Membrane distillation, Tuve
Electricity consumption, kWh/m3	1.5	1	1
Energy for heating of water from 20 to 80 degrees, kWh/m3	-	48.6 (from district heating)	69.6 (using electricity)
Water use efficiency, %	85	100	100
Investment cost, €	-	220,000	220,000
Interest rate, %	-	2	2
Technology lifetime, years	-	10	10
Maintenance costs,€/year	2,200	2,200	2,200

5.2.1.3 Results

The assessment shows that, for this system and under current assumptions, installation of Membrane distillation is not an eco-efficient alternative to reverse osmosis (Figure 5-4). The explicit values on the environmental performance (Table 5-5), the economic performance (Table 5-6) and the eco-efficiency indicators (Table 5-7) for implementation of Membrane distillation are reported below.

Table 5-5. Environmental impact results for Membrane distillation.

Indicator	Baseline Scenario	Membrane distillation, Umeå	Membrane distillation, Tuve
Climate Change (tCO2eq)	652	702	655
Freshwater Resource Depletion (m3)	1, 659	1,652	1,655
Eutrophication (kgPO4eq)	691	699	691
Human Toxicity (kg1,4-DBeq)	14,467	14,432	14,749
Acidification (kgSO2eq)	1,913	1,967	1,922
Abiotic Resource Depletion (kgSbeq)	1,008	1,005	1,030
Aquatic Ecotoxicity (kg1,4-DBeq)	16,404	16,402	16,412
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.62	0.63
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	227	233
Photochemical Ozone Formation (kgC2H4,eq)	129	132	129

Table 5-6. Economic performance results for Membrane distillation. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Membrane distillation, Umeå	Membrane distillation, Tuve
TVA	**28 889 958**	**28 866 381**	**28 858 231**
UMEVA	20 114	17 738	20 114
Volvo Trucks	28 707 303	28 686 102	28 675 815
Kretslopp och Vatten	2 100	2 100	1 860
Stena Recycling	160 441	160 441	160 441

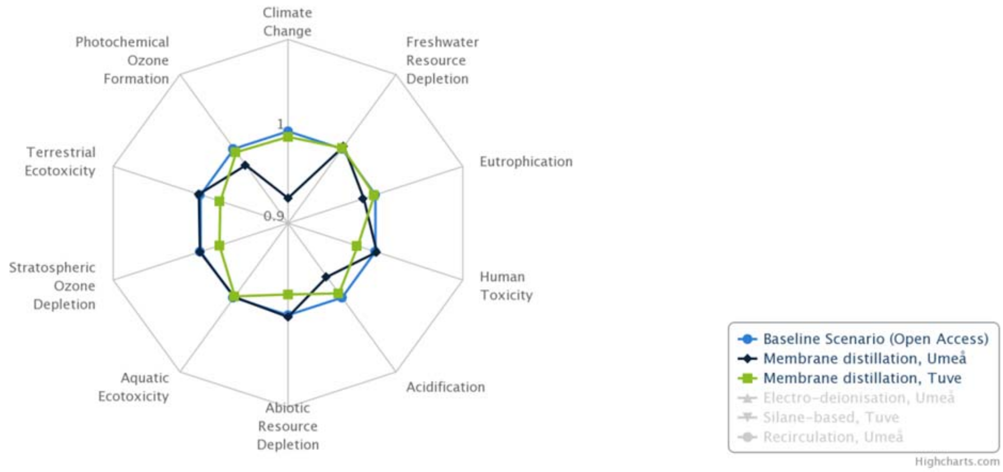

Figure 5-4. Eco-efficiency indicators for the Membrane distillation technology implemented at Volvo Trucks, Umeå and Tuve. (Values are normalized to Baseline = 1)

Table 5-7. Eco-efficiency results for Membrane distillation.

Indicator	Baseline Scenario	Membrane distillation, Umeå	Membrane distillation, Tuve
Climate Change (€/tCO2eq)	44,316	41,091	44,047
Freshwater Resource Depletion (€/m3)	17,419	17,478	17,438
Eutrophication (€/kgPO4eq)	41,823	41,269	41,775
Human Toxicity (€/kg1,4-DBeq)	1,997	2,000	1,957
Acidification (€/kgSO2eq)	15,099	14,678	15,015
Abiotic Resource Depletion (€/kgSbeq)	28,663	28,720	28,018
Aquatic Ecotoxicity (€/kg1,4-DBeq)	1,761	1, 760	1,758
Stratospheric Ozone Depletion (€/kgCFC-11eq)	46,882,457	46,920,855	45,871,797
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	126,757	127,006	123,901
Photochemical Ozone Formation (€/kgC2H4,eq)	223,882	218,959	222,889

5.2.2 Electro-Deionisation

5.2.2.1 Short Description

Electro-Deionisation (EDI) is an alternative process to clean incoming water for industrial processes, where high water quality is needed. EDI uses an electrical current to regenerate cation and anion resins. It is to a kind of combination of electrodialysis and ion-exchange within one process.

EDI needs a pre-treatment process in order to safeguard the ion-exchange resin. This is usually achieved by reverse osmosis. As EDI is a continuous process, the environmental impacts can be smaller than for conventional ion exchange.

The objectives of technology implementation are:

- Resource efficiency (saving energy and reduced use of chemicals)
- Reduced operating costs (as a result of the first bullet)

This technology is only applicable at the Umeå site.

5.2.2.2 Main Assumptions

The technology is assumed to be implemented, together with reverse osmosis as pre-treatment, as an alternative to the traditional ion-exchange at Volvo Trucks, Umeå. The values used in the technology assessment are summarized in Table 5-8.

Table 5-8. Values used for assessment of Electro-deionisation.

	Baseline using IE	**Electro-deionisation, Umeå**
Electricity consumption, kWh/m3	0.15	0.7
Water use efficiency, %	85	100
Investment cost, €	-	680,000
Interest rate, %	-	2
Technology lifetime, years	-	10
Maintenance costs,€/year	Not specified*	Same as Baseline

*The collective maintenance costs for the Water use stage Volvo Trucks, Umeå, are calculated in the model. The maintenance costs associated with the Ion-exchange unit is not individually accounted for although included in the overall cost assumption.

The baseline model has missing information regarding the Ion-exchange unit at Volvo Trucks, Umeå. Neither the amount of waste nor the amount of chemicals used was included in the model. No chemicals are used with the EDI technology so there are potential benefits from that, which are currently not modelled.

5.2.2.3 Results

The assessment shows that, for this system and under current assumptions, installation of Electro-deionisation combined with reverse osmosis has almost no impact on the eco-efficiency compared to the baseline (Figure 5-5). The explicit values on the environmental performance (Table 5-9), the economic performance (Table 5-10) and the eco-efficiency indicators (Table 5-11) for implementation of Electro-deionisation are reported below.

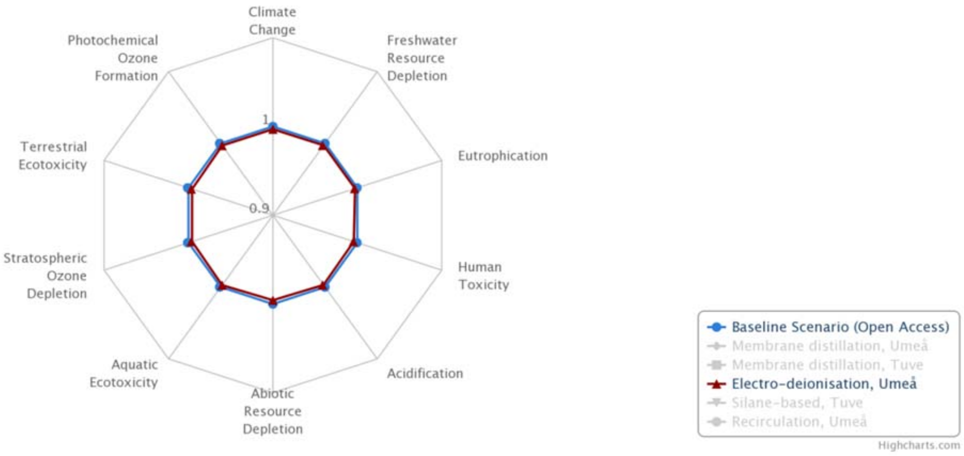

Figure 5-5. Eco-efficiency indicators for the Electro-deionisation technology implemented at Volvo Trucks, Umeå. (Values are normalized to Baseline = 1)

Table 5-9. Environmental impact from Electro-deionisation.

Indicator	Baseline Scenario	Electro-deionisation, Umeå
Climate Change (tCO2eq)	652	652
Freshwater Resource Depletion (m3)	1,659	1,659
Eutrophication (kgPO4eq)	691	691
Human Toxicity (kg1,4-DBeq)	14,467	14,489
Acidification (kgSO2eq)	1,913	1,914
Abiotic Resource Depletion (kgSbeq)	1,008	1,010
Aquatic Ecotoxicity (kg1,4-DBeq)	16,404	16,404
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.62
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	228
Photochemical Ozone Formation (kgC2H4,eq)	129	129

Table 5-10. Economic performance results for Electro-deionisation. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Electro-deionisation, Umeå
TVA	**28,889,958**	**28,813,712**
UMEVA	20,114	20,114
Volvo Trucks	28,707,303	28,631,057
Kretslopp och Vatten	2,100	2,100
Stena Recycling	160,441	160,441

Table 5-11. Eco-efficiency results for Electro-deionisation.

Indicator	Baseline Scenario	Electro-deionisation, Umeå
Climate Change (€/tCO2eq)	44,316	44,183
Freshwater Resource Depletion (€/m3)	17,419	17,373
Eutrophication (€/kgPO4eq)	41,823	41,713
Human Toxicity (€/kg1,4-DBeq)	1,997	1,989
Acidification (€/kgSO2eq)	15,099	15,055
Abiotic Resource Depletion (€/kgSbeq)	28,663	28,541
Aquatic Ecotoxicity (€/kg1,4-DBeq)	1,761	1,756
Stratospheric Ozone Depletion (€/kgCFC-11eq)	46,882,457	46,685,297
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	126,757	126,215
Photochemical Ozone Formation (€/kgC2H4,eq)	223,882	223,235

5.2.3 Silane-based metal surface treatment

5.2.3.1 Short Description

A silane-based metal surface treatment can be used as replacement of zinc-, manganese- and iron-phosphating and will provide paint bonding and corrosion protection.

The chemicals used with this technology are free of the metals Zn and Ni and the limited element P. Instead, silicon and zirconium are the active elements in chemicals. The technology operates at room temperature and with proven less water use than traditional phosphating surface treatment.

The objectives of technology implementation are:

- Resource efficiency (saving energy, water and use of scarce elements)
- Reduction of hazardous waste (sludge with high metal content)
- Reduction of pollutants in the wastewater (e.g. P, Ni and Zn)
- Reduced operating costs (as a result of the first two bullets)

A barrier for this technology is the resulting product quality. Tests have proven that the quality is good enough for hot-rolled steel but does not yet fulfil quality demands when used with cold-rolled steel (or on a mix of both kind of steel). Therefore this technology is only applicable at the Gothenburg site (Tuve site), where hot-rolled steel is used in the framebeams. The cabins that are processed at the Umeå production site contain cold-rolled steel, for which the silane-based technology has not yet proven sufficient quality results.

5.2.3.2 Main Assumptions

The assessment is made for technology implementation at Volvo Trucks, Tuve. The existing process infrastructure can be used with the new technology so no investments are needed. The values used in the technology assessment are summarized in Table 5-12.

Table 5-12. Values used for assessment of Silane-based metal surface treatment.

	Baseline, Zn-phosphating	**Silane-based, Tuve**
Electricity consumption for heating, kWh/set of framebeams	1.25	0
Water use, m3/set of framebeams	0.035	0.00875
Hazardous waste sludge, kg/set of framebeams	0.13	0
Phosphating chemicals, kg/set of framebeams	0.22	0
Zn in wastewater, kg/set of framebeams	0.00047	0
Ni in wastewater, kg/set of framebeams	0.00088	0
P in wastewater, kg/set of framebeams	0.00059	0
Zn in chemicals, kg/set of framebeams	0.006714	0
Ni in chemicals, kg/set of framebeams	0.0016	0
P in chemicals, kg/set of framebeams	0.0059	0
Zr in chemicals for silane-based tech., kg/set of framebeams	0	5.8E-5
Zr in wastewater, kg/set of framebeams	0	0
Investment cost, €	-	0
Interest rate, %	-	-
Technology lifetime, years	-	-
Maintenance costs, €/year	24,010	6,010
Chemical costs, €/year		Equivalent to baseline

5.2.3.3 Results

The assessment shows that, for this system and under current assumptions, installation of Silane-based metal surface treatment is an eco-efficient alternative compared to the baseline (Figure 5-6). The explicit values on the environmental performance (Table 5-13), the economic performance (Table 5-14) and the eco-efficiency indicators (Table 5-15) for implementation of Silane-based treatment are reported below.

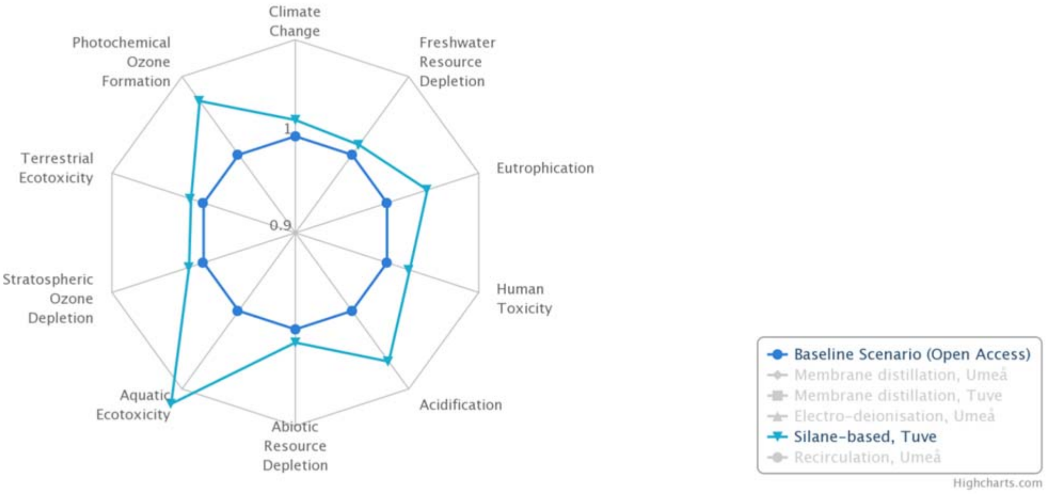

Figure 5-6. Eco-efficiency indicators for the Silane-based metal surface treatment technology implemented at Volvo Trucks, Tuve. (Values are normalized to Baseline = 1)

Table 5-13. Environmental impact from Silane-based surface treatment.

Indicator	Baseline Scenario	Silane-based, Tuve
Climate Change (tCO2eq)	652	642
Freshwater Resource Depletion (m3)	1,659	1,640
Eutrophication (kgPO4eq)	691	662
Human Toxicity (kg1,4-DBeq)	14,467	14,136
Acidification (kgSO2eq)	1,913	1,799
Abiotic Resource Depletion (kgSbeq)	1,008	995
Aquatic Ecotoxicity (kg1,4-DBeq)	16,404	14,677
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.61
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	225
Photochemical Ozone Formation (kgC2H4,eq)	129	121

Table 5-14. Economic performance results for Silane-based surface treatment. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Silane-based, Tuve
TVA	**28,889,958**	**28,925,831**
UMEVA	20,114	20,114
Volvo Trucks	28,707,303	28,835,648
Kretslopp och Vatten	2,100	903
Stena Recycling	160,441	69,166

Table 5-15. Eco-efficiency results for Silane-based metal surface treatment.

Indicator	Baseline Scenario	Silane-based, Tuve
Climate Change (€/tCO2eq)	44,316	45, 067
Freshwater Resource Depletion (€/m3)	17,419	17, 637
Eutrophication (€/kgPO4eq)	41,823	43, 663
Human Toxicity (€/kg1,4-DBeq)	1,997	2, 046
Acidification (€/kgSO2eq)	15, 099	16, 080
Abiotic Resource Depletion (€/kgSbeq)	28, 663	29, 057
Aquatic Ecotoxicity (€/kg1,4-DBeq)	1, 761	1, 971
Stratospheric Ozone Depletion (€/kgCFC-11eq)	46,882, 457	47,625, 179
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	126, 757	128, 484
Photochemical Ozone Formation (€/kgC2H4,eq)	223, 882	239, 293

5.2.4 Recirculation of process water and chemicals

5.2.4.1 *Short Description*

Although it is not a specific technology, but rather making smart use of existing technologies, it is worth studying the possibilities of recirculating water and chemicals in the automotive industry.

The rinse water from degreasing and phosphating can be recirculated within the process if it is cleaned to a certain degree fulfilling the quality criteria of the process.

Separation technologies like membrane filtration and ion exchange are often used for this purpose.

The objectives of technology implementation are:

- Resource efficiency (water and use of scarce elements)
- Reduction of pollutants in the wastewater (e.g. P, Ni and Zn)
- Reduced operating costs (as a result of the first bullet)

5.2.4.2 *Main Assumptions*

The technology is assessed for the Umeå site under the assumption that modifications in the degreasing process can result in 90% recirculation of spray-rinse process water and 50% recirculation of degreasing chemicals. This is accomplished by installation of additional reverse osmosis (RO) and ultrafiltration (UF) units. The use of district heating is lowered due to that less water needs to be heated. There is an increase in electricity consumption in order to run the RO and UF units. Evaporation losses are assumed to be the same as baseline. The values used for modelling the degreasing process step in the technology assessment are summarized in Table 5-16.

5.2.4.3 *Results*

The assessment shows that, for this system and under current assumptions, installation of Recirculation of process water and chemicals is an eco-efficient alternative compared to the baseline (Figure 5-7). The explicit values on the environmental performance (Table 5-17), the economic performance (Table 5-18) and the eco-efficiency indicators (Table 5-19) for implementation of Recirculation of process water and chemicals are reported below.

Table 5-16. Values (for the degreasing process) used for assessment of Recirculation of process water and chemicals

	Baseline	Recirculation of process water and chemicals, Umeå
District heating of process water, kWh/cabin	89	83.8
Electricity consumption, kWh/cabin	28	28.2
Degreasing chemicals, kg/cabin	0.76	0.38
Total water use in degreasing, m3/cabin	0.35	0.24
Investment cost (RO+UF), €	-	200,000
Interest rate, %	-	2
Technology lifetime, years	-	10
Maintenance costs,€/year	60,040*	61,480*

*Total maintenance costs for the Water use stage Volvo Trucks, Umeå. The maintenance costs of the degreasing process is not individually specified.

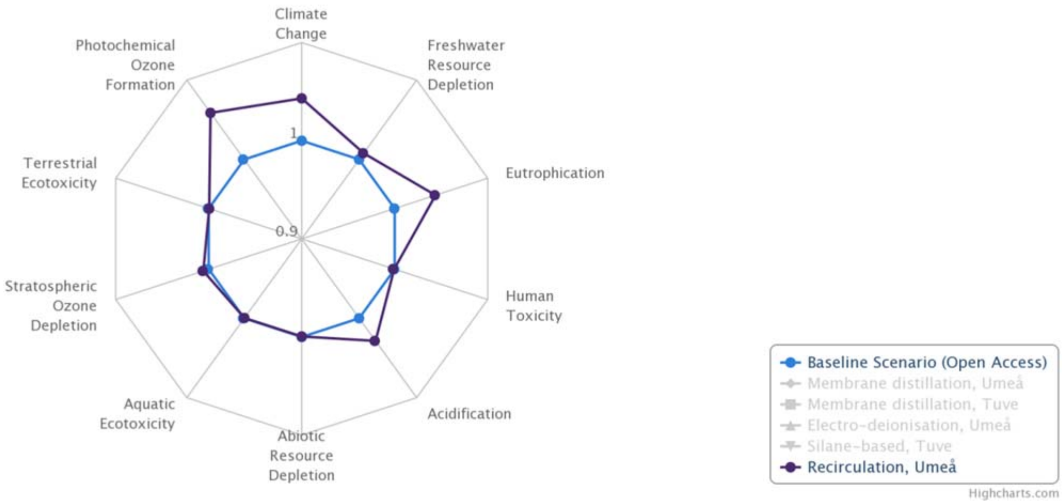

Figure 5-7. Eco-efficiency indicators for Recirculation implemented at Volvo Trucks, Umeå. (Values are normalized to Baseline = 1)

Table 5-17. Environmental impact from Recirculation of process water and chemicals.

Indicator	Baseline Scenario	Recirculation, Umeå
Climate Change (tCO2eq)	652	625
Freshwater Resource Depletion (m3)	1,659	1,645
Eutrophication (kgPO4eq)	691	661
Human Toxicity (kg1,4-DBeq)	14,467	14,470
Acidification (kgSO2eq)	1,913	1,860
Abiotic Resource Depletion (kgSbeq)	1,008	1,008
Aquatic Ecotoxicity (kg1,4-DBeq)	16,404	16,404
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.61
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	228
Photochemical Ozone Formation (kgC2H4,eq)	129	122

Table 5-18. Economic performance results for Recirculation of process water and chemicals. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Recirculation, Umeå
TVA	**28,889 958**	**28,878,714**
UMEVA	20,114	20,114
Volvo Trucks	28,707,303	28,696,058
Kretslopp och Vatten	2,100	2,100
Stena Recycling	160,441	160,441

Table 5-19. Eco-efficiency results for Recirculation of process water and chemicals.

Indicator	Baseline Scenario	Recirculation, Umeå
Climate Change (€/tCO2eq)	44,316	46,226
Freshwater Resource Depletion (€/m3)	17,419	17,555
Eutrophication (€/kgPO4eq)	41,823	43,658
Human Toxicity (€/kg1,4-DBeq)	1,997	1,996
Acidification (€/kgSO2eq)	15,099	15,529
Abiotic Resource Depletion (€/kgSbeq)	28,663	28,646
Aquatic Ecotoxicity (€/kg1,4-DBeq)	1,761	1,761
Stratospheric Ozone Depletion (€/kgCFC-11eq)	46,882,457	47,152,230
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	126,757	126,682
Photochemical Ozone Formation (€/kgC2H4,eq)	223,882	237,006

5.3 Assessment of Technology Scenarios

5.3.1 Technology scenario focusing on resource efficiency

The Resource efficiency technology scenario was chosen as a combination of those technologies that, in their individual assessment, has a positive effect on the consumption of resources (water, energy, scarce elements).

The technologies that make up the Resource efficiency scenario are:

- Silane-based surface treatment, Tuve
- Recirculation of process water and chemicals, Umeå

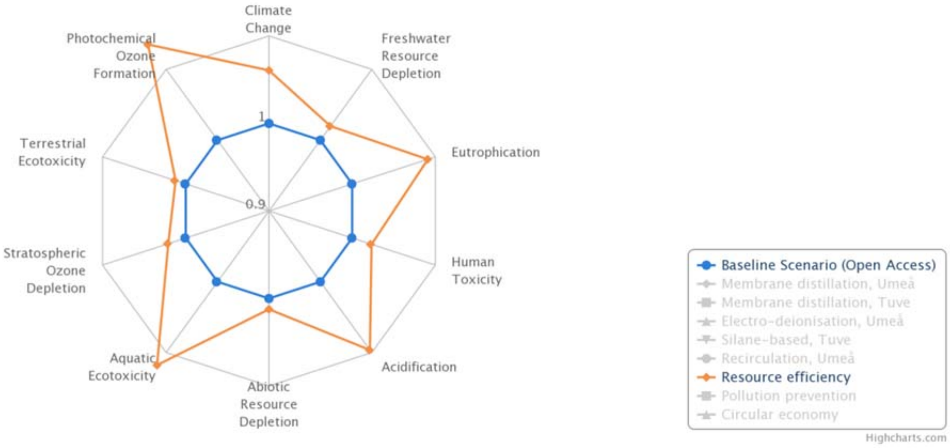

Figure 5-8. Eco-efficiency indicators for the technology scenario on Resource efficiency. (Values are normalized to Baseline = 1)

The assessment of those two technologies combined shows an increase in eco-efficiency for all indicators compared to the baseline (Figure 5-8). Table 5-20 shows the systemic environmental impact of this technology scenario, which is broken down per stage in Figure 5-9.

Table 5-20. Environmental impact of the Resource efficiency scenario.

Indicator	Baseline Scenario	Resource efficiency
Climate Change (tCO2eq)	652	615
Freshwater Resource Depletion (m3)	1,659	1,627
Eutrophication (kgPO4eq)	691	633
Human Toxicity (kg1,4-DBeq)	14,467	14,138
Acidification (kgSO2eq)	1,913	1, 745
Abiotic Resource Depletion (kgSbeq)	1, 008	996
Aquatic Ecotoxicity (kg1,4-DBeq)	16,404	14,677
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.60
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	225
Photochemical Ozone Formation (kgC2H4,eq)	129	114

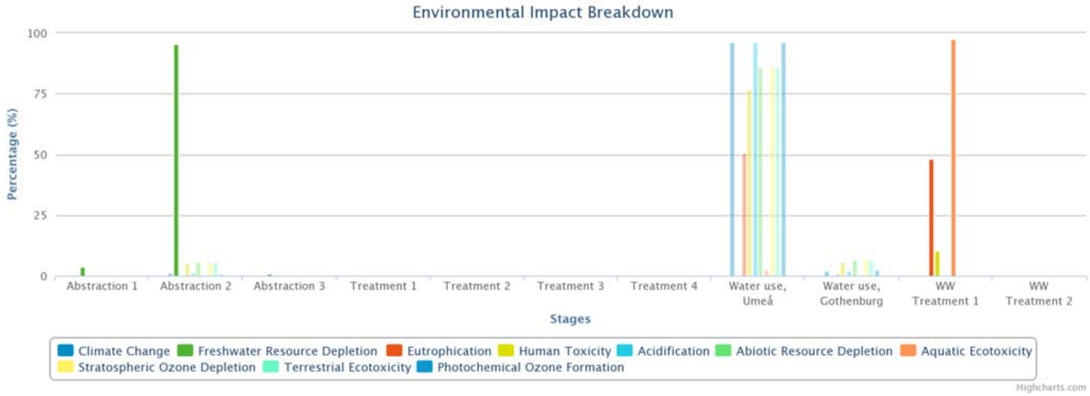

Figure 5-9. Resource efficiency technology scenario with environmental impact breakdown over stages. Transparent bars represent background impact.

Table 5-21 and Table 5-22 show the economic performance per actor. The economic performance can also be broken down into the different stages of the analysed system (Table 5-23).

Table 5-21. Economic performance results for the Resource efficiency scenario. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Resource efficiency
TVA	**28,889,958**	**28,890,095**
UMEVA	20,114	20,114
Volvo Trucks	28,707,303	28,799,912
Kretslopp och Vatten	2,100	903
Stena Recycling	160,441	69,166

Table 5-22. Economic performance results for the Resource efficiency scenario. Details per actor.

Actor	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)
UMEVA	0	2,081	0	22,196
Volvo Trucks	46,757	2,971,051,857	3,000,000,000	-101,474
Kretslopp och Vatten	0	76	0	978
Stena Recycling	0	9 134	0	78 300

Table 5-23. Economic performance per stage, Resource efficiency scenario.

Stage	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Annual Gross Income (€/yr)	Net Cash Flow (€/yr)
Abstraction 1*	0	1,481	0	-1, 481
Abstraction 2**	0	21, 337	0	-21, 337
Abstraction 3***	0	35	0	-35
Treatment 1*	0	600	0	-600
Treatment 2**	0	3, 685	0	-3, 685
Treatment 3***	0	41	0	-41
Treatment 4**	24, 492	2, 239	0	-26, 731
Water use, Umeå**	22, 265	828, 626	0	-850, 891
Water use, Gothenburg**	0	2, 970 032, 920	3, 000, 000,000	29, 967, 080
WW Treatment 1**	0	163, 050	0	-163, 050
WW Treatment 2****	0	9, 134	0	-9, 134

* Actor UMEVA

** Actor Volvo Trucks

*** Actor Kretslopp & Vatten

**** Actor Stena Recycling

5.3.2 Technology scenario focusing on pollution prevention

The Pollution prevention technology scenario was chosen as a combination of those technologies that, in their individual assessment, has a positive effect on the emissions to water and air in the foreground. In this case there are no emissions to air in the foreground, so technologies were chosen solely on their potential to reduce water pollution.

The technologies that make up the Pollution prevention scenario are:

- Silane-based surface treatment, Tuve
- Membrane distillation, Umeå
- Recirculation of process water and chemicals, Umeå

Table 5-24 shows the systemic environmental impact of this technology scenario, which is broken down per stage in Figure 5-11.

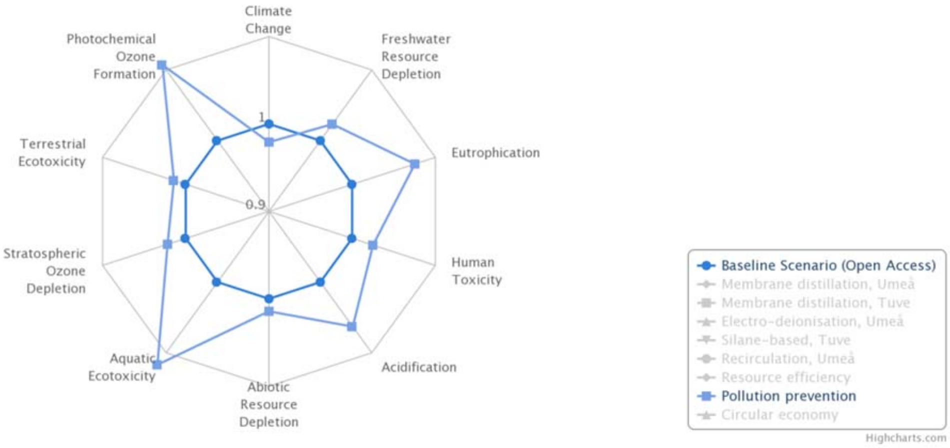

Figure 5-10. Eco-efficiency indicators for the technology scenario on Pollution prevention. (Values are normalized to Baseline = 1)

Table 5-24. Environmental impact of the Pollution prevention scenario.

Indicator	Baseline Scenario	Pollution prevention
Climate Change (tCO2eq)	652	665
Freshwater Resource Depletion (m3)	1, 659	1, 620
Eutrophication (kgPO4eq)	691	642
Human Toxicity (kg1,4-DBeq)	14, 467	14, 103
Acidification (kgSO2eq)	1, 913	1, 799
Abiotic Resource Depletion (kgSbeq)	1, 008	993
Aquatic Ecotoxicity (kg1,4-DBeq)	16, 404	14, 676
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.60
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	225
Photochemical Ozone Formation (kgC2H4,eq)	129	116

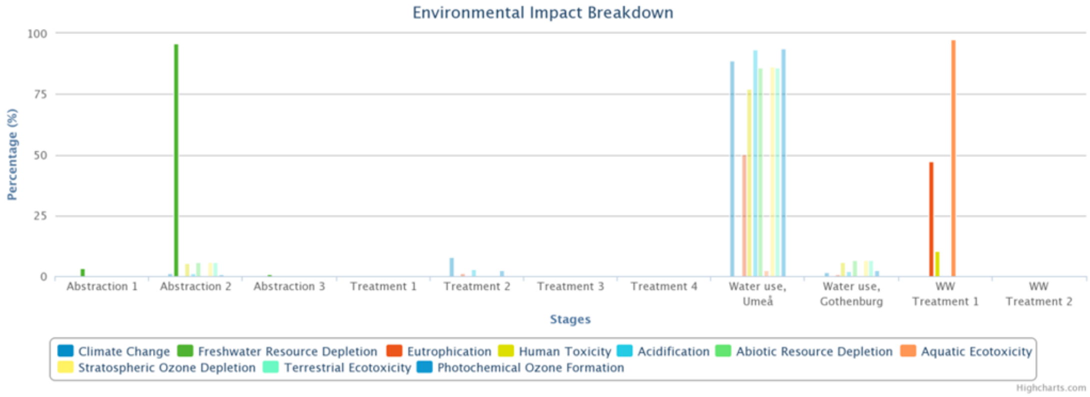

Figure 5-11. Pollution prevention technology scenario with environmental impact breakdown over stages. Transparent bars represent background impact.

Table 5-25 and Table 5-26 show the economic performance per actor. The economic performance can also be broken down into the different stages of the analysed system (Table 5-27).

Table 5-25. Economic performance results for the Pollution prevention scenario. Net Economic Output per actor and the Total Value Added.

Actor	**Baseline Scenario**	**Pollution prevention**
TVA	**28,889,958**	**28,866,517**
UMEVA	20,114	17,738
Volvo Trucks	28,707,303	28,778,710
Kretslopp och Vatten	2,100	903
Stena Recycling	160,441	69,166

Table 5-26. Economic performance results for the Pollution prevention scenario. Details per actor.

Actor	**Annual Equivalent Investment Cost (€/yr)**	**Annual O&M Cost (€/yr)**	**Gross Income (€/yr)**	**Revenues from Water Services (€/yr)**
UMEVA	0	1,837	0	19,575
Volvo Trucks	71,249	2,971,051,188	3,000,000,000	-98,853
Kretslopp och Vatten	0	76	0	978
Stena Recycling	0	9, 134	0	78,300

Table 5-27. Economic performance per stage, Pollution prevention scenario.

Stage	**Annual Equivalent Investment Cost (€/yr)**	**Annual O&M Cost (€/yr)**	**Annual Gross Income (€/yr)**	**Net Cash Flow (€/yr)**
Abstraction 1*	0	1, 307	0	-1, 307
Abstraction 2**	0	530	0	-530
Abstraction 3***	0	35	0	-35
Treatment 1*	24, 492	2, 239	0	-26, 731
Treatment 2**	22, 265	828, 626	0	-850, 891
Treatment 3***	0	2 ,970, 032, 920	3, 000,000,000	29, 967, 080
Treatment 4**	0	9, 134	0	-9, 134
Water use, Umeå**	0	162, 875	0	-162, 875
Water use, Gothenburg**	0	21, 337	0	-21, 337
WW Treatment 1**	24, 492	3, 190	0	-27, 682
WW Treatment 2****	0	41	0	-41

* Actor UMEVA

** Actor Volvo Trucks

*** Actor Kretslopp & Vatten

**** Actor Stena Recycling

5.3.3 Technology scenario promoting circular economy

The Circular economy technology scenario was chosen as a combination of those technologies that promote circular economy. In this case we have chosen technologies that either use more district heating or result in an increased process-internal recirculation.

The technologies that make up the Circular economy scenario are:

- Membrane distillation, Umeå

- Recirculation of process water and chemicals, Umeå

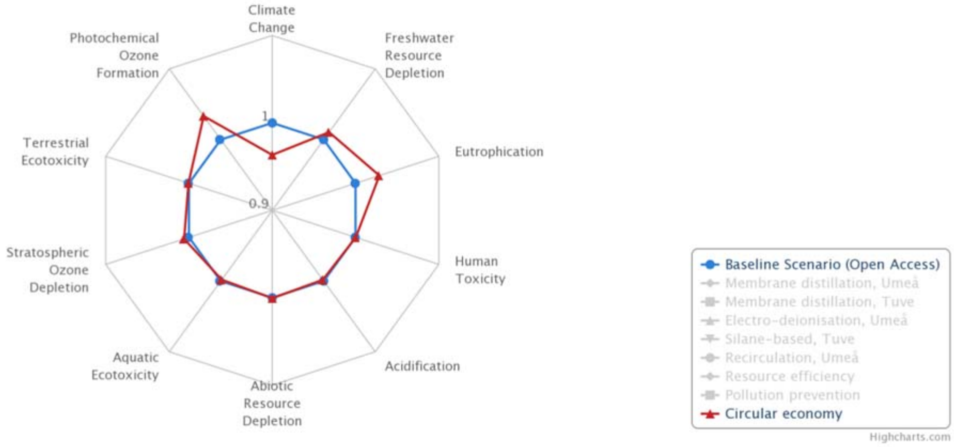

Figure 5-12. Eco-efficiency indicators for the technology scenario on Circular economy. (Values are normalized to Baseline = 1)

Table 5-28 shows the systemic environmental impact of this technology scenario, which is broken down per stage in Figure 5-13.

Table 5-28. Environmental impact of the Circular economy scenario.

Indicator	Baseline Scenario	Circular economy
Climate Change (tCO2eq)	652	675
Freshwater Resource Depletion (m3)	1, 659	1, 638
Eutrophication (kgPO4eq)	691	670
Human Toxicity (kg1,4-DBeq)	14, 467	14, 434
Acidification (kgSO2eq)	1, 913	1, 913
Abiotic Resource Depletion (kgSbeq)	1, 008	1, 005
Aquatic Ecotoxicity (kg1,4-DBeq)	16, 404	16, 403
Stratospheric Ozone Depletion (kgCFC-11eq)	0.62	0.61
Terrestrial Ecotoxicity (kg1,4-DBeq)	228	227
Photochemical Ozone Formation (kgC2H4,eq)	129	125

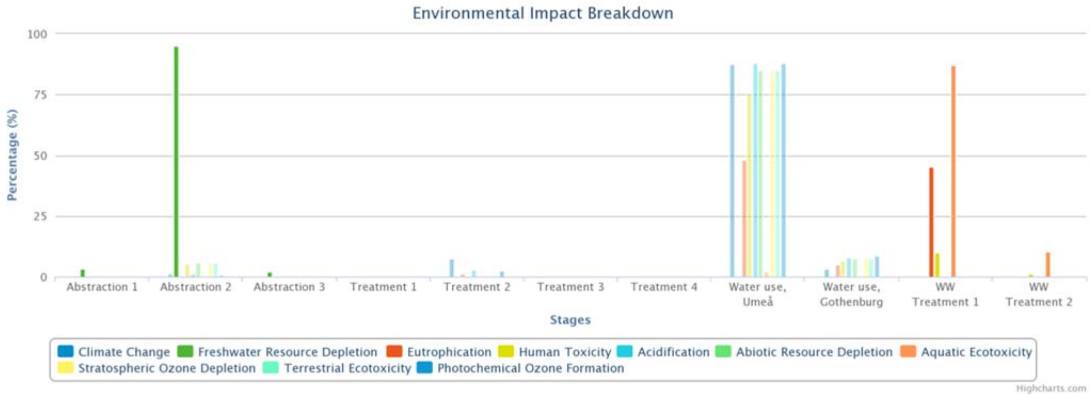

Figure 5-13. Circular economy technology scenario with environmental impact breakdown over stages. Transparent bars represent background impacts.

Table 5-29 and Table 5.30 show the economic performance per actor. The economic performance can also be broken down into the different stages of the analysed system (Table 5-31).

Table 5-29. Economic performance results for the Circular economy scenario. Net Economic Output per actor and the Total Value Added.

Actor	Baseline Scenario	Circular economy
TVA	**28,889,958**	**28,830,644**
UMEVA	20,114	17,738
Volvo Trucks	28,707,303	28,650,365
Kretslopp och Vatten	2,100	2,100
Stena Recycling	160,441	160,441

Table 5.30. Economic performance results for the Circular economy scenario. Details per actor.

Actor	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)
UMEVA	0	1,837	0	19,575
Volvo Trucks	71,249	2,971,083,736	3,000,000,000	-194,650
Kretslopp och Vatten	0	176	0	2,275
Stena Recycling	0	12,359	0	172,800

Table 5-31. Economic performance per stage, Circular economy scenario.

Stage	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Annual Gross Income (€/yr)	Net Cash Flow (€/yr)
Abstraction 1*	0	1, 307	0	-1, 307
Abstraction 2**	0	530	0	-530
Abstraction 3***	0	81	0	-81
Treatment 1*	24,492	2, 358	0	-26, 849
Treatment 2**	22,265	828, 626	0	-850, 891
Treatment 3***	0	2, 970, 065, 350	3, 000, 000,000	29, 934, 650
Treatment 4**	0	12, 359	0	-12, 359
Water use, Umeå**	0	162, 875	0	-162, 875
Water use, Gothenburg**	0	21, 337	0	-21, 337
WW Treatment 1**	24,492	3,190	0	-27, 682
WW Treatment 2****	0	94	0	-94

* Actor UMEVA

** Actor Volvo Trucks

*** Actor Kretslopp & Vatten

**** Actor Stena Recycling

5.4 Policy Recommendations Automotive industry

The assessment of silane-based corrosion protection technology has shown really promising results, both as stand-alone assessment and contributing to the goood results of the two scenarios on Resource Efficiency and Pollution Prevention. It’s implementation relies partly on the ability to prove product quality in real-life testing, something which is on the way but time-consuming. Another factor that could effect implementation of this relatively new technology is the outdated BREF document for Surface Treatment of Metals and Plastics (2006). Here the technology is mentioned only as a future technology to consider for BAT. With an update of the BREF this technology would most likely be among the BAT, thus giving more incentive to the industry to implement it.

6 Conclusions

The assessment of innovative technologies and scenarios showed that;

- The water use stages were the dominant contributors to both the total value added and the environmental impacts of the industrial water value chains studied
- The technologies which result in an increased Eco-efficiency in the water value chain are sector specific
- Combinations of technologies (scenarios) provide more eco-efficient solutions than single technologies
- Eco-innovative solutions were identified- with significant improvements in environmental performance and smaller improvements in economic performance.
- Economic performance was primarily improved for the industries- while suppliers of water and energy experienced losses.
- As an more general observation from the dialogue with the i during the analysis we learned that „industries understand «business cases and rate of return of investment» however need to be educated on the use of Eco-efficiency and total value added in decision making

The policy recommendations coming from the case studies comprise:

- Policy recommendations to increase uptake of innovative technologies are quite specific to the case studies and sectors.
- BREF documents can promote the implementations of more eco-innovative technologies
- Economic incentives may be needed to promore the demonstation and implementation of more eco-innovative technologies in particular in sectors with low economic profit
- Legislation remains an important factor in promoting eco-innovative technologies

7 References

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