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

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Technology assessment and scenario analysis

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Abstract

The Deliverable 3.4 “Technology assessment and scenario analysis” presents the results of the case studies in Sofia, Bulgaria (CS3) and Canton of Zurich, Switzerland (CS4) of the EcoWater FP7 project. They have been derived based on last EcoWater deliverables 3.2 “Baseline eco-efficiency assessment in urban water systems” and 3.3 “Innovative technologies for eco-efficiency improvement. In this report, the selected technologies have been assessed regarding their effects on the previously calculated baseline eco-efficiency of the current state individually, and as characteristic combinations of measures in scenario analysis.

An updated and finalized baseline-eco-efficiency assessment for each case study area is presented as starting point and is followed by individual assessments of innovative technologies. Six technologies were assessed in the Bulgarian case study and seven in the Swiss case study. All technologies are shortly described emphasising on the main assumptions for the proposed technical implementation, environmental and economic parameters. Subsequently, the calculated results are presented for the environmental, economic and eco-efficiency performance for each technology. Results are visualised with spider diagrams for the whole system and from different actors’ view. Additionally x-y-diagrams visualising the nominator and denominator of the eco-efficiency formula are presented to highlight potential trade-offs between economic and environmental performance.

In addition to individual technologies’ assessments, three scenarios are elaborated according to three overarching sustainability goals: 1) resource efficiency, 2) pollution prevention and 3) circular economy. Individual technologies have been assigned to one or more of these three goals, depending on their environmental performance, assessed by twelve indicators. Each scenario has been described in regard to its assumptions and results of its environmental and economic performance. Finally the analysis of the relative eco-efficiency assessment against the baseline is presented.

The results reveal the potential to improve against the key objectives but also challenges for interpretation and implementation and will guide the formulation of policy recommendations in the final phase.

Contents

List of tables

List of figures

Abbreviations

D – Deliverable (EcoWater)
DMA – District metering area
NSI – National statistical institute
PRV – Pressure reduction valve
PRT – Pressure reduction turbine
SEWRC – State energy and water regulatory commission
WTP – Water treatment plant
WWTP – Waste water treatment plant

1 Introduction

In the following report the results of technology and scenario assessment and analysis for Sofia case study (Bulgaria) are presented in chapter 2 and for Waedenswil urban case study (Switzerland) - in chapter 3. For both urban case studies first an updated baseline scenario assessment of the water service and use system is introduced (chapters 2.1/3.1). Then the individual assessments of innovative technologies are presented (chapters 2.2/3.2). For each technology, a short description, main assumptions and finally the results in form of absolute and relative changes compared to the baseline in economic, environmental and eco-efficiency indicators are provided. Subsequently, in chapters 2.3/3.3 the assessment of scenarios is conducted, in which technologies are clustered according to three overarching sustainability goals: resource efficiency, pollution prevention and circular economy. In chapters 2.4/3.4 the results are discussed for each of the case studies. In chapter 4 main similarities and differences between the case studies are described to derive generic conclusions.

2 Sofia urban case study

2.1 Updated baseline scenario assessment

The following model updates in the baseline scenario were implemented after D3.2:

- Fixed costs of the urban water systems were added to the model (i.e. salaries, depreciation, amortization, maintenance, taxes)
- In the previous model the eutrophication potential was calculated based on the output loads of BOD, N and P from each stage. However, only the final effluent of the WWTP has impact on the receiving water body. That is why not all of the generated pollution, but only this final part was assigned to the stages. It was done manually proportional to the contribution of the initial pollution load of the stage to the sewerage system.
- The background factors for gas heat production are updated thus the values of some of the impact categories are changed. The differences between factors used in D3.2 and new ones are shown in Table 1.
- One of the technology scenarios considers a pressure management option with pressure reduction turbines. This has two positive effects: 1) water losses reduction from the network due to lower pressure; and 2) utilization of hydro energy potential in the water distribution network by generating electricity.

Table 1 Change in background factors for gas heat production process per kWhheat

	OLD	NEW*	Unit
Acidification	0.000771008	0.000193454	kgS0$_2$eq/kWh
Eutrophication	0.000149826	0.000031881	kgP0$_4$eq/kWh
Aquatic Ecotoxicity	0.003416979	0.002676075	kgl,4-Dbeq/kWh
Climate Change	0.60601591	0.254556616	kgC0$_2$eq/kWh
Human Toxicity	0.004897345	0.026412598	kgl,4-Dbeq/kWh
Stratospheric Ozone Depletion	0.00000012	0.00000005611	kgCFC-lleq/kWh
Photochemical Ozone Formation	0.00006254	0.000017280	kgC$_2$H$_4$,eq/kWh
Terrestrial Ecotoxicity	0.00001150	0.000006366	kgl,4-Dbeq/kWh
Mineral Depletion	0.002140000	0.000919389	kgFe-eq/kWh
Fossil Fuels Depletion	0.023000000	0.105731079	MJ/kWh
Respiratory Inorganics	0.000077813	0.00002787394	kgPM$_{10}$,eq/kWh

*The factors were derived with SimaPro 7.1 using Ecoinvent 2.2 Database

The chosen year for the baseline scenario is 2011 (D3.2) where in many district metering areas (DMAs) pressure management was already applied by means of pressure reduction valves. In order to simulate the reduction effect on water losses after implementation of pressure management solutions based on real data provided from the water operator, a virtual baseline scenario was built under the only assumption that the pressure reduction valves, in DMAs with higher hydro energy potential, had not been installed yet. Thus real measurements for the effect of pressure management could be used in the calculations.

The results for the updated baseline scenario are shown below.

Environmental performance

In Table 2 the values of the environmental indicators are summarized distinguished between foreground values within the project perimeter and the background values stemming from outside the project perimeter systems. Figure 1 reveals the significance of the background systems for the environmental impacts. Only two environmental impact indicators are dominated by the foreground system.

Table 2: Environmental indicators results for CS3 baseline assessment (2011)

Indicator (Unit per year, i.e. 2011)	Total emissions	Foreground system emissions	Background system emissions
Climate Change (tC0$_2$eq)	838,665	10,058	828,607
Fossil Fuels Depletion (MJ)	10,714,494,472	0	10,714,494,472
Freshwater Resource Depletion (m^3)	76,032,334	76,032,334	0
Eutrophication (kgP0$_4$eq)	1,891,044	1,620,563	270,481
Human Toxicity (kgl,4-DBeq)	71,003,651	0	71,003,651
Acidification (kgS0$_2$eq)	17,909,303	0	17,909,303
Aquatic Ecotoxicity (kgl,4-DBeq)	5,934,883	0	5,934,883
Stratospheric Ozone Depletion (kgCFC-lleq)	145	0	145
Terrestrial Ecotoxicity (kgl,4-DBeq)	153,637	0	153,637
Respiratory Inorganics (kgPM$_{10}$,eq)	3,503,654	0	3,503,654
Photochemical Ozone Formation (kgC$_2$H$_4$,eq)	708,799	0	708,799
Mineral Depletion (kgFe-eq)	1,861,282	0	1,861,282

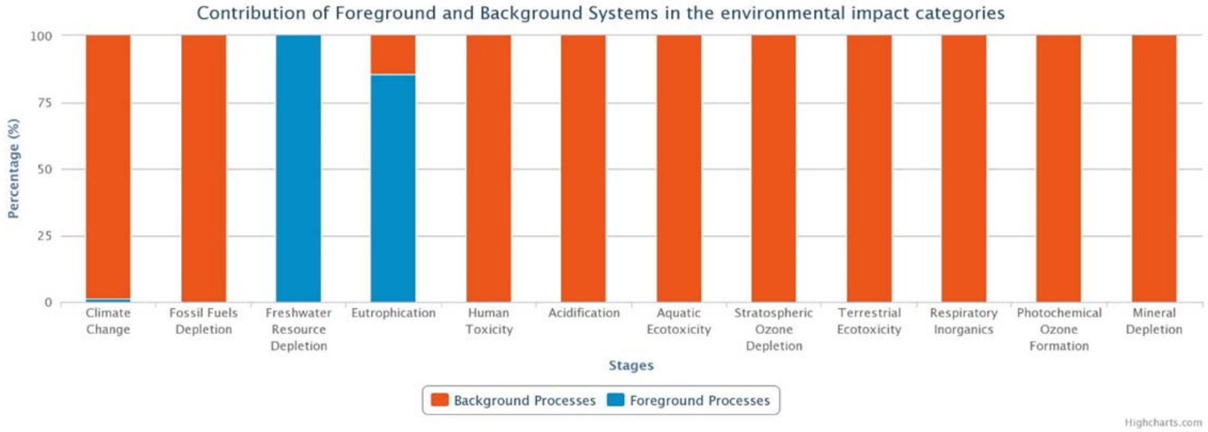


Figure 1: Contribution of Foreground and Background Systems in the environmental impact categories

The environmental impact breakdown per stages for background and foreground system is presented in Figure 2 and Figure 3 respectively.

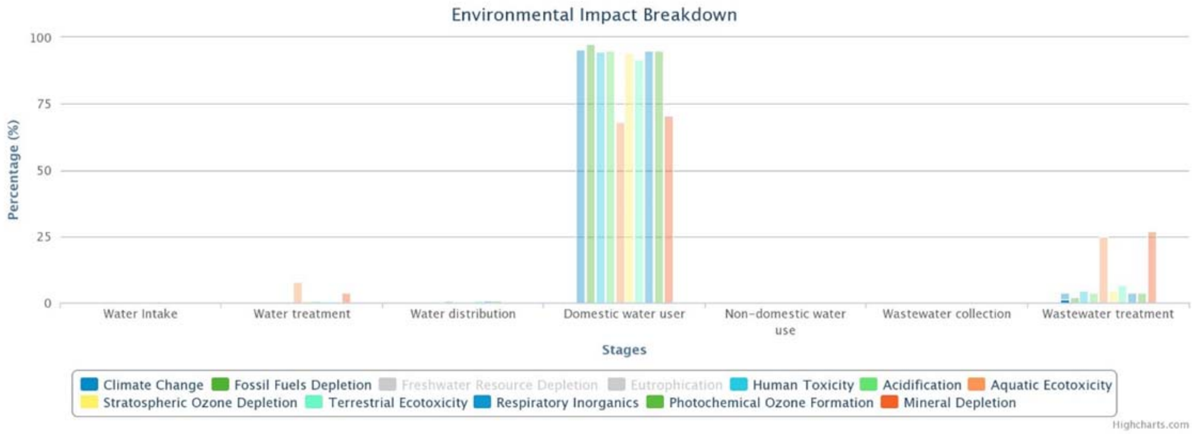


Figure 2: Environmental impact contribution breakdown, percentage per stage of total except for freshwater resource depletion and eutrophication, which are presented in Figure 3

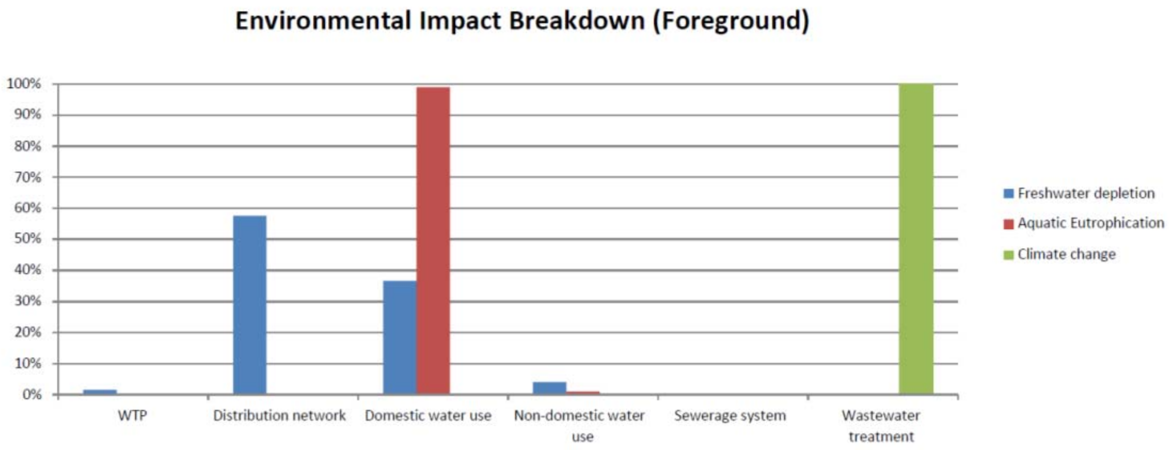


Figure 3 Environmental impact contribution breakdown of foreground processes, percentage per stage's contribution (Eutrophication, Freshwater Resource Depletion and Climate Change)

Economic performance

The results from the economic assessment are summarized in Table 3. The Total Value Added from water use is about 78 Mio € per year (2011) for the Sofia water service and use system. In Figure 4 the economic interactions between the involved actors are presented.

Table 3 Economic performance results in € per year

Actor	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues (+) from / Costs (-) for Water Services (€/yr)	Net Economic Output (€/yr)
Water operator	32,728,617	33,406	54,043,453	21,348,242
Domestic water users	97,465,852	198,178,400	-48,636,896	52,075,652
Non-domestic water users	0.00	10,834,686	-5,406,557	5,428,130
Total	130,194,469	209,046,492	0.00	78,852,024

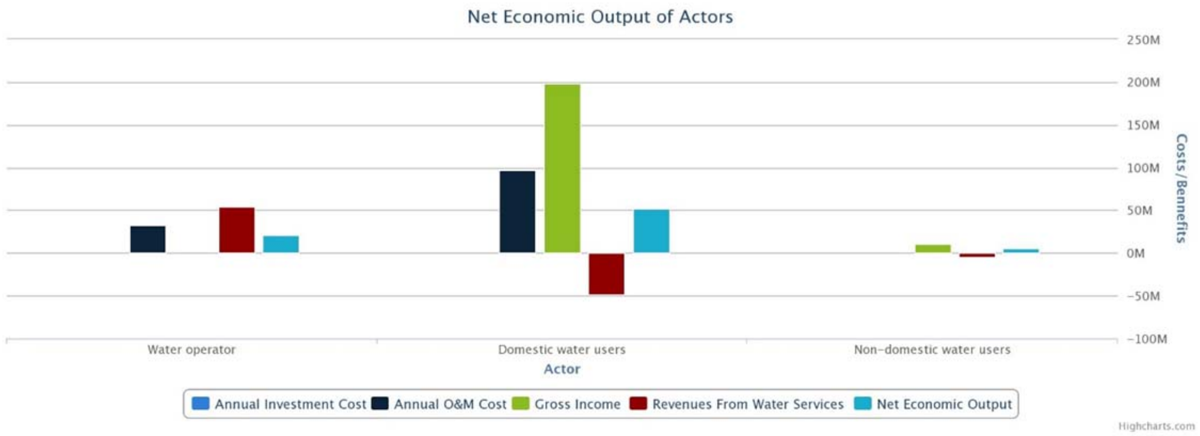


Figure 4 Economic Performance per Actor

Eco-efficiency indicators

The values of the eco-efficiency indicators for the selected midpoint impact categories are summarized in Table 4.

Table 4 Baseline eco-efficiency indicators

Eco-efficiency Indicator (Unit)	Value (€/Unit)
Climate Change (€/$tC0_2eq$)	94.02
Fossil Fuels Depletion (€/MJ)	0.01
Freshwater Resource Depletion (€/m^3)	1.04
Eutrophication (€/$kgP0_4eq$)	41.70
Human Toxicity (€/kgl,4-DBeq)	1.11
Acidification (€/$kgS0_2eq$)	4.40
Aquatic Ecotoxicity (€/kgl,4-DBeq)	13.29
Stratospheric Ozone Depletion (€/kgCFC-lleq)	542,751.14
Terrestrial Ecotoxicity (€/kgl,4-DBeq)	513.24
Respiratory Inorganics (€/kgPM10,eq)	22.51
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.25
Mineral Depletion (€/kgFe-eq)	42.36

The results from the baseline scenario are used as reference values to compare the situation after implementation of technologies and the scenarios.

2.2 Individual technology assessments for Sofia urban case study

2.2.1 Pressure reduction turbine (PRT) (Technology assessment 1 in the Toolbox)

Short description

Figure 5 Pressure Reduction Turbine (Source: www.zeropex.com)

The water distribution network of Sofia is operating almost entirely by gravity. The water reservoirs are placed on strategic places between 600 – 700 m a.s.l. while the average altitude of the city is 580 m a.s.l. The current disadvantage of this scheme is that there are many regions in the network with pressure above the recommended optimal one, especially at night time when the water consumption and flow rates are low. This results in higher water losses through leakages as well as in more pipeline failures. A possible solution to these challenges is pressure management. For this purpose, the water supply network is divided into several district metering areas (DMA) in which pressure reduction devices are installed. Traditionally these were pressure reduction valves (PRV). In recent years an innovative solution has been developed – pressure management with pressure reduction turbines (PRT). It appears to be an attractive solution, because together with solving the high pressure problem, described above, it utilizes the hydro potential energy to produce electricity, thus improving the energy efficiency of the overall system. Herein a technology assessment of the implementation of pressure reducing turbines for the Sofia system will be studied.

Assumptions and calculations

To measure the effect of pressure management on water losses, data for water flows in DMAs before and after implementation of PRVs was requested and provided from the water operator. Water losses closely depend on the specific conditions and materials of the pipes, but in most cases the pressure management in the DMAs leads to 15% - 20% water losses reduction. An example PMA was selected to demonstrate this effectiveness. The reduction of water losses is shown in Figure 6. The red line shows the minimum water flow at night which could be considered as water losses from leakages. Before introduction of pressure management the water losses are about 50m3/h and after installing a PRV they are reduced to 40m^3/h which means about 20% water losses reduction

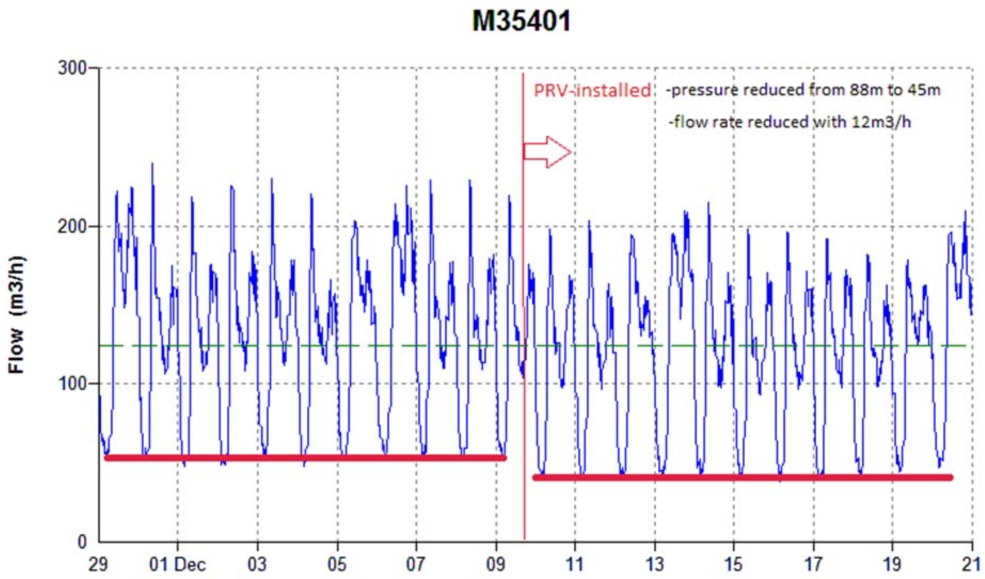


Figure 6 Water flow before and after implementation of PRV (taken from water operator’s data)

Detailed data for pressure and flow characteristics at the inlet of the PMA were collected. During summer the water consumption is lower, which could be explained by the fact that people go on holidays, resulting in lower pressure losses in the pipes and higher pressure in the water distribution network, thus the differential pressure in the PRV increased at summer. The opposite, due to the increased water use in winter, higher water flow and lower net pressure in the PRV are registered (Table 5).

Table 5 Pressure and flow characteristics in different seasons for an existing PRV in the Sofia network

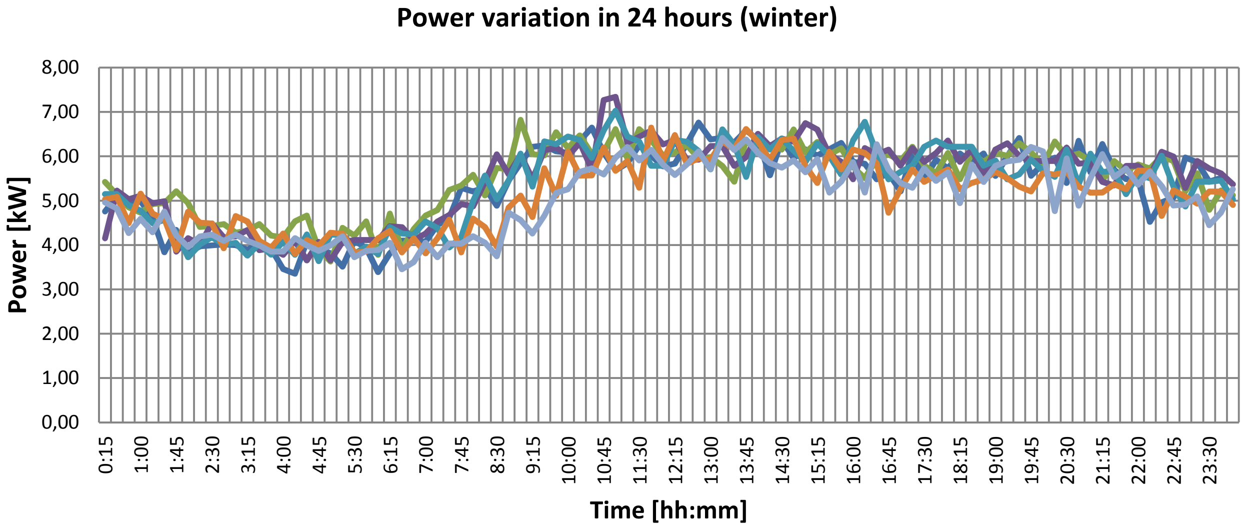
Winter

	Pressure Inlet DMA [m]	Pressure outlet DMA [m]	Net pressure [m]	Flow [m3/h]
Average	78.95	60.61	18.34	152.46
Maximum	80.43	61.49	19.90	288.00
Minimum	76.84	59.01	16.78	84.00

Summer

	Pressure Inlet DMA [m]	Pressure outlet DMA[m]	Net pressure [m]	Flow [m3/h]
Average	79.19	55.55	23.64	133.67
Maximum	80.53	55.96	24.76	180.00
Minimum	78.13	55.20	22.64	84.00

The power generation pattern after PRT has been installed in the selected PMA is shown in Figure 7. For its calculation pressure and flow characteristics in 15 minutes intervals for water consumption were used. Data were collected for six representative days at winter and summer. In the current case the yearly average power output of the PRT is about 6 kW. The minimum and maximum power output varies around 50% above or below the mean value, i.e. from 3kW to 9kW.



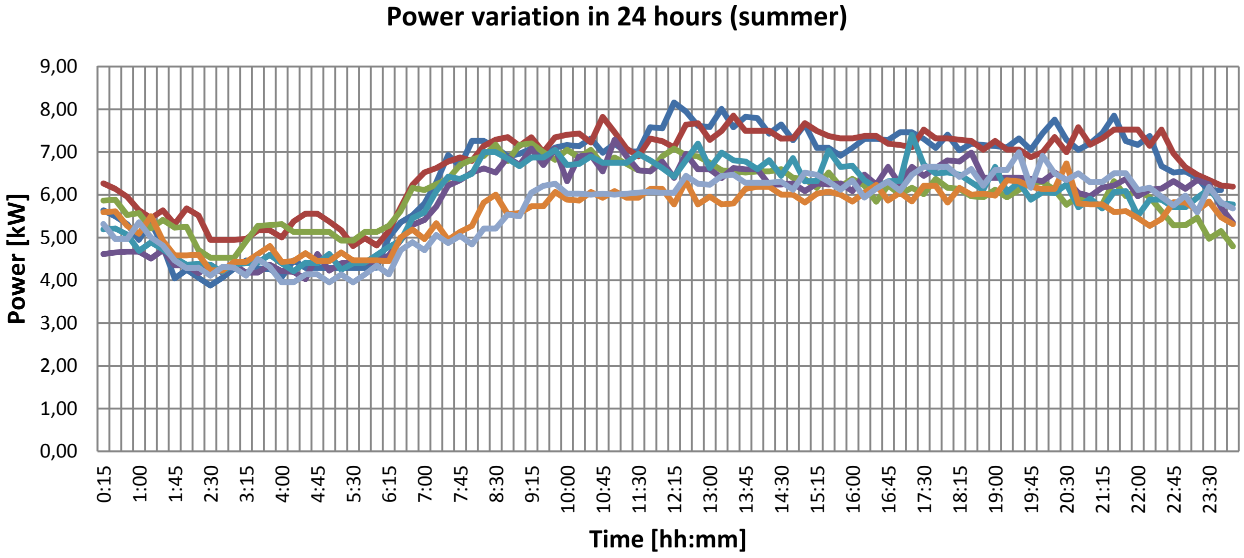


Figure 7 Power generation pattern of a PRT (calculated by the team)

There are about 180 Pressure management areas (PMAs) in Sofia’s water distribution network. The most common currently used practice for pressure management is achieved by means of pressure reduction valves, which converts the kinetic energy into heat. On the other side, the pressure reduction turbines fulfil the same function as the PRVs, but in addition they convert this kinetic energy into electricity. Thus in this technology scenario the effect of using PRTs instead of PRVs for pressure management as an innovative solution is assessed. As it was stated above, the “Baseline scenario” represents a state of the system where the biggest PRVs have not been installed yet. This allows the impact of pressure management on the system’s eco-efficiency performance to be estimated considering real measurement data before and after PRVs installation. Data show that the average observed effect of pressure management on water losses reduction is about 20%. As not all of DMAs have appropriate characteristics for PRTs, the following criteria were used to select the PRVs to be changed with PRT:

1. Mean average daily flow rate bigger than 26 l/s, which guarantees minimum flow, necessary for the turbine’s operation;

2. Net pressure drop bigger than 20 meters for average daily flow rate to guarantee the operational head of the turbine;
3. Average power potential for of the turbines bigger than 6 kW, because for less power the investment is not efficient.

With these screening criteria, 44 PMAs were selected to be considered in the scenario. For calculation of the average power output of converting kinetic energy into electricity, data for water flow characteristics of the existing PRVs was collected. If PRTs are installed in all 44 PMAs, the total average power output will be about 836 kW. This means that 7.32 GWh of electricity could be generated per year. The generated electricity would be fed to the electrical grid and used in other places in the system to cover part of the electricity needs, mainly for the biggest energy consumers - water and waste water treatment plants. Thus the energy efficiency of the water system will be improved. Less non-renewable electricity will be used, reducing the negative environmental impact from energy production in background processes. Considering the current price for electricity from the grid - 0.06 €/kWh an additional income of 439,200 € per year could be generated.

The equipment costs for a PRT unit are classified in three categories depending on the average daily water flow on the PMA inlet (Table 5).

Table 6 Costs for PRT implementation (Zeropex, 2014)

Criteria	Equipment costs [€]	Other costs [€]	Total costs [€]
PMA with water flow less than 50l/s	75,000	20,000	95,000
PMA with water flow more than 50l/s	95,000	20,000	105,000
Pressure reduction before "Boyana" reservoir (295l/s)	120,000	80,000	200,000

The input data for SEAT/EVAT model are shown in Table 7.

Table 7 Input data for the SEAT/EVAT model

SEAT			
	Baseline	After technology implementation	Unit
Generated electricity in water distribution stage	0	7,320,000	kWh/year
Water losses	101,821,000	91,821,000	m^3/year
EVAT			
Investment costs	4,465,000 €		
Technology lifetime	20 years		
Interest rate	2%/y		
Costs savings from electricity production (€/y)	439,200		

The total investment costs for utilizing the hydro energy potential of the selected PMAs (44 in total) will be around 4.7 Mio €. The producers of PRTs give an expected lifetime of about 20 years (2014, Zeropex).

Results

Table 8 present the change in environmental performance in this technology scenario. The biggest change is observed in Freshwater Resource Depletion indicator. All other indicators show improvement relative to reduced energy consumption and lower material consumption for water purification. The economic performance is improved only for the water operator (Table 9). The effect in this technology scenario is relatively small considering the feasible level of implementation. However the overall eco-efficiency is improved (Table 10 and Figure 8),Table 9.

Table 8 Environmental performance

Environmental Impact Indicator (unit per year)	Baseline	After implementing technology	Change
Climate Change (tCO_2eq/y)	838,665	831,922	-0.80%
Fossil Fuels Depletion (MJ/y)	10,714,494,472	10,648,368,484	-0.62%
Freshwater Resource Depletion (m^3/y)	76,032,334	71,659,616	-5.75%
Eutrophication ($kgPO_4eq/y$)	1,891,044	1,887,914	-0.17%
Human Toxicity (kg1,4-DBeq/y)	71,003,651	70,528,283	-0.67%
Acidification ($kgSO_2eq/y$)	17,909,303	17,664,881	-1.36%
Aquatic Ecotoxicity (kg1,4-DBeq/y)	5,934,883	5,904,516	-0.51%
Stratospheric Ozone Depletion (kgCFC-11eq/y)	145	144	-0.69%
Terrestrial Ecotoxicity (kg1,4-DBeq/y)	153,637	151,654	-1.29%
Respiratory Inorganics ($kgPM_{10}$,eq/y)	3,503,654	3,455,656	-1.37%
Photochemical Ozone Formation (kgC_2H_4,eq/y)	708,799	699,304	-1.34%
Mineral Depletion (kgFe-eq/y)	1,861,282	1,857,398	-0.21%

Table 9 Economic performance in Euro per year

Actor	Baseline (Euro/y)	After technology implementation (Euro/y)	Change
TVA	78,852,024	79,131,423	0.35%
Water operator	21,348,242	21,627,641	1.31%
Domestic water users	52,075,652	52,075,652	0.00%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 10 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	95.12	1.17%
Fossil Fuels Depletion (€/MJ)	0.007359	0.007431	0.98%
Freshwater Resource Depletion (€/m^3)	1.037	1.104	6.46%
Eutrophication (€/$kgPO_4eq$)	41.70	41.91	0.50%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.122	0.99%
Acidification (€/$kgSO_2eq$)	4.403	4.480	1.75%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	13.40	0.83%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	548,310	1.02%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	521.8	1.68%
Respiratory Inorganics (€/kgPM10,eq)	22.51	22.90	1.73%
Photochemical Ozone Formation (€/kgC2H4,eq)	111.2	113.2	1.80%
Mineral Depletion (€/kgFe-eq)	42.36	42.60	0.57%

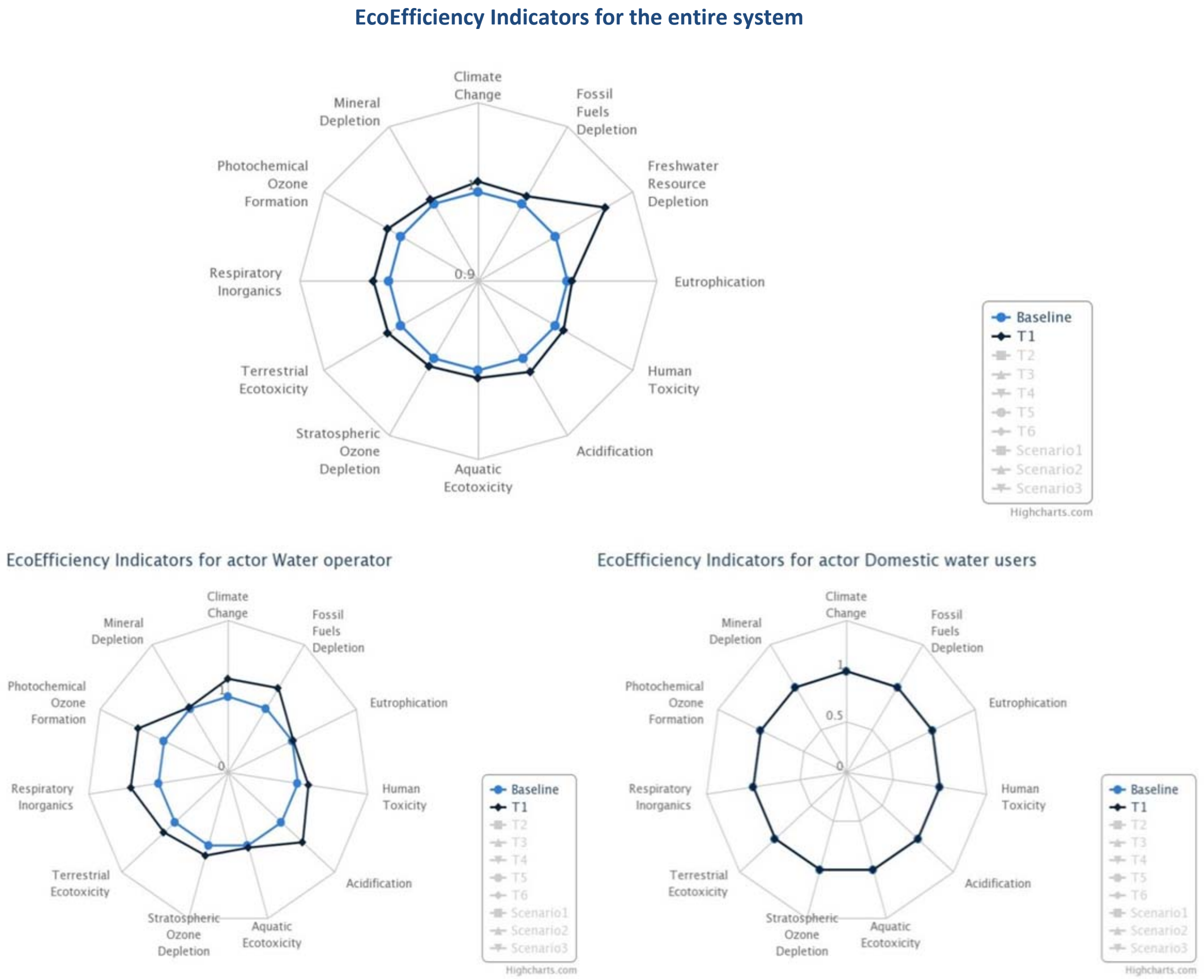


Figure 8 Eco-efficiency performance relative to baseline = 1

2.2.2 Hydro power plant (Technology assessment 2 in the Toolbox)

Short description

The largest part of the water for Sofia city is taken from Iskar reservoir. It is situated at higher altitude than the city, so the abstracted water is transported by pressurized water mains to the water treatment plant (WTP) Bistritsa. The WTP is situated around 60 m lower than the Iskar reservoir thus there is a huge hydro-energy potential at the inlet of the plant. In this technology assessment the effect of building a hydro power plant before the WTP is assessed (see figure 9). The purpose is to transform the hydro potential energy into electricity. This technology was suggested by the stakeholders during the first workshop with them in Sofia.

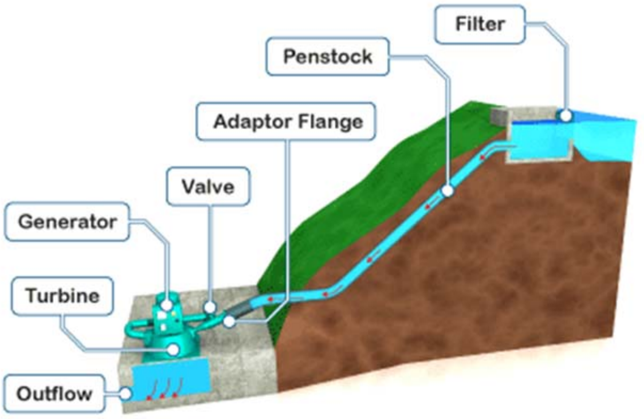


Figure 9 Hydro power plant (http://www.raine-or-shine.com)

Assumptions and calculations

The water flow in WTP-Bistritsa varies in the range of 1.5 to 3.2 m^3/s, depending on the water needs of the city. The pressure at the outlet of the water main varies from 50 to 60 m. The yearly average water flow and pressure are around 2 m^3/s and 52.5 m, respectively. With these flow characteristics the net power rating of a hydropower plant with 75% efficiency would be 720 kW and could produce about 6.3 GWh of electric energy per year. The generated electricity could be used in the water supply and sewerage system substituting electricity purchased from the grid. Thus the energy efficiency of the system will be improved and the environmental impact from production of conventional electricity would be reduced. Considering the current price of the electricity - 0.06 €/kWh the costs for purchasing electricity from the grid will be reduced by 378,500 €/year. According to SEWRC the investment costs are about 3,050 € per kW installed power (SEWRC, 2013). The installed power would be about 1,100 kW which is determined by the maximum power output reached when the water flow is on its maximum. Thus the total investment costs are estimated at about 3.5 Mio €. The input data for SEAT/EVAT model are shown in Table 11.

Results

Table 12 presents the expected change in environmental performance. This technology scenario improves the energy efficiency of the system thus the main effect is observed in reduced impact indicators relative to energy production processes. The total value added is increased and the overall eco-efficiency is improved.

Table 11 Input data for the SEAT/EVAT model

SEAT			
	Baseline	After technology implementation	Unit
Produced electricity in water distribution stage	0	6,300,000	kWh/year

EVAT	
Investment costs	3,500,000 €
Technology lifetime	20 years
Interest rate	2%/y
Reduced electricity costs	-378,500 €/y

Table 12 Environmental performance

Environmental impact indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	832,954	-0.68%
Fossil Fuels Depletion (MJ)	10,714,494,472	10,658,575,571	-0.52%
Freshwater Resource Depletion (m^3)	76,032,334	76,032,334	0.00%
Eutrophication ($kgPO_4eq$)	1,891,044	1,888,472	-0.14%
Human Toxicity (kg1,4-DBeq)	71,003,651	70,610,398	-0.55%
Acidification ($kgSO_2eq$)	17,909,303	17,701,381	-1.16%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,929,349	-0.09%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	145	0.00%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	151,992	-1.07%
Respiratory Inorganics ($kgPM_{10},eq$)	3,503,654	3,462,830	-1.17%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	700,722	-1.14%
Mineral Depletion (kgFe-eq)	1,861,282	1,860,261	-0.05%

Table 13 Economic performance in Euro per year

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	79,015,975	0.21%
Water operator	21,348,242	21,512,194	0.77%
Domestic water users	52,075,652	52,075,652	0.00%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 14 Eco-efficiency performance

Eco-efficiency Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	94.86	0.89%
Fossil Fuels Depletion (€/MJ)	0.007359	0.007413	0.73%
Freshwater Resource Depletion (€/m^3)	1.037	1.039	0.19%
Eutrophication (€/$kgPO_4eq$)	41.70	41.84	0.34%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.119	0.72%
Acidification (€/$kgSO_2eq$)	4.403	4.464	1.39%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	13.33	0.30%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	546,748	0.74%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	519.9	1.31%
Respiratory Inorganics (€/$kgPM_{10},eq$)	22.51	22.82	1.38%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	112.8	1.44%
Mineral Depletion (€/kgFe-eq)	42.36	42.48	0.28%

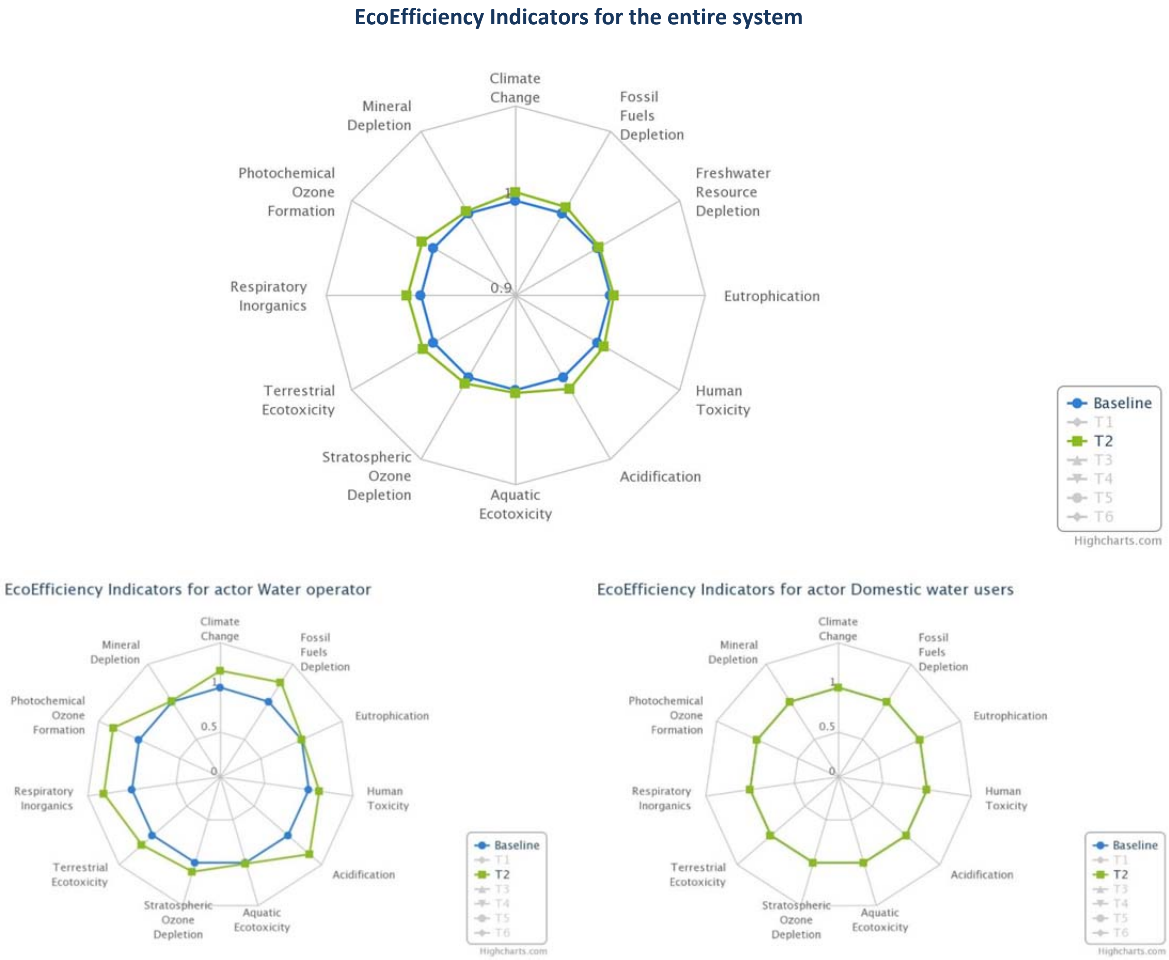


Figure 10 Eco-efficiency performance

2.2.3 Solar sludge drying (Technology assessment 3 in the Toolbox)

Short description

Figure 11 Thermo-System installed in Okeechobee, Florida, USA (www.parkson.com)

The fate of the sludge after its treatment in the WWTPs is a serious problem. It is associated with large areas for storage, transport (which means emissions to the air), disposal etc. The capacity of sludge drying beds of Sofia WWTP is limited to 80,000 t of sludge per annum. By 2025 the sludge amount is expected to reach about 130,000 t/y (D 3.3). If the present status of sludge treatment remains, new terrains for temporary sludge storage (sludge drying beds) have to be allocated. Therefore it is critical to implement a treatment unit which either decreases the sludge amount or makes the sludge appropriate for utilization for other purposes. There are different solutions for further reduction of water quantity in the sludge but one of the most advantageous is the solar drying of sludge, as the main part of the energy in the treatment process comes from a renewable source – the sun (D3.3). The general construction of a solar sludge dryer consists of a greenhouse equipped inside with drying fans. The key parameters that govern the solar sludge drying are: (1) the drying air temperature, (2) the drying air humidity, (3) the air flow velocity over the sludge, (4) the surface structure of the sludge and (5) the sludge temperature. In summary, this study will focus on the assessment of the eco-efficiency improvement after implementation of solar sludge drying beds.

Assumptions and calculations

The total generated sludge in Sofia WWTP for 2011 is 101,537 t with a dry solids content in the range of 25-30 %, which results in about 27,500 t DS with an estimated average DS of 27%. The solar sludge drying system is expected to generate about 0.5 - 3 t/m^2 dewatered sludge per year (D 3.3). If an average value of 1.5 t/m^2 per year is assumed, the required area for the system will be 18,400 m^2 for the 27,500 t DS. Currently about 35,000 m^2 in the WWTP is occupied with open sludge drying beds, which appears as a perfect opportunity for implementation of this innovative technology (Figure 12). The available space of the sludge drying beds will be used to build on their place a solar sludge drying system and allocation of storage areas for sludge in cold periods of the year when the efficiency of solar drying system is low.

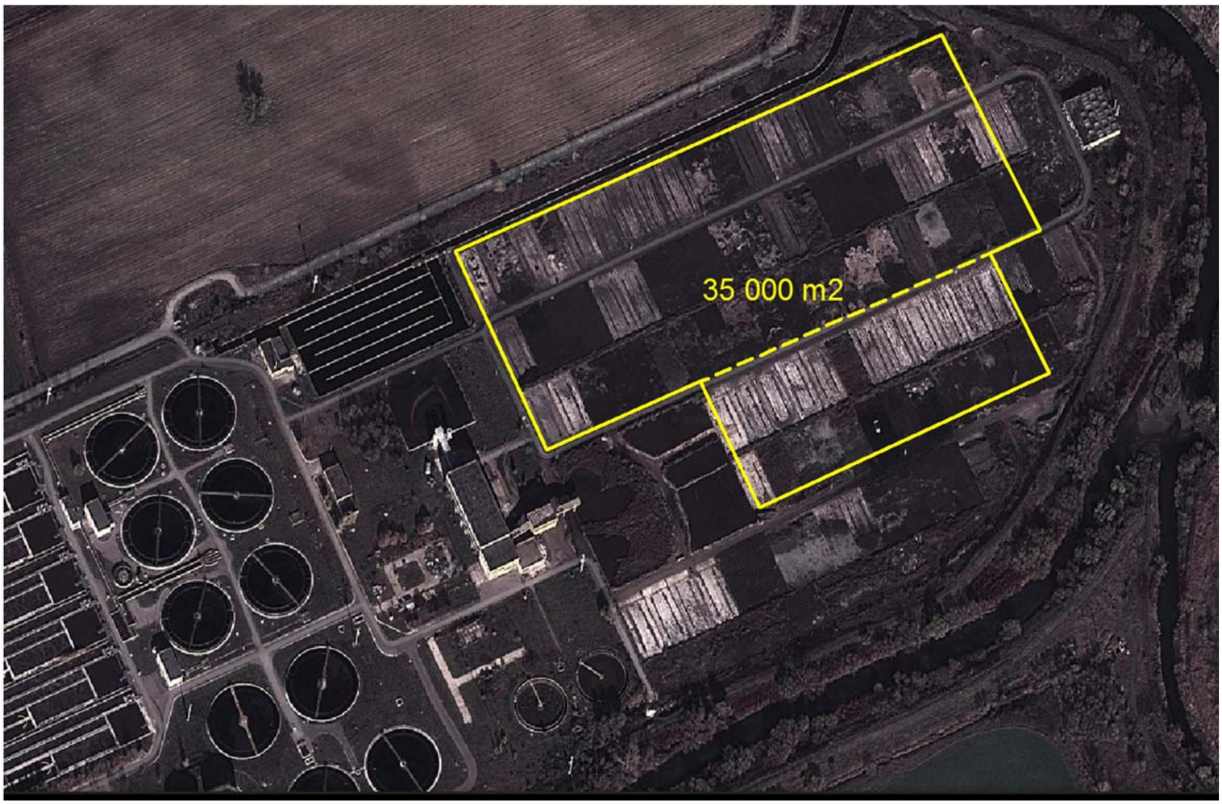


Figure 12 Available area for solar sludge drying system in Sofia WWTP (Google Earth, 2014)

Depending on the seasonal weather conditions the expected sludge dry solids content in the dried sludge vary from 50% to 90% (D 3.3). For the Bulgarian climate, the yearly average targeted DS content in the sludge is assumed about 80%, which means that sludge quantity (dry matter and water content of the sludge) will be reduced from 101,537 t to 34,400 t/year. The electricity required for the system's operation is about 25 kWh per ton evaporated water (MOEW, 2013). This means that 567,600 kWh of additional energy input is required per year or 16.5 kWh per ton dewatered sludge. Costs for this electricity is expected to be 100,740 €/y.

According to other studies, the investment cost range between 350 and 500 €/m^2 for civil engineering works and mechanical equipment (D 3.3). Considering that the costs for civil engineering works in Bulgaria are expected to be lower than in the cited studies, 300 €/m^2 investment costs are assumed. Thus the total investment for the system is calculated to be about 5.5 Mio €.

The machinery part is estimated to be about 1,500,000 €, with an expected lifetime of 15 years. The expected lifespan of the other elements of the system (4,000,000 €) is reported to be about 30 years.

Many studies report also a significant decrease of pathogen content in the solar dried sludge in a way that the sludge can reach the requirements of Environmental Protection Agency (EPA) for bio solids class A (Bux et.al., 2001; EPA, 2007; Salihoglu N.K 2007; Mathioudakis et. al 2009). Thus the dried sludge is foreseen to be used in agriculture and for land reclamation. An average sale price of 50 € per ton dried sludge is assumed. This will generate an additional income of 1,720,000 €/year for the water operator. Additionally it could also be used to substitute fossil fuels in industry, e.g. cement kilns.

The input data for SEAT/EVAT model are shown in Table 15.

Table 15 Input data for SEAT/EVAT model

SEAT			
	Baseline	After technology implementation	Unit
Transport	2,538,018	0	t-km
Electricity for sludge drying	0	567600	kWh/year
Sludge volume	101,537	34,400	t/a
EVAT			
Investment costs machinery	1,500,000 €		
Technology Lifetime	15 years		
Interest Rate	2%/y		
Investment costs (other)	4,000,000 €		
Technology Lifetime	30 years		
Interest Rate	2%/y		
Income from sold solar dried sludge	1,720,000 €/year		

Results

Assuming that the sludge will be converted to fertilizer the environmental impact from transport for sludge disposal will be avoided. Table 16 presents the change in environmental performance. The environmental impact in categories relative to transport process is reduced – Climate Change, Fossil fuels depletion, Mineral depletion, etc. However, considering the environmental impact in the entire system, more than 90% of climate change and fossil fuels depletion is due to energy consumption. Thus this scenario affects at most the mineral depletion indicator as the biggest contributor from all other processes in the system. The TVA for the water operator shows significant improvement due to additional income from produced fertilizer (Table 17).

Table 16 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO2eq)	838,665	838,619	-0.01%
Fossil Fuels Depletion (MJ)	10,714,494,472	10,710,957,176	-0.03%
Freshwater Resource Depletion (m3)	76,032,334	76,032,334	0.00%
Eutrophication (kgPO4eq)	1,891,044	1,890,727	-0.02%
Human Toxicity (kg1,4-DBeq)	71,003,651	70,956,145	-0.07%
Acidification (kgSO2eq)	17,909,303	17,925,929	0.09%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,891,452	-0.73%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	145	0.00%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	153,695	0.04%
Respiratory Inorganics (kgPM10,eq)	3,503,654	3,506,888	0.09%
Photochemical Ozone Formation (kgC2H4,eq)	708,799	709,461	0.09%
Mineral Depletion (kgFe-eq)	1,861,282	1,838,582	-1.22%

Table 17 Economic performance in Euro per year

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	80,432,924	2.00%
Water operator	21,348,242	22,929,143	7.41%
Domestic water users	52,075,652	52,075,652	0.00%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 18 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	95.91	2.01%
Fossil Fuels Depletion (€/MJ)	0.007359	0.007509	2.04%
Freshwater Resource Depletion (€/m^3)	1.037	1.058	2.03%
Eutrophication (€/kgPO_4eq)	41.70	42.54	2.01%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.134	2.07%
Acidification (€/kgSO_2eq)	4.403	4.487	1.91%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	13.65	2.71%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	553,671	2.01%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	523.3	1.97%
Respiratory Inorganics (€/kgPM_{10},eq)	22.51	22.94	1.91%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	113.4	1.98%
Mineral Depletion (€/kgFe-eq)	42.36	43.75	3.28%

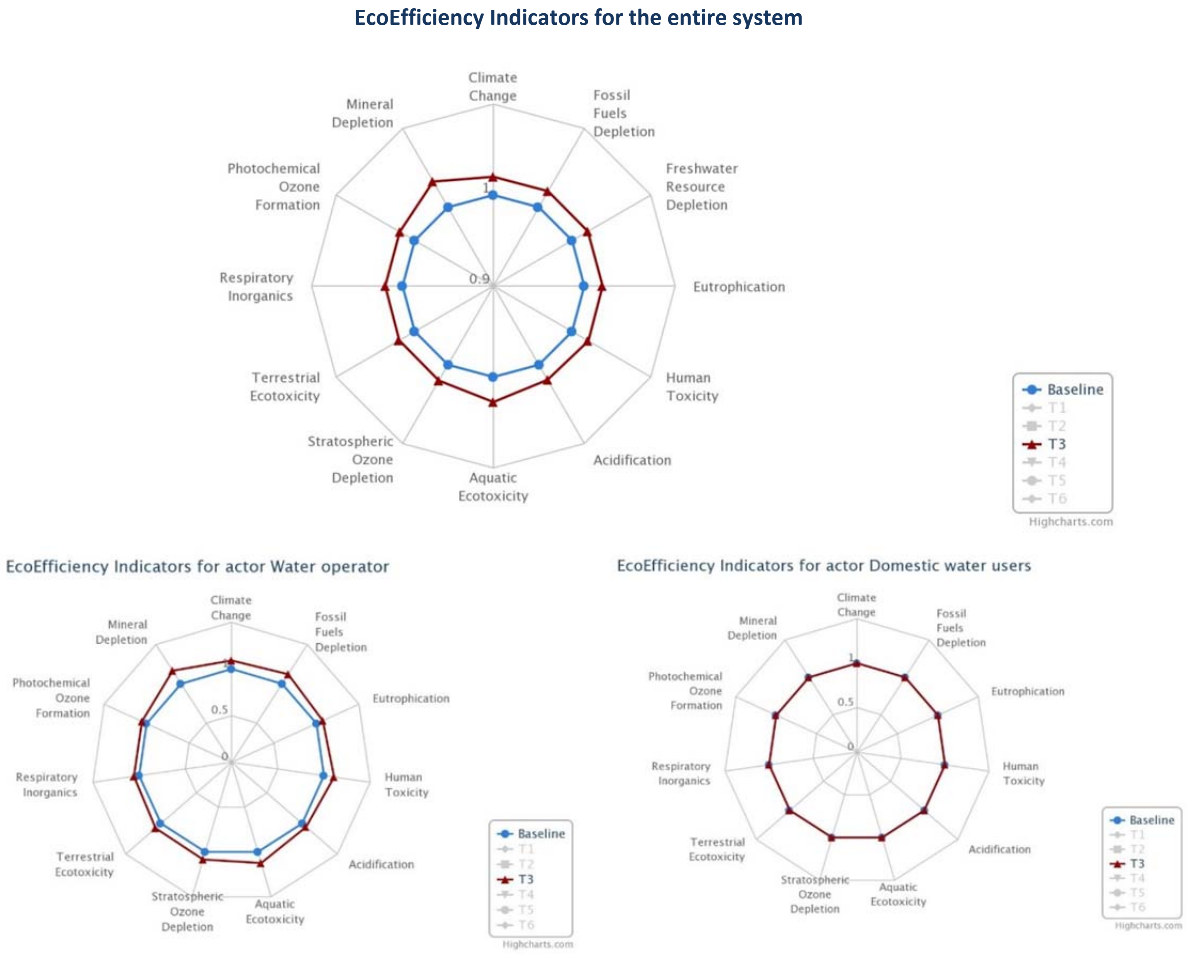


Figure 13 Eco-efficiency performance (relative to baseline = 1)

2.2.4 Water and energy saving appliances (Technology assessment 4 in the Toolbox)

Short description

The baseline scenario revealed that the domestic water use stage is the environmentally most relevant one in regard to all environmental impact indicators. This is mainly due to the energy consumption for water heating and water appliances operation. Reducing the water demand in households and replacing the water appliances with more energy efficient ones are promising technologies for a reduction of the environmental impacts and improvement of the overall eco-efficiency. This study will assess the potential for increasing the eco-efficiency of the domestic water stage through replacement of sanitary appliances.

Figure 14 Water saving appliances

Assumptions and calculations

As there were few available data about the water demand and energy consumption in the households, an additional study was carried out. It included 5 representative districts for which data from the national census of 2011 was bought from the national statistical institute. For the same district, the water operator provided records of the water meter accounts in households and revenue water meters in the buildings. The analysis of these data showed that in 2011:

1. The water consumption depends also on the way the water is heated. Two main types of households are therefore distinguished: 1) households with local water heating and 2) households with district water heating.
2. Almost all households have washing machines;
3. About 25% of the households have dishwashers;

Table 19 Water consumption in buildings (calculated by the team based on the collected data, D 3.2)

	Water consumption measured by individual water meters in households	Total water consumption (Measured by revenue water meter in the building)	Unit
Total water demand in buildings with local water heating	31.38	43.93	m^3/(ca·year)
Total water demand in buildings with district water heating	39.54	55.36	m^3/(ca·year)

Based on the records of the water accounts of the individual water meters and data provided from NSI the average water demand for each type of households was calculated in the baseline scenario D3.2). However, big differences (about 30%) between the sum of the accounted water from the individual meters and the revenue meter of the building were observed. The reasons for this are the common water needs in the building, water thefts, inaccuracy of water meters, and the continuous leakages from old water appliances, which the individual water meters are not capable to capture. Table 19 shows these differences, which were considered in the model.

In terms of water appliances efficiency, households are assigned into two categories (D3.2). The first one represents so-called “wealthy” households (around 25%). They have already implemented water efficiency measures, such as dishwashers or more energy efficient washing machines. It is assumed that the average energy class for dishwashers and washing machines in “wealthy” households is “A”. The second group are the majority of households, which are called “average” (75% of the households). It is assumed that their water appliances are less water efficient. Most of them do not have dishwashers. Their washing machines are old, consuming more energy and water. Thus an average energy class “C” is assumed for them.

This technology assessment introduces the effect of applying water and energy saving measures in households on full theoretical potential, e.g. all households are equipped with the best water saving appliances (water saving faucets, low flush toilets, water saving shower heads), dishwashers and washing machines class A+++. The assumptions for the technology assessment are presented in Table 20. For replacement of existing technologies which have the same utility only the additional costs for improving their energy and water efficiency is considered. If a new appliance is introduced – the full investment costs are accounted.

Table 20 Assumptions for the technology assessment

	Assumption	Additional investment costs for achieving the best efficiency
"Average" households	All of households' old water appliances, inefficient toilets and shower heads will be replaced; All water machines will be replaced with water and energy efficient ones expected improvement of the average energy class from "C" to "A+++"; New dishwashers class "A+++" will be applied.	Water efficient faucets (upgrade): 10 - 20 €; Water saving shower heads (upgrade): 10 - 20 €; Low flush toilets (upgrade): 60 - 100 €; Washing machine (upgrade) - 80 €; Dishwasher (new) – 300 €; Total: 500 € per household;
"Relatively wealthy" households	All households have already applied water efficient faucets, low flush toilets and water saving shower heads; All water machines and dishwashers will be replaced with more water and energy efficient ones. Expected improvement of the average energy class from "A" to "A+++";	Luxury washing machine (upgrade): 100 €; Luxury dishwasher (upgrade): 150 €; Total: 250 € per household;

Calculation of energy demand for dishwashers and washing machines

The yearly electricity consumption for dishwashers and washing machines are calculated depending on their energy efficiency class (Table 21) considering EU regulation.

Table 21 Energy efficiency for washing machines and dishwashers (COMMISSION DELEGATED REGULATION of 28.9.2010), in brackets are EEI values used for calculation in this study

Energy efficiency class	EEI for dishwashers	EEI for washing machines
A+++	EEI<50 (45)	EEI<46 (40)
A++	50<EEI<56	46<EEI<52
A+	56<EEI<63	52<EEI<59
A	63<EEI<71 (67)	59<EEI<68 (64)
B	71<EEI<80	68<EEI<77
C	80<EEI<90	77<EEI<87 (80)
D	EEI>90	EEI>87

The standard annual energy consumption (SAEc) of the household dishwasher is calculated using Equation 1 (COMMISSION DELEGATED REGULATION of 28.9.2010).

$$SAEc = 25{,}2 * ps + 126 = 25{,}2 * .10 + 126 = 378 kWh/year \quad (1)$$

$$\text{Energy efficiency dishwashers Class A} = EEI * SAEc = 67\% * 378 = 253 \text{ kWh/year} \quad (2)$$

$$\text{Energy efficiency dishwashers Class A+++} = EEI * SAEc = 45\% * 378 = 170 \text{ kWh/year} \quad (3)$$

The standard annual energy consumption (SAEc) of the household washing machine is calculated according Equation 4 (COMMISSION DELEGATED REGULATION (EU) of 28.9.2010):

SAEc =47,0*c +51,7 = 47,0*6+51,7 = 334 kWh/year (4)

Energy efficiency washing machines Class C = EEI*SAEc = 80%*334 = 267 kWh/year (5)

Energy efficiency washing machines Class A = EEI*SAEc = 64%*334 = 214 kWh/year (6)

Energy efficiency washing machines Class A+++=EEI*SAEc=40%*334=134 kWh/year (7)

It is expected that as a result of the application of all water efficient measures in households the total water consumption per capita could be reduced by 30%. The input data for SEAT/EVAT model are shown in Table 22.

Table 22 Input data for the SEAT/EVAT model

SEAT		
	Baseline	After technology implementation
Electricity used for dishwasher operation in “relatively wealthy” household	253 kWh/year (Class A)	170 kWh/year (Class A+++)
Electricity used for washing machine operation in “relatively wealthy” household	214 kWh/year (Class A)	134 kWh/year (Class A+++)
Electricity used for dishwasher operation in “average” household	0 kWh/year (-)	170 kWh/year (Class A+++)
Electricity used for washing machine operation in “average” household	267 kWh/year (Class C)	134 kWh/year (Class A+++)
Total water demand per capita in buildings with local water heating	43.93 m^3/(ca·year)	30.75 m^3/(ca·year)
Total water demand per capita in buildings with district water heating	55.36 m^3/(ca·year)	38.75 m^3/(ca·year)
EVAT		
Investment costs	180,000,000 €	
Technology Lifetime	10 years	
Interest Rate	2%/y	

Results

Table 23 shows the expected changes in environmental performance. A significant improvement in all environmental indicators is observed. The main reason for the impact reduction is the lower water consumption in households resulting in less energy and materials for processing water to customers. The water efficient taps and shower heads also save hot water which decreases the energy demand for water heating.

The decreased water consumption results in reduced costs for customers for satisfying their water needs and less income for water operator. Thus the value added for water users is increased while for the water operator decreases significantly (Table 24). The overall eco-efficiency in this scenario is considerably improved (Table 25 and Figure 15).

Table 23 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	665,465	-20.65%
Fossil Fuels Depletion (MJ)	10,714,494,472	8,363,307,925	-21.94%
Freshwater Resource Depletion (m^3)	76,032,334	67,525,316	-11.19%
Eutrophication ($kgPO_4eq$)	1,891,044	1,840,889	-2.65%
Human Toxicity (kg1,4-DBeq)	71,003,651	56,046,923	-21.06%
Acidification ($kgSO_2eq$)	17,909,303	14,679,117	-18.04%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	4,897,861	-17.47%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	115	-20.69%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	126,346	-17.76%
Respiratory Inorganics ($kgPM_{10},eq$)	3,503,654	2,872,840	-18.00%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	580,012	-18.17%
Mineral Depletion (kgFe-eq)	1,861,282	1,529,134	-17.85%

Table 24 Economic performance

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	81,711,625	3.63%
Water operator	21,348,242	7,052,232	-66.97%
Domestic water users	52,075,652	69,231,263	32.94%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 25 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	122.79	30.60%
Fossil Fuels Depletion (€/MJ)	0.007359	0.009770	32.76%
Freshwater Resource Depletion (€/m^3)	1.037	1.210	16.68%
Eutrophication (€/$kgPO_4eq$)	41.70	44.39	6.45%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.458	31.23%
Acidification (€/$kgSO_2eq$)	4.403	5.567	26.44%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	16.68	25.51%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	713,361	31.43%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	646.7	26.01%
Respiratory Inorganics (€/$kgPM_{10},eq$)	22.51	28.44	26.34%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	140.9	26.71%
Mineral Depletion (€/kgFe-eq)	42.36	53.44	26.16%

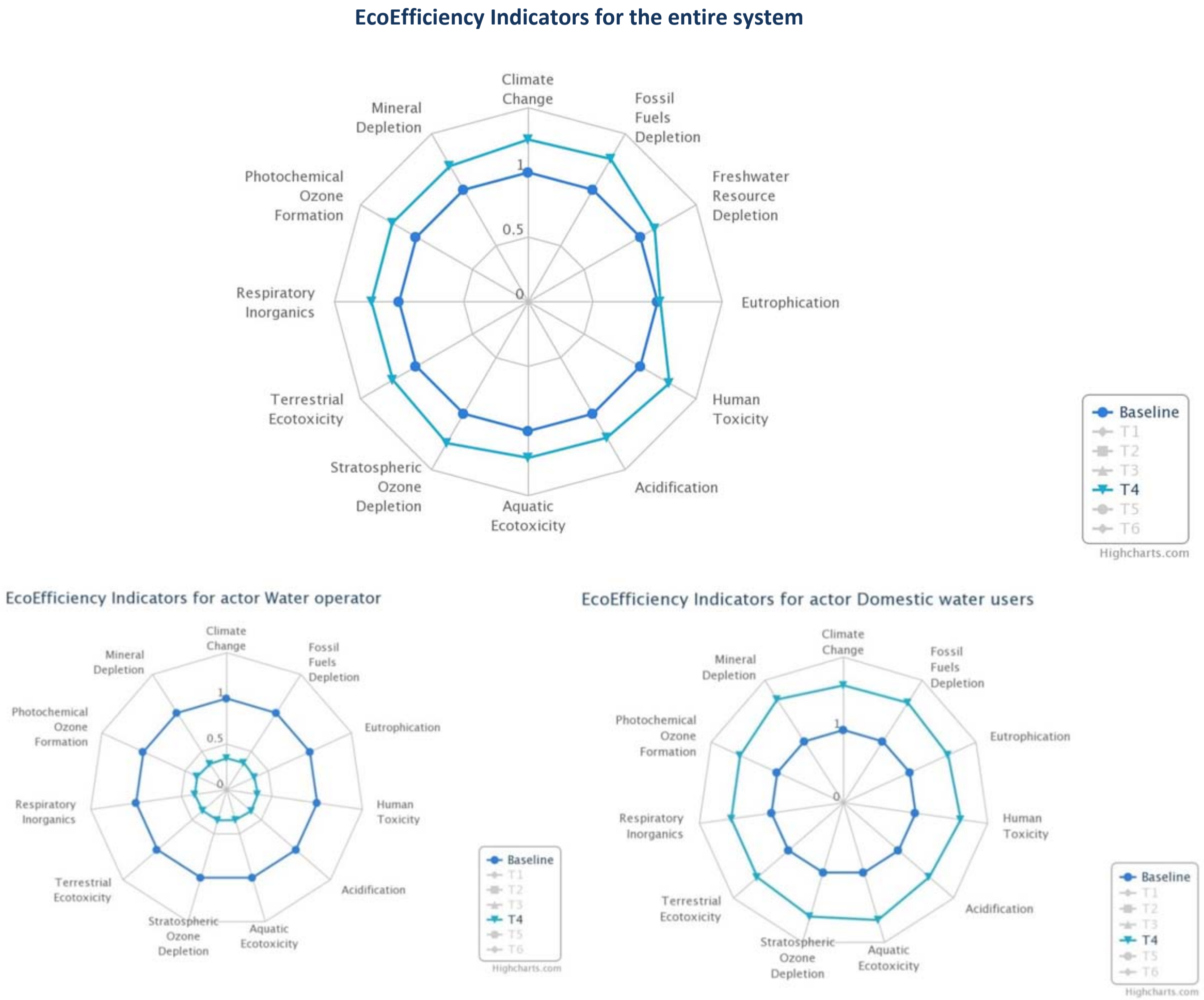


Figure 15 Eco-efficiency performance relative to baseline = 1

2.2.5 Solar water heating (Technology assessment 5 in the Toolbox)

Short description

Figure 16 Central water heating installations with large storage tanks (Chromagen)

The water heating process is the biggest GHG emitter in the entire water supply chain. It is also the second biggest GHG emitter in regard to the energy consumed in an average household. Solar thermal systems are advantageous solutions for apartment buildings, because they reduce the large consumption of conventional energy for water heating by replacing it with a renewable source – the solar energy. The yearly average sunlight duration in Bulgaria is above 2,100 hours which means that it has a good solar potential and thus, the technology could be successfully applied.

It has been reported that in Romania, which has a similar solar potential, the use of solar energy covers approximately 35-50% of the thermal energy needs for water heating from October to April and 80-100 % from May to September (Spiru et al., 2012). On average solar water heaters provide around 80% of the yearly energy demand for water heating. However, at winter and cloudy days back-up electrical water heating needs to be foreseen. This study will check the potential for improvement of eco-efficiency due to implementation of solar water heating systems.

Main Assumptions

Currently in Sofia the water in the households is heated either locally (electrical boilers, gas boilers, oil etc.) or centrally from district water heating network. For this technology assessment, it is assumed that all households with electrical local water heating will install additional solar water heating systems with solar panels on the roofs of their buildings. Based on literature data the investment costs are estimated to be around 1,150 € per household. There are about 181,192 households of this type in Sofia which mean that the total investment costs will be about 207.9 Mio €.

The energy demand in the baseline scenario to heat the cold water in households with electrical boilers is 60 kWh/m^3. Assuming that 80% of this energy could be covered by a solar heating system, 12 kWh/m^3 will be the yearly average necessary amount of electrical energy for back-up heating.

Lifetimes of solar water heating system are reported to be 20 – 30 years, for this calculation we assumed 30 years.

The input data for SEAT/EVAT model are shown in Table 26.

Table 26 Input data for the SEAT/EVAT model

SEAT			
	Baseline	After technology implementation	Unit
Electricity demand for heating 1 m^3 of water	60	12	kWh/m^3

EVAT	
Investment costs	207,860,000 €
Technology Lifetime	30 years
Interest Rate	2%/y

Results

In this technology scenario the non-renewable energy demand for water heating is significantly reduced resulting in less environmental impact from background conventional energy production processes. Table 27 presents the change in environmental performance. The overall TVA is increased due to reduced costs for conventional energy use in water use stage (Table 28). Considering the reduction of the environmental impact and increased TVA a significant improvement of eco-efficiency is observed (Table 29 and Figure 17).

Table 27 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	600,361	-28.41%
Fossil Fuels Depletion (MJ)	10,714,494,472	8,381,209,705	-21.78%
Freshwater Resource Depletion (m^3)	76,032,334	76,032,334	0.00%
Eutrophication ($kgPO_4eq$)	1,891,044	1,783,712	-5.68%
Human Toxicity (kg1,4-DBeq)	71,003,651	54,594,716	-23.11%
Acidification ($kgSO_2eq$)	17,909,303	9,233,509	-48.44%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,703,978	-3.89%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	113	-22.07%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	84,995	-44.68%
Respiratory Inorganics ($kgPM_{10},eq$)	3,503,654	1,800,222	-48.62%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	371,781	-47.55%
Mineral Depletion (kgFe-eq)	1,861,282	1,818,696	-2.29%

Table 28 Economic performance in Euro per year

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	85,343,804	8.23%
Water operator	21,348,242	21,348,242	0.00%
Domestic water users	52,075,652	58,567,432	12.47%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 29 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	142.15	51.19%
Fossil Fuels Depletion (€/MJ)	0.007359	0.010183	38.37%
Freshwater Resource Depletion (€/m^3)	1.037	1.122	8.20%
Eutrophication (€/$kgPO_4eq$)	41.70	47.85	14.75%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.563	40.68%
Acidification (€/$kgSO_2eq$)	4.403	9.243	109.93%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	14.96	12.57%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	752,099	38.57%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	1,004.1	95.65%
Respiratory Inorganics (€/kgPM10,eq)	22.51	47.41	110.62%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	229.6	106.47%
Mineral Depletion (€/kgFe-eq)	42.36	46.93	10.79%

EcoEfficiency Indicators for the entire system

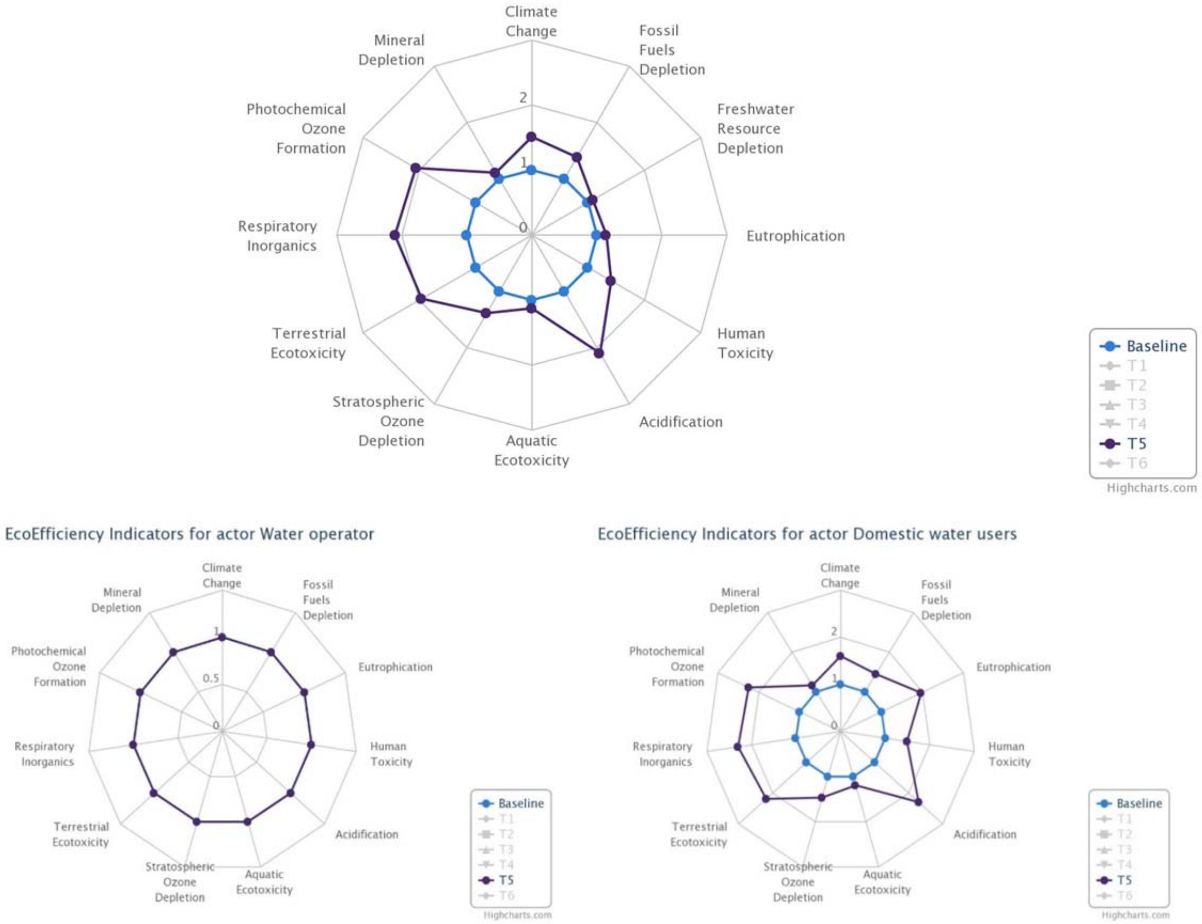


Figure 17 Eco-efficiency performance relative to baseline = 1

2.2.6 Drain water heat recovery (Technology assessment 6 in the Toolbox)

Short description

The grey water, which comes from showers in households contains a lot of heat energy which usually disappears into the drains. Innovative technologies have already appeared in the market to recover and reuse this grey-water heat. This could reduce significantly the energy demand for water heating. The heat is recovered by means of filters and heat exchangers and is used to preheat the cold water going to the tap, to the boiler or both. Figure 18 show a principle scheme of the technology.

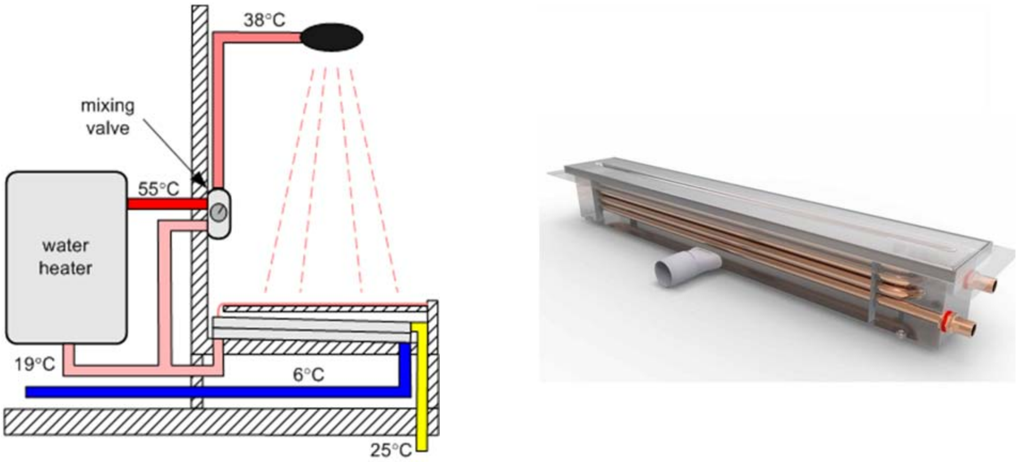


Figure 18 Shower platform with integrated DWHR (http://www.heatsnagger.com)

Main Assumptions

In this technology assessment it is assumed that all households with local water heating will apply the technology. The heat exchangers which are integrated in the shower platform, recover up to 40% of the heat from the waste water. In a research project for investigation of heat exchangers used in showers, it was found that a simple heat exchanger design directly saves 37% of the energy used by a 9.8 kW shower unit (Hinchliffe, D. & Corrigan, S., 2012). Other studies state even higher values - near 50% heat recovery efficiency (Kimmels, A., 2011). In this technology scenario an average value of 35% energy savings for water heating are assumed.

A small heat exchanger costs about 400 € (Kimmels, A., 2011). In addition, 200 € are assumed for other equipment installation costs which means around 600 € investment costs per household. The total number of households with local water heating is 181,192. If all of them apply this technology, the total investment costs for this scenario will be 108,7 Mio €.

The input data for SEAT/EVAT model are shown in Table 30.

Table 30 Input data for the SEAT/EVAT model

SEAT			
	Baseline	After technology implementation	Unit
Energy demand in households with electric water heating	60	39	kWh/m^3
EVAT			
Investment costs	108,700,000 €.		
Technology Lifetime	20 years		
Interest Rate	2%/y		

Results

Applying the drain water heat recovery system considerable amount of energy is recovered from shower grey water. This increase the energy efficiency of the water heating process resulting in less energy used and respectively less impact to the nature due to conventional energy production. Table 31 presents the change in environmental performance. The value added for water users is increased due to reduced costs for water heating (Table 32).

Considering the reduction of the environmental impact and increased TVA a significant improvement of eco-efficiency is observed (Table 33 and Figure 19).

Table 31 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	734,407	-12.43%
Fossil Fuels Depletion (MJ)	10,714,494,472	9,693,682,387	-9.53%
Freshwater Resource Depletion (m^3)	76,032,334	76,032,334	0.00%
Eutrophication ($kgPO_4eq$)	1,891,044	1,844,086	-2.48%
Human Toxicity (kg1,4-DBeq)	71,003,651	63,824,742	-10.11%
Acidification ($kgSO_2eq$)	17,909,303	14,113,643	-21.19%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,833,862	-1.70%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	131	-9.66%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	123,606	-19.55%
Respiratory Inorganics ($kgPM_{10}$,eq)	3,503,654	2,758,402	-21.27%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	561,354	-20.80%
Mineral Depletion (kgFe-eq)	1,861,282	1,842,651	-1.00%

Table 32 Economic performance

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	79,104,763	0.32%
Water operator	21,348,242	21,348,242	0.00%
Domestic water users	52,075,652	52,328,392	0.49%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 33 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	107.71	14.56%
Fossil Fuels Depletion (€/MJ)	0.007359	0.008160	10.88%
Freshwater Resource Depletion (€/m^3)	1.037	1.040	0.29%
Eutrophication (€/$kgPO_4eq$)	41.70	42.90	2.88%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.239	11.52%
Acidification (€/$kgSO_2eq$)	4.403	5.605	27.30%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	13.56	2.03%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	602,170	10.95%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	639.97	24.70%
Respiratory Inorganics (€/kgPM10,eq)	22.51	28.68	27.41%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	140.9	26.71%
Mineral Depletion (€/kgFe-eq)	42.36	42.93	1.35%

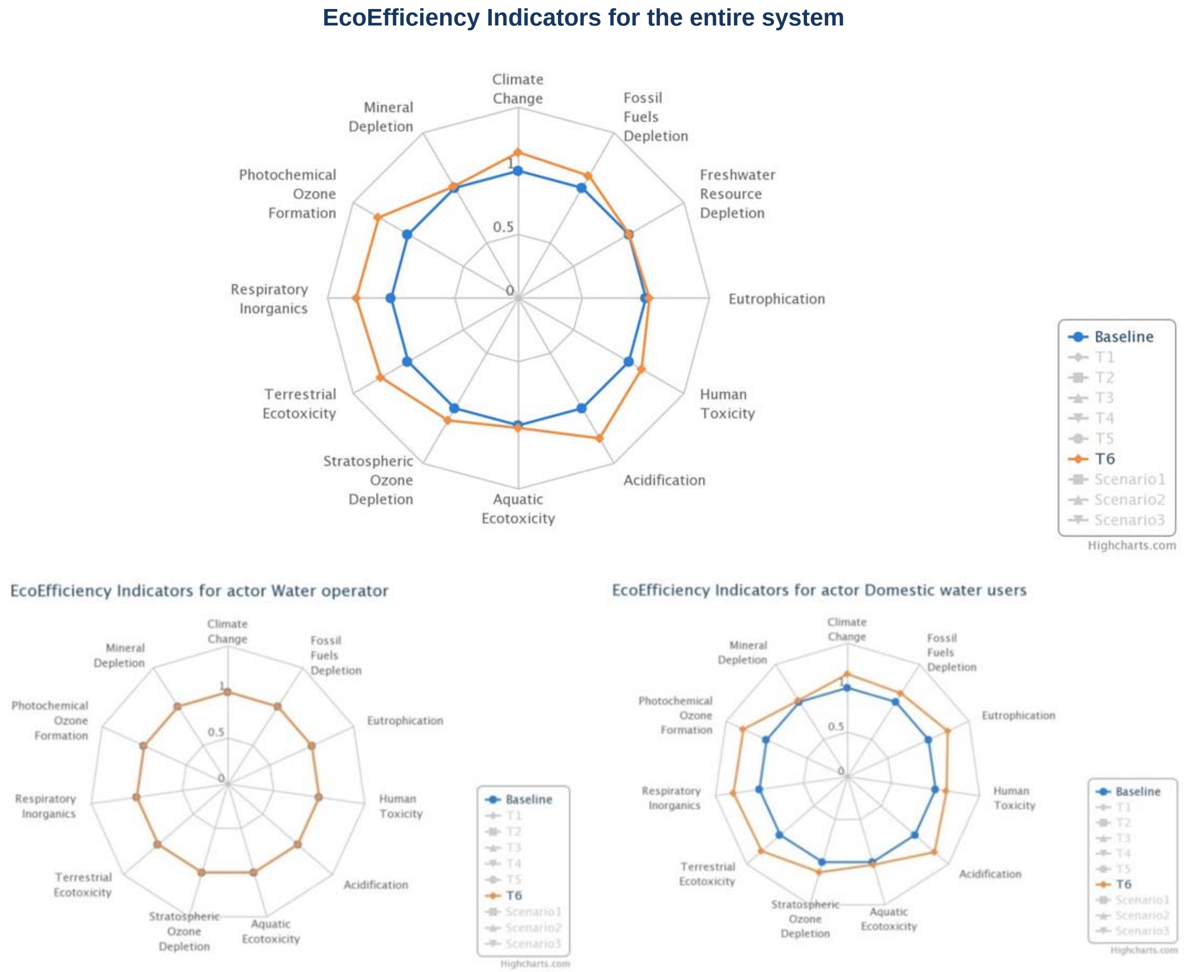


Figure 19 Eco-efficiency performance relative to baseline = 1

2.3 Assessment of scenarios

Based on the results of the individual technologies assessments, combinations among them are studied to develop scenarios, addressing the major goals of a more sustainable development: resource efficiency, pollution prevention and circular economy. Three scenarios are set, considering that: i) urban water systems exploit primary freshwater recourses and ii) energy consumption and source play the most significant role for the environmental performance of these systems as concluded in D3.2 (Table 34).

Table 34 Selection of the technologies for the scenarios

Scenarios	Technologies, considered as appropriate for the scenario
Sc. 1. Towards resource efficiency (focus on freshwater)	Water saving appliances Pressure reduction turbines
Sc. 2. Towards pollution prevention (focus on reduction of energy from non-renewable sources as a pollution emitter)	Water and energy saving appliances Drain water heat recovery Solar water heating Pressure reduction turbines Hydro power plant (before WTP)
Sc. 3. Towards circular economy with focus on by-products	Pressure reduction turbines Solar sludge drying Hydro power plant (before WTP)

2.3.1 Scenario 1: Towards resource efficiency (focus on freshwater)

Short description

In urban water systems the biggest exploited natural resource is the freshwater. Therefore, the scenario is focused on technologies for efficient use of this resource. The individual technology assessment shows that two of the technologies contribute in greatest extend to reducing the environmental impact of the category "freshwater resource depletion". These are "Pressure reduction turbines" and "Water saving appliances" (Chapter 2.2). The pressure management reduces the amount of leakages and failures in the system while a water saving appliance reduces the water used for satisfying human water needs. In this scenario the multiple effect of both technologies in combination is assessed. Taking into account social, technical and economic factors, a realistically feasible level of implementation of the water saving measures in households is assumed (Table 35). The considered time period for this scenario is 10 years from baseline year, i.e. until 2021.

Table 35 Assumptions for the scenario 1

	Assumption	Investment costs
"Average" households	70% of the households will replace their old water appliances, inefficient toilets and shower heads with more efficient ones.	Water efficient faucets (upgrade): 10 - 20 €; Water saving shower heads (upgrade): 10 - 20 €; Low flush toilets (upgrade): 60 - 100 €; Total: 100 €;
	30% of the households will replace their washing machines with water and energy efficient ones Expected improvement of the average energy class from "C" to "A";	Washing machine (upgrade) - 80 €;
"wealthy" households	All households have already applied water efficient faucets, low flush toilets and water saving shower heads; 30% of the households will replace their washing machines and dishwashers with more water and energy efficient ones. Expected improvement of the average energy class from "A" to "A+";	Luxury washing machine (upgrade): 100 €; Luxury dishwasher (upgrade): 150 €; Total: 250 € per household;

Based on the literature data, it is estimated that as a result of the application of these measures in the households, the total water consumption per capita will be reduced by 10%.

The input data for SEAT/EVAT model are shown in Table 36.

Table 36 Input data for the SEAT/EVAT model

SEAT		
	Baseline	After technology implementation
Electricity used for dishwasher operation in “wealthy” household on average	253 kWh/year (Class A)	227 kWh/year (Class A+)
Electricity used for washing machine operation in “wealthy” household on average	214 kWh/year (Class A)	184 kWh/year (Class A+)
Electricity used for washing machine operation in “average” household on average	267 kWh/year (Class C)	214 kWh/year (Class A)
Total water demand per capita in buildings with local water heating	43.93 m^3/(ca·year)	39.54 m^3/(ca·year)
Total water demand per capita in buildings with district water heating	55.36 m^3/(ca·year)	49.82 m^3/(ca·year)
Generated electricity in water distribution stage	0	7,320,000
EVAT		
Water saving appliances	Investment costs	51,500,000 €
	Technology Lifetime	10 years
	Interest Rate	2%/y
Pressure reduction turbines	Investment costs	4,465,000 €
	Technology lifetime	20 years
	Interest rate	2%/y

Results

Although this scenario is focused on one indicator “Freshwater resource depletion”, it has almost equally positive impact on all environmental impact categories (Table 37). This result is not surprising, having in mind that both technologies reduce not only water use, but also the use of non-renewable energy sources.

In regard to the economic performance, results show that the NEO (net economic output) is much higher for the domestic users than for the water operator (Table 38 and Table 40). This is the reason for the increased eco-efficiency for the user for all categories and not so explicit improvement of the eco-efficiency for the water operator (Figure 20).

Table 37 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	758,350	-10%
Fossil Fuels Depletion (MJ)	10,714,494,472	9,753,219,159	-9%
Freshwater Resource Depletion (m^3)	76,032,334	68,823,883	-9%
Eutrophication ($kgPO_4eq$)	1,891,044	1,862,194	-2%
Human Toxicity (kg1,4-DBeq)	71,003,651	64,652,622	-9%
Acidification ($kgSO_2eq$)	17,909,303	15,806,679	-12%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,598,334	-6%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	132	-9%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	136,483	-11%
Respiratory Inorganics ($kgPM_{10},eq$)	3,503,654	3,091,720	-12%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	626,239	-12%
Mineral Depletion (kgFe-eq)	1,861,282	1,763,578	-5%

Table 38 Economic performance

Actor	Baseline (€/y)	After technology implementation (€/y)	Change
TVA	78,852,024	81,330,901	3%
Water operator	21,348,242	16,862,204	-21%
Domestic water users	52,075,652	59,040,568	13%
Non-domestic water users	5,428,130	5,428,130	0%

Table 39 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	107.25	14%
Fossil Fuels Depletion (€/MJ)	0.007359	0.008339	13%
Freshwater Resource Depletion (€/m^3)	1.037	1.182	14%
Eutrophication (€/$kgPO_4eq$)	41.7	43.67	5%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.258	13%
Acidification (€/$kgSO_2eq$)	4.403	5.145	17%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	14.53	9%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	614,011	13%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	595.9	16%
Respiratory Inorganics (€/$kgPM_{10},eq$)	22.51	26.31	17%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	129.9	17%
Mineral Depletion (€/kgFe-eq)	42.36	46.12	9%

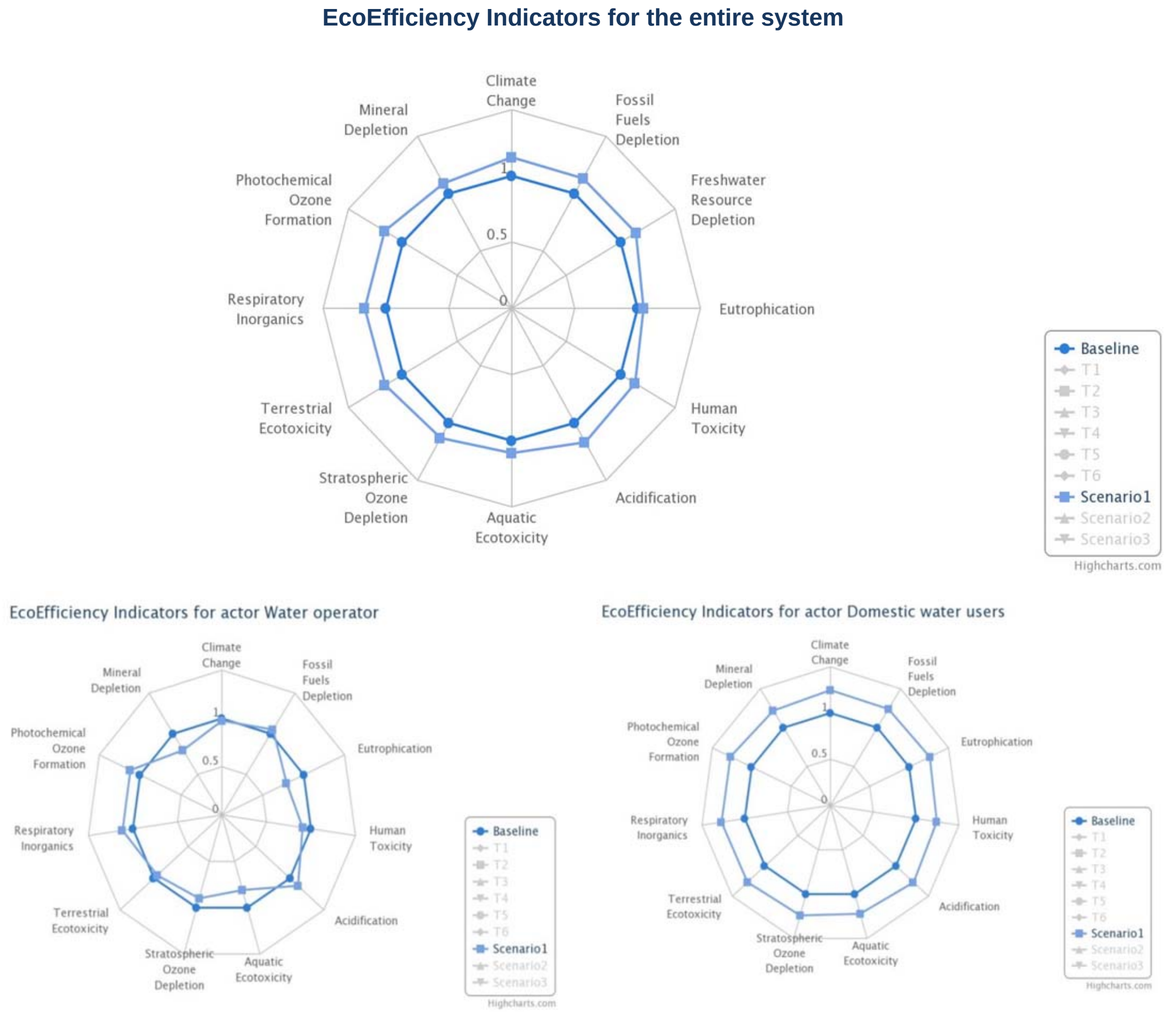


Figure 20 Eco-efficiency performance relative to baseline = 1

Table 40 Estimation of net economic output per actor and analysis of distributional Issues

Actor	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Water operator	273,065	32,077,798	33,406	49,179,660	16,862,204
Domestic water users	5,733,316	89,631,412	198,178,400	-43,773,104	59,040,568
Non-domestic water users	0	0	10,834,686	-5,406,557	5,428,130
	6,006,381	121,709,210	209,046,492	0	81,330,901

2.3.2 Scenario 2: Towards pollution prevention (focus on reduction of energy from non-renewable sources as a pollution emitter)

Short description

Technologies that have the greatest positive effect on pollution indicators have been identified from the individual technology assessments. These are mostly technologies that improve the energy efficiency of the system, as it was revealed that the energy use from non-renewable energy sources is the most significant contributor to pollution. Therefore in this scenario, a combination of technologies aiming either to reduce the used energy or to suggest alternatives to non-renewable energy sources is studied: i.e. 1) Water and energy saving appliances, 2) Drain water heat recovery, 3) Solar water heating, 4) Pressure reduction turbines, and 5) Hydro power plant (before WTP).

For each technology a feasible level of implementation is assumed considering a 10 years' time period from the baseline (until 2021) (Table 41).

Table 41 Assumptions for the scenario 2

Technology	Assumptions
1) Water and energy saving appliances	The same as in scenario 1 (Chapter 2.3.1)
2) Drain water heat recovery	30% of the households with electrical water heating will apply the technology
3) Solar water heating	30% of the households with electrical water heating will apply the technology
4) Pressure reduction turbines	The same as in individual technology assessment (Chapter 2.2.1)
5) Hydro power plant (before WTP)	The same as in individual technology assessment (Chapter 2.2.2)

It is assumed also that there will be no overlapping when applying “drain water heat recovery” and “solar water heating” in households with electrical water heating.

The input data for SEAT/EVAT model are shown in Table 42.

Table 42 Input data for the SEAT/EVAT model

SEAT			
	Baseline	Scenario 2	Unit
Generated electricity (HPP)	0	6,300,000	kWh/y
Generated electricity (PRT)	0	7,320,000	kWh/y
Energy demand in households with electric	60	39.3	kWh/m^3
Electricity used for dishwasher operation in “wealthy” household	253 (Class A)	227 (Class A+)	kWh/year
Electricity used for washing machine operation in “wealthy” household	214 (Class A)	184 (Class A+)	kWh/year
Electricity used for washing machine operation in “average” household	267 (Class C)	214 (Class A)	kWh/year
Total water demand per capita in buildings with local water heating	43.93	39.54	m^3/(ca·year)
Total water demand per capita in buildings with district water heating	55.36	49.82	m^3/(ca·year)

EVAT		
1) Water saving appliances	Investment costs	51,500,000 €
	Technology Lifetime	10 years
	Interest Rate	2%/y
2) Hydropower plant	Investment costs	3,500,000 €
	Technology Lifetime	20 years
	Interest Rate	2%/y
3) Drain water heat recovery	Investment costs	81,700,000 €
	Technology Lifetime	20 years
	Interest Rate	2%/y
4) Solar water heating	Investment costs	54,400,000 €
	Technology Lifetime	25 years
	Interest Rate	2%/y
5) Pressure reduction turbines	Investment costs	4,465,000 €
	Technology Lifetime	20 years
	Interest Rate	2%/y

Results

The environmental categories show an expected significant improvement, which have strongest relation with energy, produced from non-renewable sources (Table 43). Similar to the first scenario, domestic users gain higher economic benefit (Table 44 and Table 46). This leads to eco-efficiency improvement for all categories for the domestic users and incomplete eco-efficiency improvement for the water operator (Figure 21).

Table 43 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	658,189	-22%
Fossil Fuels Depletion (MJ)	10,714,494,472	8,772,525,613	-18%
Freshwater Resource Depletion (m^3)	76,032,334	68,823,883	-9%
Eutrophication (kgPO_4eq)	1,891,044	1,817,082	-4%
Human Toxicity (kg1,4-DBeq)	71,003,651	57,755,849	-19%
Acidification (kgSO_2eq)	17,909,303	12,160,191	-32%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,501,283	-7%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	119	-18%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	107,632	-30%
Respiratory Inorganics (kgPM_{10},eq)	3,503,654	2,375,758	-32%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	484,588	-32%
Mineral Depletion (kgFe-eq)	1,861,282	1,745,679	-6%

Table 44 Economic performance

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	79,639,109	1%
Water operator	21,348,242	16,990,318	-20%
Domestic water users	52,075,652	57,220,661	10%
Non-domestic water users	5,428,130	5,428,130	0%

Table 45 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	121	29%
Fossil Fuels Depletion (€/MJ)	0.007359	0.009078	23%
Freshwater Resource Depletion (€/m^3)	1.037	1.157	12%
Eutrophication (€/kgPO4eq)	41.7	43.83	5%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.379	24%
Acidification (€/kgSO_2eq)	4.403	6.549	49%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	14.48	9%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	668,735	23%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	739.92	44%
Respiratory Inorganics (€/kgPM_{10},eq)	22.51	33.52	49%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	164.3	48%
Mineral Depletion (€/kgFe-eq)	42.36	45.62	8%

EcoEfficiency Indicators for the entire system

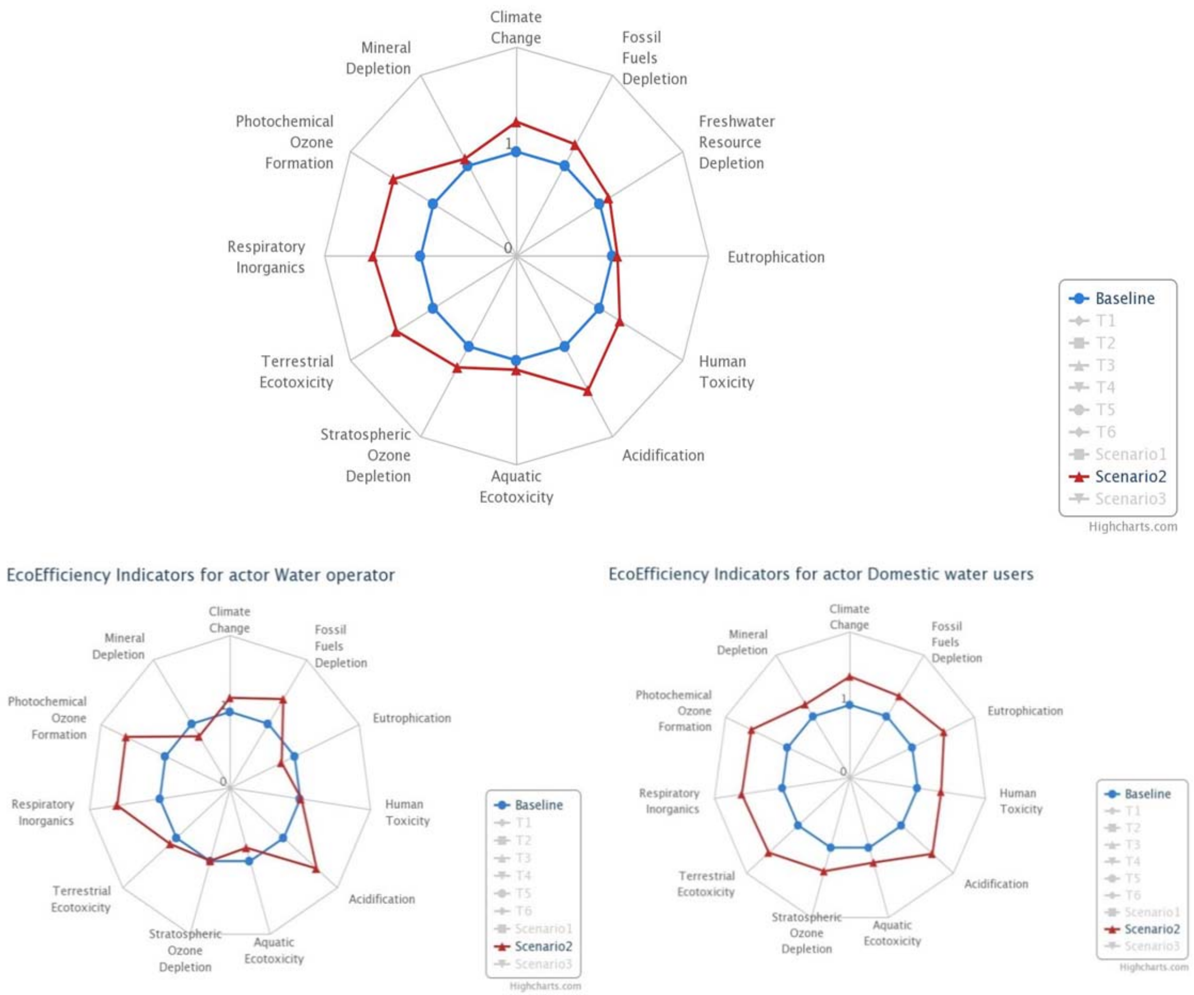


Figure 21 Eco-efficiency performance relative to baseline = 1

Table 46 Estimation of net economic output per actor and analysis of distributional Issues

Actor	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Water operator	487,113	31,735,635	33,406	49,179,660	16,990,318
Domestic water users	13,840,343	83,344,293	198,178,400	-43,773,104	57,220,661
Non-domestic water users	0	0	10,834,686	-5,406,557	5,428,130
	14,327,456	115,079,928	209,046,492	0	79,639,109

2.3.3 Scenario 3: Towards circular economy with focus on by-products

Short description

The “Circular economy” scenario is focused on technologies generating by-products which could be used outside system boundaries. From the list of the studied technologies, three satisfy this requirement: i) “Solar sludge drying” which creates a by-product - fertilizer, suitable for use in agriculture and land reclamation; ii) “Pressure reduction turbines“ and “Hydro power plant (before WTP)“ generating renewable energy, which is exported to the grid. The exported electricity could be used anywhere. As the urban water systems consume considerable amount of electricity, it is assumed that the same amount of the produced electricity will be granted to the water operator free of charge. In this scenario the eco-efficiency performance of the combination of these three technologies is assessed.

Table 47 Assumptions for the scenario 3

Technology	Assumptions
1) Solar sludge drying	The same as in individual technology assessment
2) Pressure reduction turbines	The same as in individual technology assessment
3) Hydro power plant (before WTP)	The same as in individual technology assessment

The input data for SEAT/EVAT model are shown in Table 48.

Table 48 Input data for the SEAT/EVAT model

<table>
<tr><th colspan="4">SEAT</th></tr>
<tr><th></th><th>Baseline</th><th>Scenario 3</th><th>Unit</th></tr>
<tr><td>Generated electricity (HPP)</td><td>0</td><td>6,300,000</td><td>kWh/y</td></tr>
<tr><td>Generated electricity (PRT)</td><td>0</td><td>2,190,000</td><td>kWh/y</td></tr>
<tr><td>Transport for sludge disposal</td><td>2,538,018</td><td>0</td><td>t-km</td></tr>
<tr><td>Electricity for sludge drying</td><td>0</td><td>567600</td><td>kWh/year</td></tr>
<tr><td>Sludge volume</td><td>101,537</td><td>34,400</td><td>t/a</td></tr>
<tr><th colspan="4">EVAT</th></tr>
<tr><td rowspan="3">1) Pressure reduction turbines</td><td>Investment costs</td><td colspan="2">4,465,000 €</td></tr>
<tr><td>Technology Lifetime</td><td colspan="2">20 years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">2%/y</td></tr>
<tr><td rowspan="3">2) Hydropower plant</td><td>Investment costs</td><td colspan="2">3,500,000 €</td></tr>
<tr><td>Technology Lifetime</td><td colspan="2">20 years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">2%/y</td></tr>
<tr><td rowspan="7">3) Solar sludge drying</td><td>Investment costs machinery</td><td colspan="2">1,500,000 €</td></tr>
<tr><td>Technology Lifetime</td><td colspan="2">15 years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">2%/y</td></tr>
<tr><td>Investment costs (other)</td><td colspan="2">4,000,000 €</td></tr>
<tr><td>Technology Lifetime</td><td colspan="2">30 years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">2%/y</td></tr>
<tr><td>Income from sold solar dried sludge</td><td colspan="2">1,720,000 €/year</td></tr>
</table>

Results

The comparison between this scenario and the previous two shows that here the increase of the environmental performance is smallest, around 5 times less than in the other two scenarios (Table 37, Table 43 and Table 49).

Table 49 Environmental performance

Indicator	Baseline	After technology implementation	Change
Climate Change (tCO_2eq)	838,665	826,272	-1.48%
Fossil Fuels Depletion (MJ)	10,714,494,472	10,590,065,839	-1.16%
Freshwater Resource Depletion (m^3)	76,032,334	76,032,334	0.00%
Eutrophication ($kgPO_4eq$)	1,891,044	1,885,166	-0.31%
Human Toxicity (kg1,4-DBeq)	71,003,651	70,105,971	-1.26%
Acidification ($kgSO_2eq$)	17,909,303	17,476,422	-2.42%
Aquatic Ecotoxicity (kg1,4-DBeq)	5,934,883	5,879,488	-0.93%
Stratospheric Ozone Depletion (kgCFC-11eq)	145	144	-0.69%
Terrestrial Ecotoxicity (kg1,4-DBeq)	153,637	150,138	-2.28%
Respiratory Inorganics ($kgPM_{10},eq$)	3,503,654	3,418,630	-2.43%
Photochemical Ozone Formation (kgC_2H_4,eq)	708,799	692,000	-2.37%
Mineral Depletion (kgFe-eq)	1,861,282	1,836,376	-1.34%

Table 50 Economic performance

Actor	Baseline	After technology implementation	Change
TVA	78,852,024	80,763,011	2.42%
Water operator	21,348,242	23,259,230	8.95%
Domestic water users	52,075,652	52,075,652	0.00%
Non-domestic water users	5,428,130	5,428,130	0.00%

Table 51 Eco-efficiency performance

Indicator	Baseline	After technology implementation	Change
Climate Change (€/tCO_2eq)	94.02	97.74	3.96%
Fossil Fuels Depletion (€/MJ)	0.007359	0.007626	3.63%
Freshwater Resource Depletion (€/m^3)	1.037	1.062	2.41%
Eutrophication (€/$kgPO_4eq$)	41.7	42.84	2.73%
Human Toxicity (€/kg1,4-DBeq)	1.111	1.152	3.69%
Acidification (€/$kgSO_2eq$)	4.403	4.621	4.95%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	13.29	13.74	3.39%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	542,751	562,322	3.61%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	513.2	537.9	4.81%
Respiratory Inorganics (€/$kgPM_{10},eq$)	22.51	23.62	4.93%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	111.2	116.7	4.95%
Mineral Depletion (€/kgFe-eq)	42.36	43.98	3.82%

There is relatively equal change for all categories when the scenario is compared to the baseline scenario (Table 51). Although TVA for the users does not change due to the implementation of the selected technologies, as shown in Table 50, their NEO is still two times higher than the NEO of the operator (Table 52). This is the only scenario with improved eco-efficiency for all categories for the water operator.

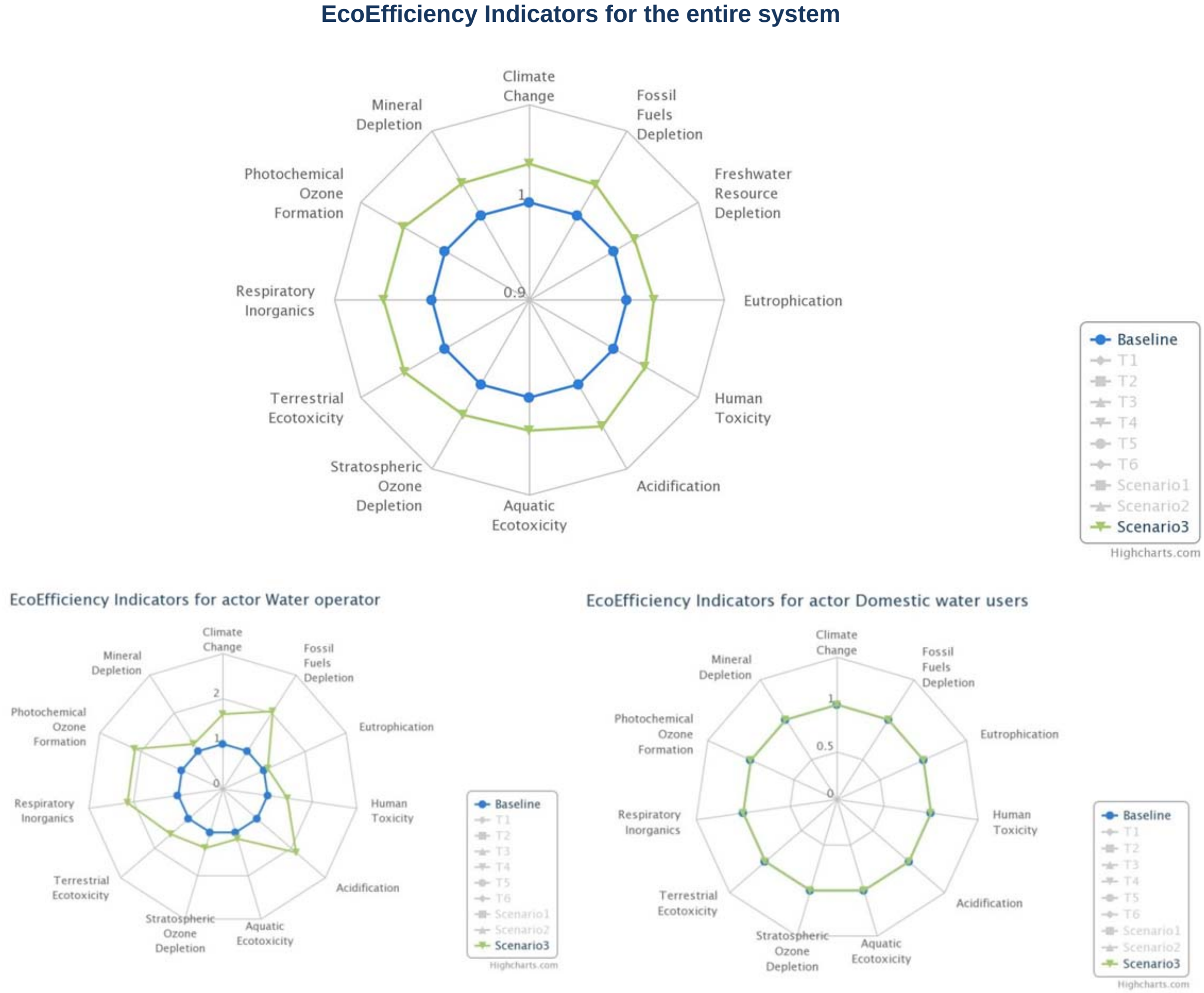


Figure 22 Eco-efficiency performance relative to baseline = 1

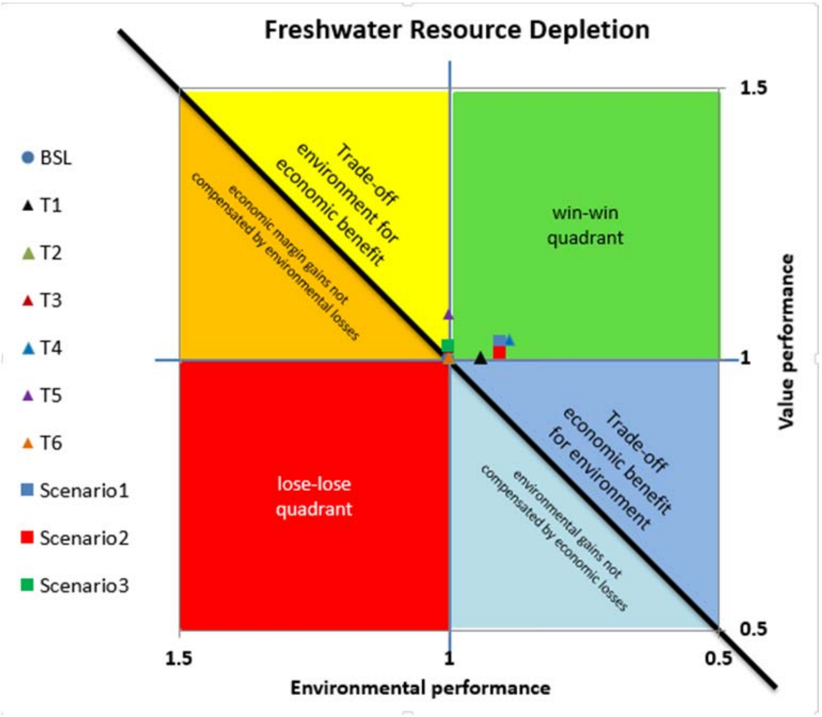
Table 52 Estimation of net economic output per actor and analysis of distributional Issues

Actor	Annual Equivalent Investment Cost (€/yr)	Annual O&M Cost (€/yr)	Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Economic Output (€/yr)
Water operator	782,451	31,755,121	1,753,350	54,043,453	23,259,230
Domestic water users	0	97,465,852	198,178,400	-48,636,896	52,075,652
Non-domestic water users	0	0	10,834,686	-5,406,557	5,428,130
	782,451	129,220,973	210,766,436	0	80,763,011

2.4 Discussion Sofia case study

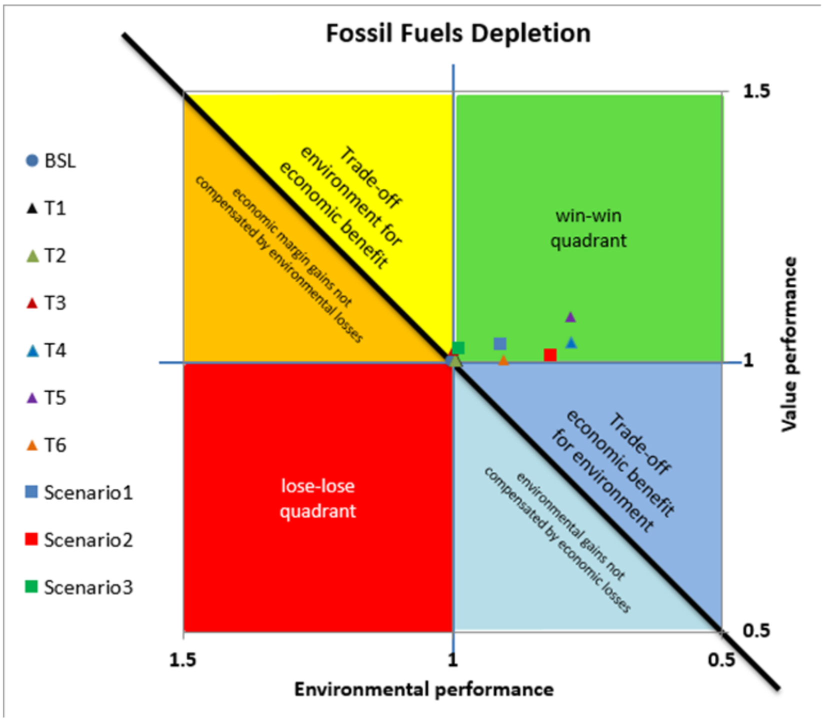
2.4.1 Comparative eco-efficiency assessment of the technologies and scenarios

In the text above, the eco-efficiency was calculated as a ratio of the value added and environmental performance. Another way of presentation of the results is by using X-Y diagrams as shown in Figure 23 below. This presentation facilitates drawing conclusions, because of the simultaneous visualisation of both parameters – value performance and environmental performance. The discussions for each eco-efficiency value pair of each technology is presented in Figure 23.



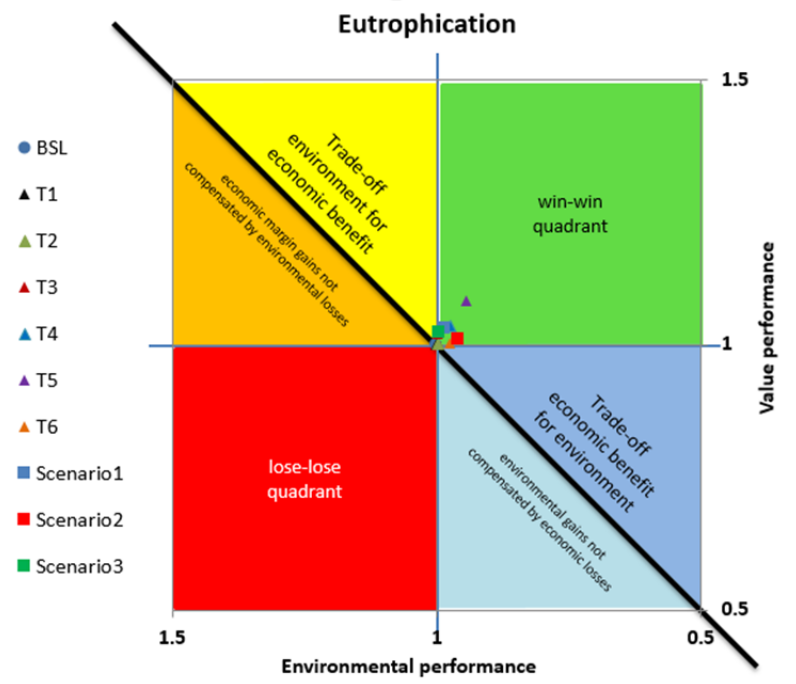
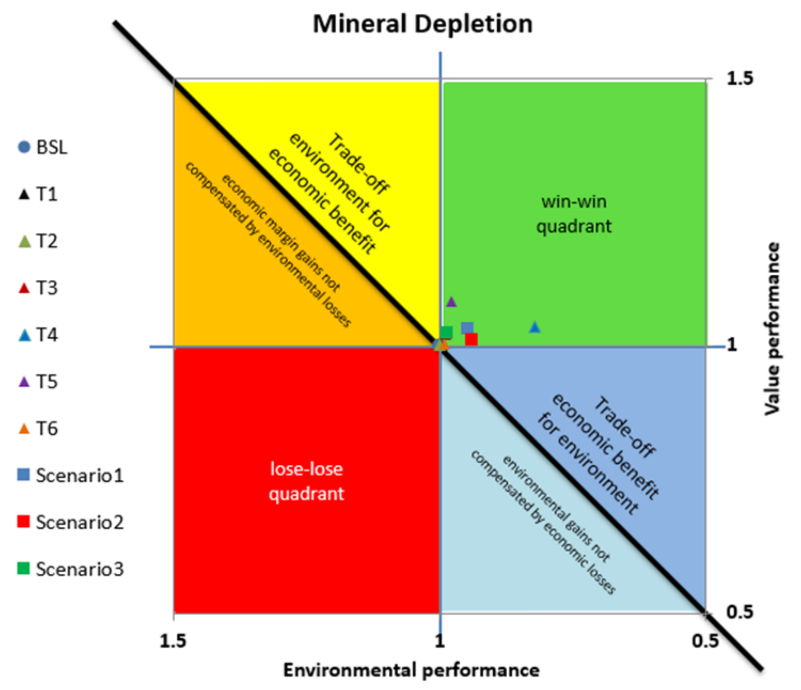
For all alternatives eco-efficiency in regard to the category "Freshwater resource depletion" improves. However, only two technologies (T1 and T4) and their respective scenarios (S1 and S3) reduce the impact on freshwater depletion. All other technologies improve their eco-efficiency only due to the increased value performance of the system.

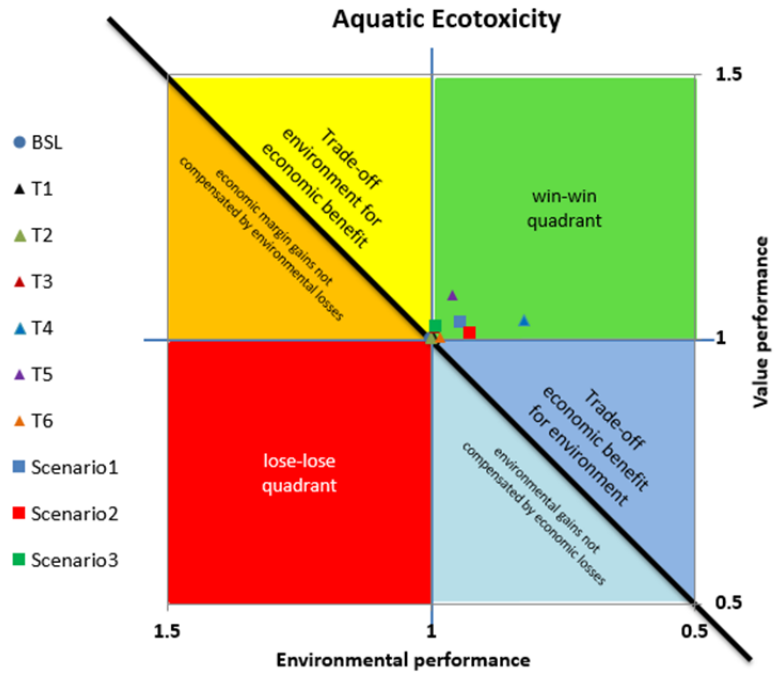
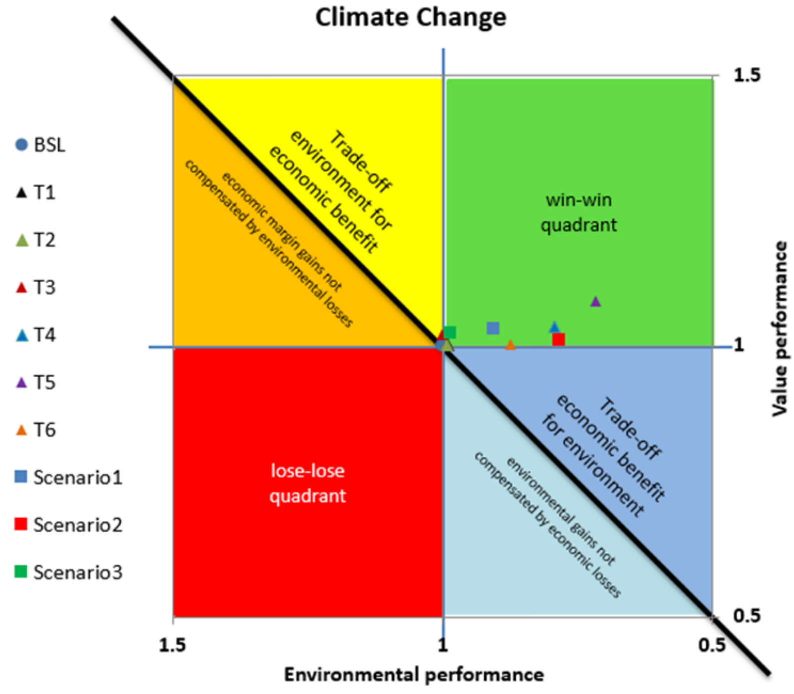
The individual implementation of T4 has the highest eco-efficiency improvement. This is an expected result, considering that T4 includes full technical potential, which could not be realised practically due to many reasons, including social behaviour. As expected, S1 has the best eco-efficiency performance in comparison with other two scenarios given the fact that it aims at improving freshwater resource efficiency.

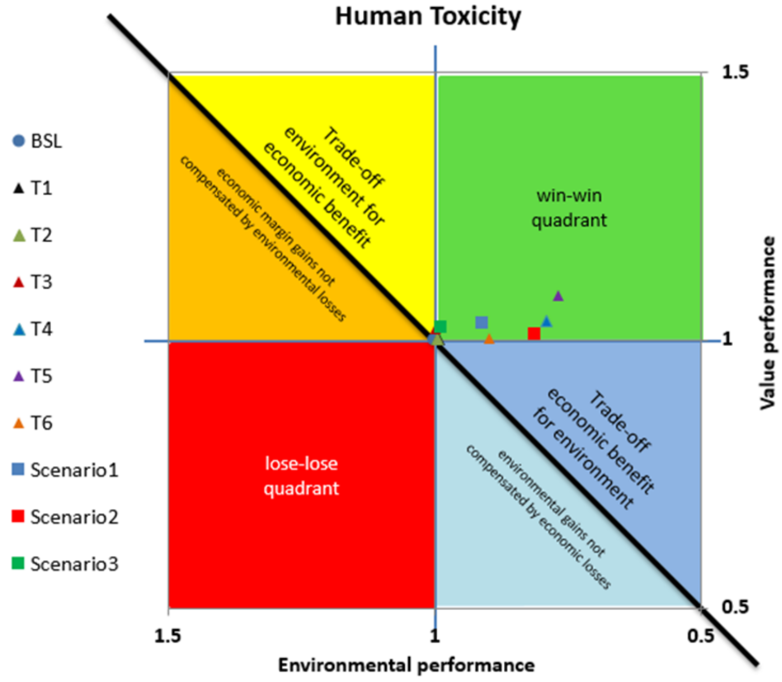
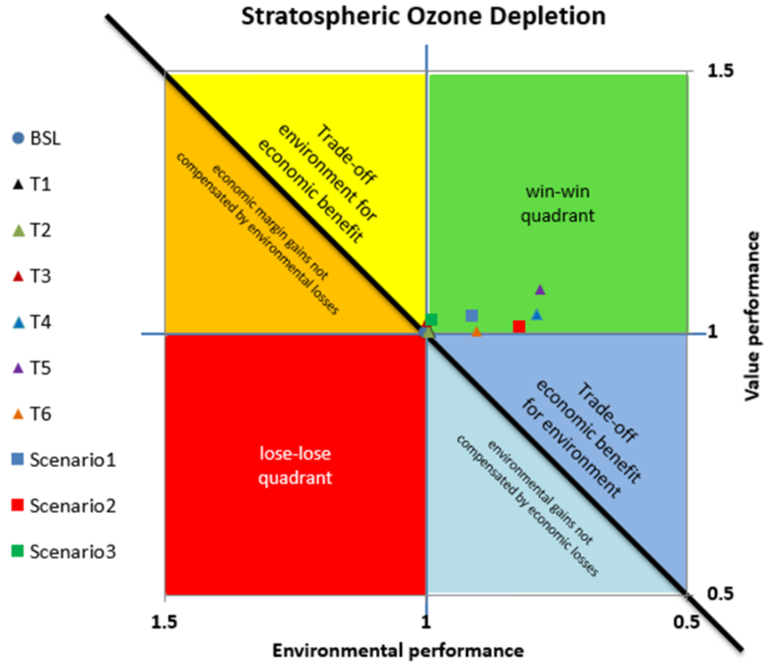


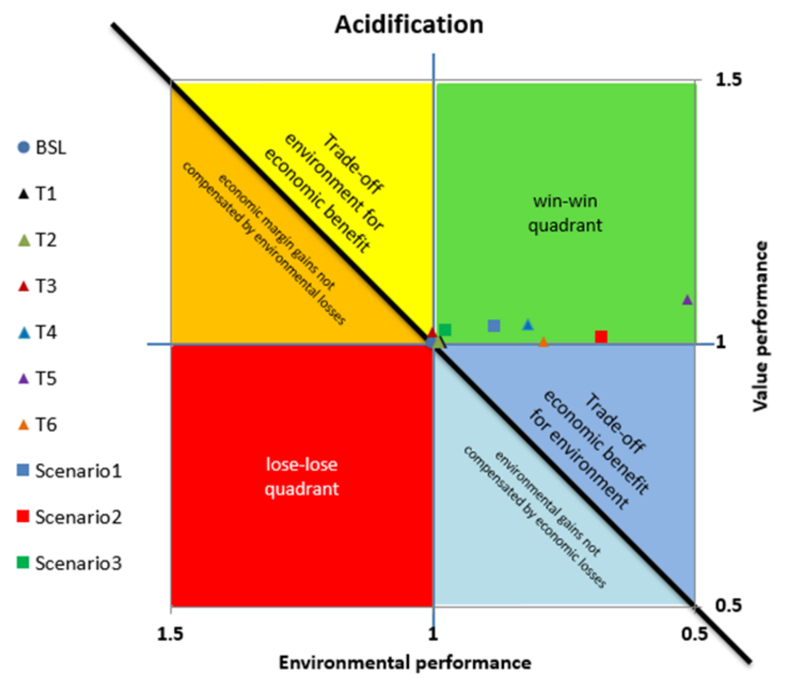
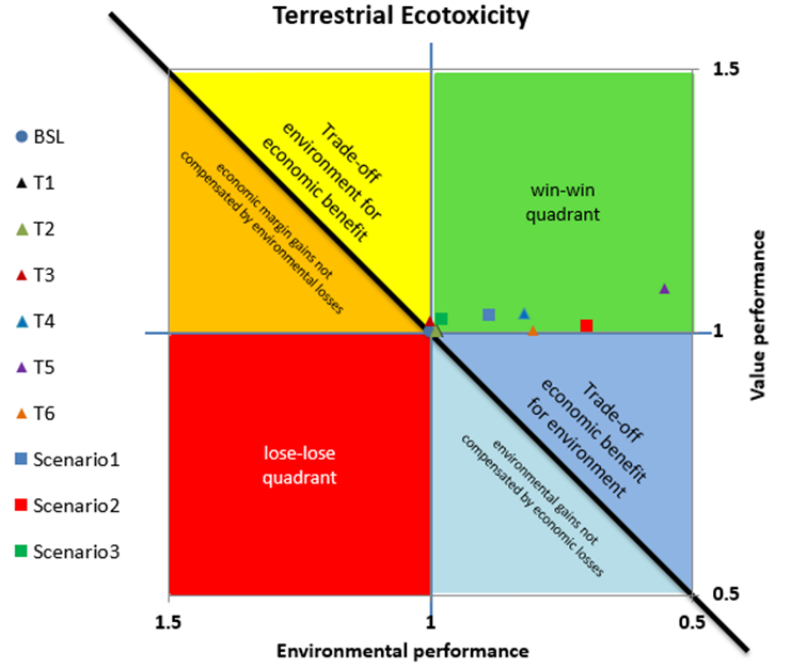
Again, eco-efficiency of all alternatives increases. There is an interesting observation for S1 and S2. S2, targeted at reduction of pollution from non-renewable energy sources has an expected highest environmental improvement (among scenarios). S1 has almost equal eco-efficiency improvement with S2, but it is due to its higher value performance. So, here, the phenomenon of the co-benefits is well visualized. S1 aims at freshwater use reduction, but it achieves significant co-benefit in regard to “fossil fuel depletion”.

As for the individual technologies, T4 and T6 show equal improvement of environmental performance. The lower value performance of T4 shows that the environmental impact is reduced at a higher economic price. It should not be forgotten that technologies are virtual improvements (assumption for 100% use of the technical potential).

	Small environmental improvement is observed given the fact that none of the technologies focuses on eutrophication improvement. The figure shows well that the improvement of the eco-efficiency is mainly due to increased value performance.
	If implemented with its full technical potential (all households), T4 (water and energy saving appliances) will have the highest environmental improvement. However, it has similar eco-efficiency improvement with T5 (solar water heating), due to its better value performance. Surprisingly, S1 has better performance than S2, considering the primary aims of them. This is one more argument for the importance of considering co-benefits.

	Similar to previous category.
	Scenario 2 have greater impact on the environmental performance but with lower value performance while in Scenario 1 with less investment costs bigger improvement of environmental performance is achieved.

	Similar to previous category.
	Similar to previous category.

	Solar water heating (T5) shows the highest eco-efficiency improvement, but in practice it will be hard to achieve it (to convince all households to implement it). As it is expected, the largest improvement of environmental performance is achieved in the pollution prevention scenario (S2). However, considerable investment costs are necessary for technologies focused on pollution prevention thus the value performance is only slightly improved.
	Similar to previous category.

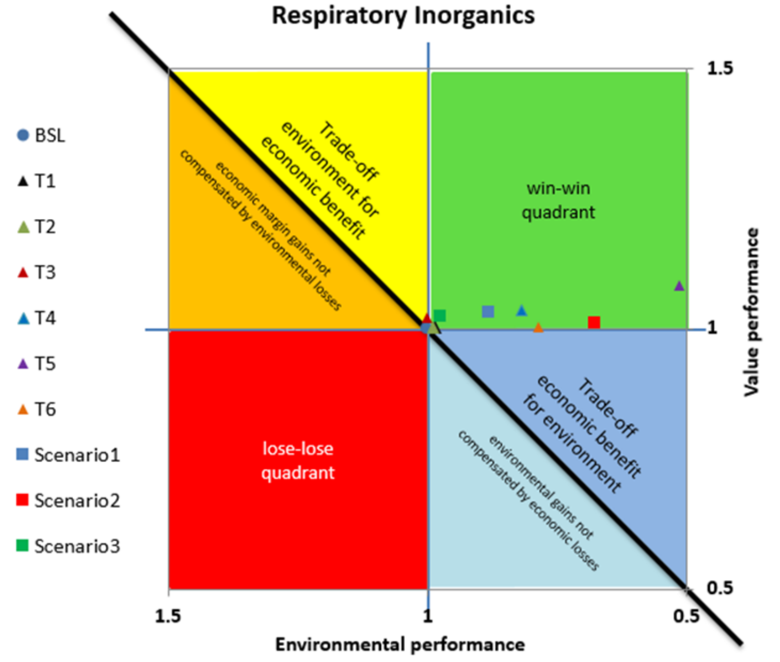
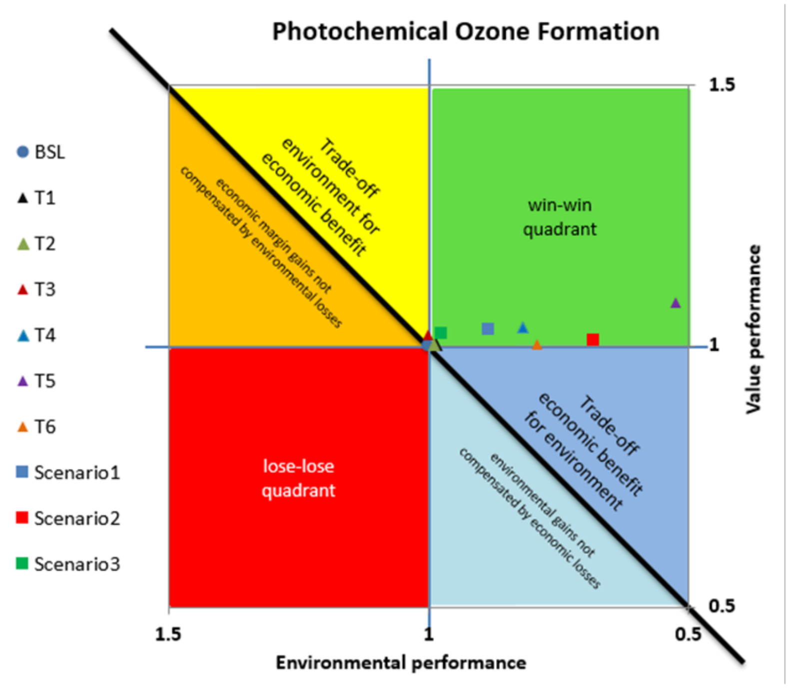
	Similar to previous category.
	Similar to previous category.

Figure 23 Results from eco-efficiency assessment presented in XY-diagrams

Figure 23 shows that all individual technologies and all scenarios improve or do not change their environmental, economic and eco-efficiency performance. It visualises the magnitude of the changes as well.

The solar water heating technology (T5) shows the strongest increase of both value and environmental performance, thus, the strongest increase of the eco-efficiency for all indicators. On the second place are the water and energy saving appliances (T4), for which the environmental performance shows better improvement than the value performance. It should not be forgotten, that these scenarios are built on the assumption for full technical implementation – all appropriate households, which in practice would be hardly possible to achieve. But, still, this observation demonstrates very well the hidden potential of the system.

2.4.2 Opportunities, provided by the eco-efficiency tool

The results of Sofia case study show that eco-efficiency is a powerful concept, which allows: i) comparison of single technology or combination of technologies with the baseline state of the system; ii) comparison between technologies and scenarios themselves. Furthermore, it facilitates the decision making process. An example for this is given below.

The individual technology assessment of the technology “water saving appliances” show that the eco-efficiency of the entire system increases (Chapter 2.2.1). However, the spider diagrams of the eco-efficiency indicators for each actor show that the eco-efficiency of the water users increases while it decreases for the water operator (Chapter 2.2.4). The explanation for this result is that water use for satisfying human water needs is reduced, i.e. the water operator sells less water to customers. This means lower TVA for him. The main problem for the water operator is that the water losses in the network remain the same. They might even increase, because of the higher pressure in the system due to lower water flow in the pipes. An expected measure that water operators could take to cover for their losses is to increase the water price. This decision should be agreed with the regulatory institution (SWRC), which approves the price of water for the customers. It is possible that, due to the social affordability, only slight change in the price may be feasible. Therefore, in order to increase his eco-efficiency, the water operator will be forced to decrease his water losses.

In Scenario 1, the two solutions - decreasing the water consumption and reducing the water losses are studied together. This is a means to aid decision making, leading to benefits for both sides and increasing the total eco-efficiency of the system. The water users could be considered as indirectly investing money for the water supply system through their bills therefore the water operator and the water users “jointly invest” for technologies aiming at reducing water losses. A possible wise solution here might be to introduce a water tariff, dependant on the water consumption. If there is a base price for the useful water consumption in household with best available water appliances installed, each cubic meter above could be billed at a higher price. So, a “win-win” situation could be created: Water users have an incentive to reduce their consumption, implementing the best available water saving appliances to save money from their bills. The water operator will have additional income from the billed water above the set threshold. This money might be invested in water losses reduction measures. Moreover, depending on the water stress in the region the SWRC could set higher taxes for freshwater abstraction from nature thus the water operator will be incentivised to reduce the water losses in order to pay less for the freshwater resource.

3 Zurich urban case study CS4

3.1 Finalized baseline scenario assessment

3.1.1 Environmental performance

The baseline results of the environmental impacts of the entire system and of the contribution of the background and foreground processes into the environment are presented in Table 53 and Figure 24. For the analysed system some environmental impacts can be attributed mostly to the foreground system, like climate change, freshwater resource depletion, eutrophication, and micropollutants emissions. The influence on the indicators climate change is due to the fact that the emissions from burning gas and oil for water heating are occurring inside the system boundaries and are very much larger than the production of oil and gas which occurs outside the system boundaries. The freshwater withdrawal is a purely foreground issue as the water is abstracted and used inside the system boundaries. The same is true for the eutrophication and micropollutants emissions, as the wastewater is discharged inside the system boundaries. The indicators fossil fuels depletion and stratospheric ozone depletion are attributed mainly to the background system as the main impacts happen outside the system boundaries.

Table 53: Environmental indicators results for CS4 baseline assessment for 2011

Indicator	Total Value	Foreground Value	Background Value
Climate Change (tCO_2eq)	6,728.01	5,056.26	1,671.76
Fossil Fuels Depletion (MJ)	95,093,417.96	4,303,504.42	90,789,913.54
Freshwater Resource Depletion (m^3)	79,387.50	79,387.50	0
Eutrophication ($kgPO_4eq$)	505,500.96	504,427.64	1,073.32
Human Toxicity (kg1,4-DBeq)	558,840.17	377,178.25	181,661.92
Acidification ($kgSO_2eq$)	11,683.13	3,908.87	7,774.26
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070.10	73,957.83	87,112.27
Stratospheric Ozone Depletion (kgCFC-11eq)	1.01	0.04	0.98
Terrestrial Ecotoxicity (kg1,4-DBeq)	417.95	157.40	260.55
Respiratory Inorganics ($kgPM_{10},eq$)	1,995.40	635.54	1,359.86
Photochemical Ozone Formation (kgC_2H_4,eq)	656.30	194.73	461.58
Micropollutants (kg)	60.00	60.00	0

The relative contribution of foreground and background systems in the different environmental impact categories are shown in Figure 24.

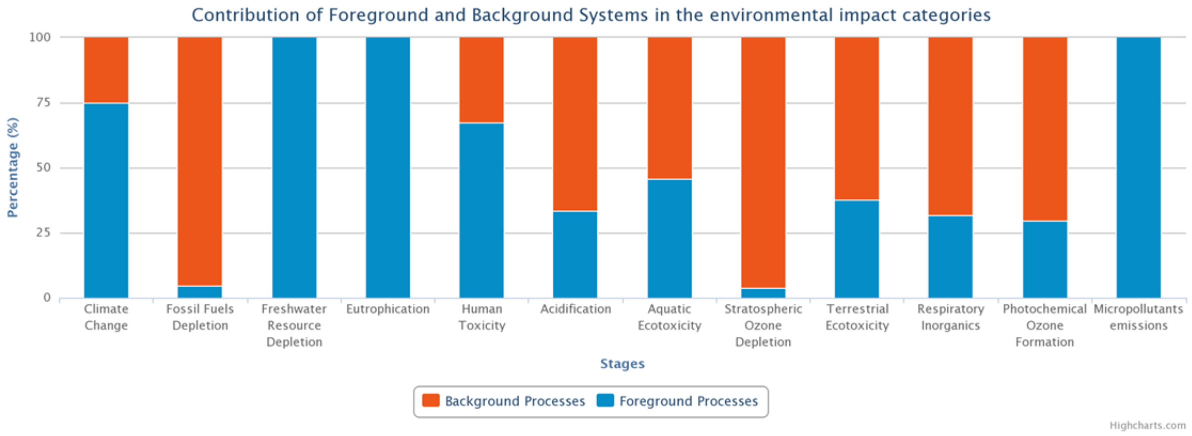


Figure 24: Relative contribution of foreground and background systems in the different environmental impact categories

The results on environmental indicators are presented as percentage per stage in Figure 25. Solid bars represent the foreground system and transparent bars the background system.

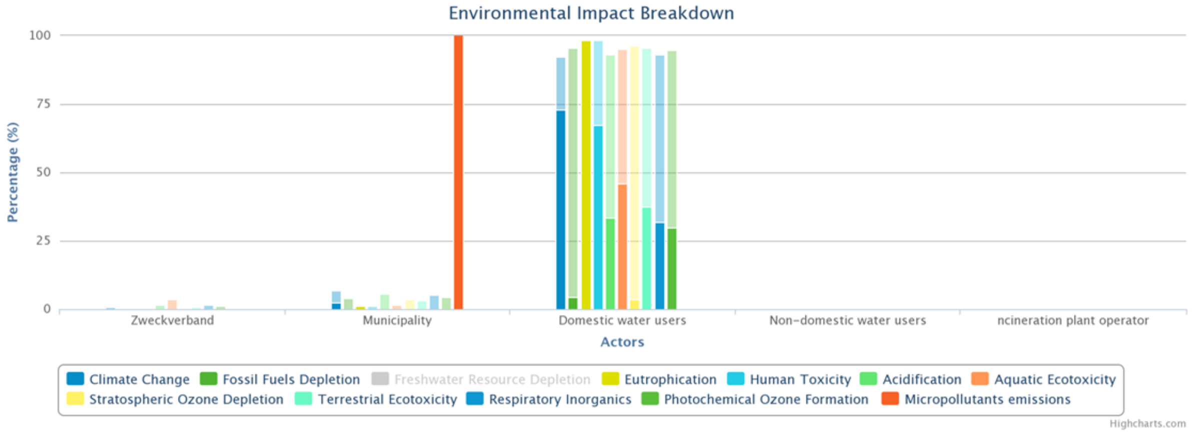


Figure 25: Environmental impact breakdown, percentage per stage of total except for freshwater resource depletion

3.1.2 Economic performance

Table 54 summarizes the economic performance assessment of the studied system. The total value added to the product from the water use is the sum of the net economic output of the actors, which is estimated to about 2.5 Mio € per year.

Table 54: Actors and their economic performance results in € per year

Actor	Annual Equivalent Investment Cost	Annual O&M Cost	Gross Income	Revenues from(+) /costs for (-) water services	Net Economic Output
Zweckverband	993,775	316,980	0	1,310,889	134
Municipality	2,888,158	1,799,063	67,320	4,712,469	92,568
Domestic Water Users	1,628,278	2,815,363	10,154,545	-4,259,712	1,451,193
Non-Domestic Water Users		0	2,728,375	-1,763,647	964,729
Total Value Added per year					2,508,623

The economic performance per actor with annual investment costs, operation and management costs, gross income, revenues from water services and the net economic output are shown in Figure 26. The annual investment and operation and management costs for the actors Zweckverband and municipality have been estimated based on their annual reports. The annual investment costs for domestic water users are assumed cost for water heating systems installed. Their operation and management costs consist of energy costs for water heating. The gross income for domestic and non-domestic water users is estimated on the basis of willingness to pay as presented in Deliverable 3.2. The revenues from water services have a positive value for the actors for which they represent an income, as for the actors Zweckverband and municipality. The revenues from water services have a negative value for the actors domestic and non-domestic water users, where they represent the costs for water services.

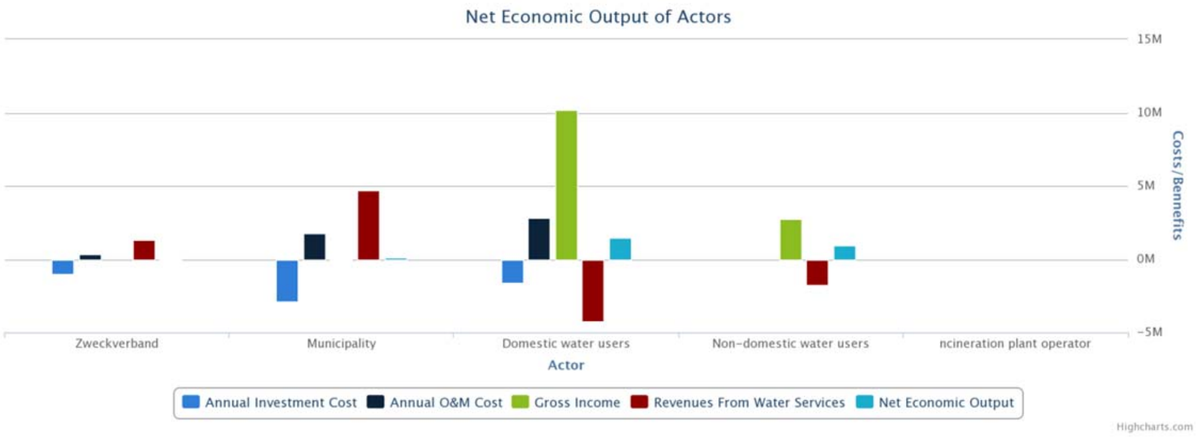


Figure 26: Economic performance per actor

3.1.3 Eco-efficiency indicators

The eco-efficiency indicators for the baseline are derived from combining the results of environmental impact and economic value assessment presented above. Table 55 summarizes the values of the eco-efficiency indicators, corresponding to the 12 relevant environmental impact categories. These absolute values are difficult to interpret, but will be used in the following assessment as reference to compare the impacts of technologies and system changes to improve the eco-efficiency of the system.

Table 55: Eco-efficiency indicators for baseline assessment

Eco-efficiency indicator	**Value**
Climate Change (€/tCO_2eq)	372.86
Fossil Fuels Depletion (€/MJ)	0.03
Freshwater Resource Depletion (€/m^3)	31.6
Eutrophication (€/kgPO_4eq)	4.96
Human Toxicity (€/kg1,4-DBeq)	4.49
Acidification (€/kgSO_2eq)	214.72
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632.02
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002.28
Respiratory Inorganics (€/kgPM10,eq)	1,257.20
Photochemical Ozone Formation (€/kgC2H4,eq)	3,822.35
Micropollutants (€/kg)	41,810.39

The costs of resources used in the baseline and in the following technology and scenario assessments are presented in Table 56. Some of these costs (e.g. ozone) are estimations which are used for example to represent the known operation and management cost of the water supply where at the same time not all elements of expenditure were known.

Table 56: Costs of main resources

Resource	Costs	Unit
Fee for water abstraction from lake	0.03	(€/m^3)
Fee for water abstraction from groundwater	0.01	(€/m^3)
Drinking water	1.22	(€/m^3)
Wastewater	1.46	(€/m^3)
Gas	0.05	(€/kWh)
Oil	1.15	(€/kg)
Electricity	0.15	(€/kWh)
Cl_2	1	(€/kg)
Ozone	1	(€/kg)
NaClO	1	(€/kg)
$Al_2(SO_4)_3$	1	(€/kg)
Flocculants	0.70	(€/kg)
Transport sludge	0.08	(€/tkm)

3.2 Individual assessment of innovative technologies

In the sections below the following seven potential technologies are individually assessed:

1. Smart pumping for water supply system (section 3.2.1)
2. Micropollutants removal technologies (section 3.2.2)
3. Advanced phosphorus recovery technologies (section 3.2.3)
4. Water reuse for domestic water users (section 3.2.4)
5. Water saving appliances for domestic water users – cold water (section 3.2.5)
6. Water saving appliances for domestic water users – warm water (section 3.2.6)
7. Solar thermal water heating (section 3.2.7)

3.2.1 Smart pumping for the water supply system (CS4T1)

Short description

Smart pumping systems are centrifugal pumps equipped with special instrumentation and a microprocessor that can be operated at variable speed. The smart pumping systems have advantages regarding the failure frequency of pumps and hence reduce maintenance costs and increase pump efficiency.

Main assumptions

Proposed technical implementation

The water distribution system in the case study area operates already very efficiently. The water loss rate of around 9% is already an economically viable level. The efficiency of the pumping system has been substantially improved in the last 10 years. Therefore, the potential for improvement in energy efficiency at this stage is assumed to be rather low and accordingly, a maximal reduction of around 10% of current electricity consumption for pumping is assumed due to organizational measures. These measures can include optimised management of the reservoirs or a better regulation concept of the network.

Environmental performance

It is estimated that the energy consumption of the system could be decreased by maximal 10% through implementation of state of the art smart pumping measures compared to the current practice in Waedenswil, see Table 57 for affected primary flow in the model.

Table 57: Affected energy flow by smart pumping technology implementation

Resource flow affected	In baseline	After technology implementation	Unit
Electricity consumption for water pumping	952,650	846,032	kWh/year

Economic performance

According to estimations made for Switzerland (Infrawatt, 2014) 92% of pumping costs are electricity cost, 6% are capital costs and 2% are maintenance costs. Based on the costs distribution and the savings achieved through lower energy consumption, the investment and operational costs for smart pumping were deducted in Table 58.

Table 58: Economic data for smart pumping system

Parameter for stage	After technology implementation	Unit
Investment cost		
Investment costs	15,000	€
Lifetime	15	years
Interest rate	2.5	%/year
Annualised investment costs	1,211	€/year
Annual operation and maintenance cost		
Fixed costs (incl. maintenance)	300	€/year
Annual savings		
Savings in electricity costs	- 14,290	€/year
Total annual additional costs (+)/ savings (-)		
Total savings	-12,778	€/year

Results

Table 59 represents the environmental performance indicators in the baseline and after implementation of the smart pumping technology. It can be observed that all indicators slightly improve, but the changes are below 1% in all indicators.

Table 59: Environmental performance indicators of baseline and technology CS4T1

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO2eq)	6'728.01	6'719.89	-0.1208%
Fossil Fuels Depletion (MJ)	95,093,418	95,057,800	-0.0375%
Freshwater Resource Depletion (m3)	79,388	79,388	0%
Eutrophication (kgPO4eq)	505,501	505,638	0.0271%
Human Toxicity (kg1,4-DBeq)	558,840	558,740	-0.0179%
Acidification (kgSO2eq)	11,683	11,668	-0.1337%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	161,047	-0.0144%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0129	0.0000%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	418	-0.0691%
Respiratory Inorganics (kgPM10,eq)	1,995	1,993	-0.1296%
Photochemical Ozone Formation (kgC2H4,eq)	656	656	-0.0938%
Micropollutants (kg)	60	60	0%

Table 60 represents the economic performance in the baseline and after implementation of the smart pumping technology. It can be observed that the value added of the actor municipality is increasing by 14%, as the costs saving after the technology implementation compensate the investment costs. This leads also to a slight increase, below 1%, of the total value added.

Table 60: Economic performance of baseline and technology CS4T1 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	134	0
Municipality	92,568	105,346	12,778
Domestic water users	1,451,193	1,451,193	0
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	2,521,401	12,778

Table 61 represents the eco-efficiency performance indicators in the baseline and after implementation of the smart pumping technology. Similarly to the case of environmental impact indicators and the total value added, the eco-efficiency indicators improve slightly by below 1% change.

Table 61: Eco-efficiency performance indicators of baseline and technology CS4T1

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO2eq)	372.86	375.21	0.63%
Fossil Fuels Depletion (€/MJ)	0.0264	0.0265	0.55%
Freshwater Resource Depletion (€/m^3)	32.60	32.76	0.51%
Eutrophication (€/kgPO$_4$eq)	4.96	4.99	0.48%
Human Toxicity (€/kg1,4-DBeq)	4.49	4.51	0.53%
Acidification (€/kgSO2eq)	215	216	0.64%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57	15.66	0.52%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	2,489,247	0.51%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	6,037	0.58%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	1,265	0.64%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	3,845	0.60%
Micropollutants (€/kg)	41,810	42,023	0.51%

Figure 27 shows the eco-efficiency performance in the baseline and after implementation of the smart pumping technology for the whole system. As discussed above, the positive changes are rather minimal from this perspective.

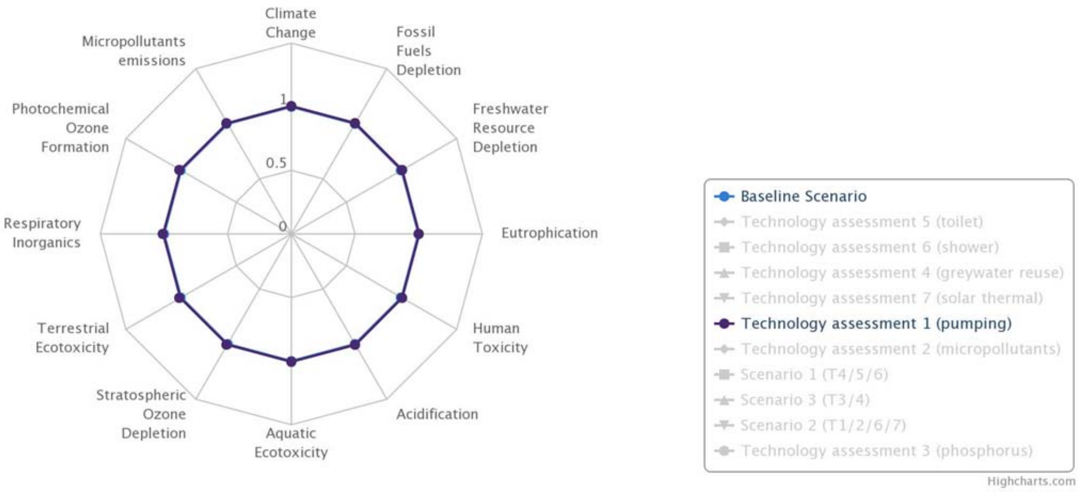


Figure 27: Eco-efficiency performance comparison of the whole system

Figure 28 shows the eco-efficiency performance in the baseline and after implementation of the smart pumping technology from the perspective of the actor municipality, which would introduce the technology. Here, a slightly bigger change to the positive can be observed, due to the significant change in the value added for this actor.

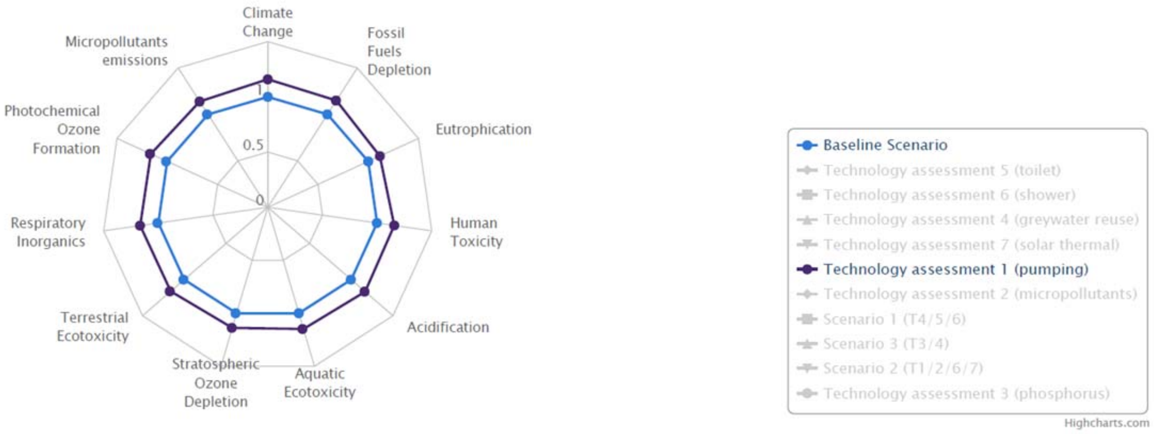


Figure 28: Eco-efficiency performance for actor municipality

To sum up, the smart pumping technology would be implemented by the actor municipality as it is increasing its individual net economic output, by compensating the investment and operational costs with the savings in energy costs. No compensations from other actors are required. The water distribution system in Waedenswil has already recognised the improvement potential of such measures, so that the efficiency of the water distribution network is being continuously improved.

3.2.2 Micropollutants removal technology (CS4T2)

Short description

At the moment there is no additional step to reduce the amount of micropollutants emitted into Lake Zurich at the WWTP Rietliau. In a publication from the Swiss Federal Office for the Environment (BAFU, 2012) average concentrations at the point of discharge of WWTP were estimated for around 40 particular micropollutants for Switzerland. Given the amount of water discharged by the WWTP Rietliau, the emissions of micropollutants are estimated to around 60 kg per year.

In Switzerland there are two established technologies regarding their potential for micropollutants removal and costs, which are ozonation and powdered activated carbon (PAC) adsorption. Ozonation is an advanced oxidation process which uses ozone (produced on-site) to decompose molecules down. Activated carbon adsorption technology removes micropollutants from the water by adsorption. An example process is shown in Figure 29.

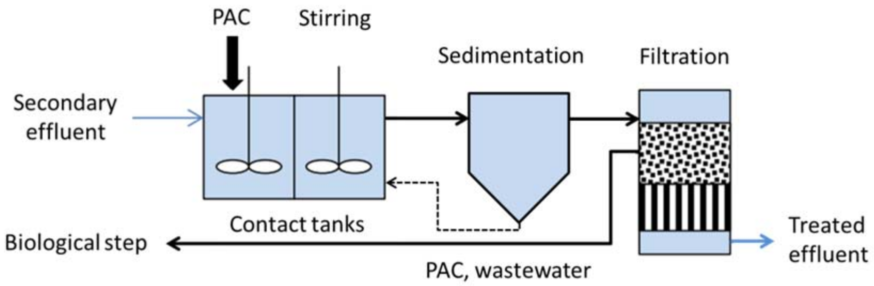


Figure 29: Example of process scheme for activated carbon adsorption

The effectiveness of this process depends on the available surface of the powdered activated carbon and the load of adsorbing substances in the water. According to J. Margot

(Margot, et al., 2011) and (BAFU, 2012), the PAC technology can remove more than 80% on average of the micropollutants from the wastewater as indicated in Table 62.

Main assumptions

Proposed technical implementation

For Waedenswil the implementation of the PAC technology with a sand filter is proposed, dosing 12 g of PAC per m3 of secondary effluent water (Table 62). This technology will increase the sludge production by 5% and the electricity consumption of the WWTP by 0.025 kWh per m3.

Table 62: Elimination of micropollutants in wastewater treatment plants (BAFU, 2012)

Criteria	Powdered Activated Carbon (PAC) + Sand Filter
Micropollutants removal (including biological treatment)	80%
Waste production	Increase by 5% the sludge production of the WWTP
Electricity consumption of system	0.025 kWh/m^3
Material consumption PAC	12 g PAC/m^3

Environmental performance

An attempt to account for the environmental benefits of micropollutants removal was made by (Larsen, Olsen, Hauschild, & Laurent, 2009) using the EDIP97 (Environmental Design of Industrial Products) method as a basis for calculation of unknown characterization factors of certain micropollutants. Subsequently, this method was used to assess the environmental cost of ozonation and PAC technologies and benefits of removing 22 common micropollutants (Larsen, Hansen, & Boyer-Souchet, 2010). The 22 micropollutants were only characterized by their contribution to the EDIP97 environmental impact category on “ecotoxicity water chronic” in m3/kg. On the contrary, for the baseline scenario the indicator “freshwater aquatic ecotoxicity” was calculated with the CML2001 method and the unit kg 1,4-DBeq. Therefore, for a first approximation an ancillary indicator for micropollutants emissions in kg per year is used as shown in Table 63. For that, the average concentrations of most typical micropollutants for Switzerland measured at the outlet of wastewater treatment plants reported by the Swiss Federal Office for the Environment (BAFU, 2012) was used to calculate the amount of micropollutants emitted per year.

The affected flows by the micropollutants removal technology shown in Table 63 include a reduction of micropollutants emissions by 80%, whereas the sludge production, energy and material consumption increase.

Table 63: Affected flows by PAC technology implementation

Flow	Baseline	After technology implementation	Unit
Micropollutants emissions to lake	60	12	kg/year
Sludge	2,200	2,310	ton/year
Electricity consumption	1,720,000	1,797,474	kWh/m^3
Material consumption PAC	0	37,188	kg/year

Economic performance

The average lifetime of both technologies is assumed to be 10 years. According to data from Hunziker (Hunziker, 2008) the costs for a PAC system in a WWTP Au for 66,000 person equivalent are estimated as shown in Table 64. This was the closest reference to the amount of pe in Waedenswil of 40,000 which could be found in literature. There are plans for the WWTP in Waedenswil to connect another municipality, Richterswil, in the next few years due to necessary modernisation. This will increase the person equivalents in Waedenswil. Therefore, as a conservative assumption, the costs for a 66,000 pe system from literature will be taken into account.

Table 64: Costs for PAC technology for Waedenswil WWTP

Parameter for stage	After PAC technology implementation	Unit
Investment costs		
Investment costs	10,000,000	€
Lifetime	15	years
Interest rate	2.5	%/year
Annualised investment costs	807,664	€/year
Annual operation and maintenance cost		
Fixed costs (incl. maintenance)	290,000	€/year
Cost of productive inputs - electricity	10,846	€/year
Cost of productive inputs - PAC	74,375	€/year
Total annual additional costs (+)/ savings (-)		
Total costs	1,182,886	€/year

Results

Table 65 presents the environmental performance indicators of the baseline and after the introduction of the micropollutants removal technology. A very slight increase (below 0.1%) in environmental impact indicators due to the additional energy and material consumption and a significant drop in micropollutants emissions indicator are estimated.

Table 65: Environmental performance indicators of baseline and with technology CS4T2

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6'728.01	6'719.89	0.0982%
Fossil Fuels Depletion (MJ)	95,093,418	95,122,384	0.0305%
Freshwater Resource Depletion (m^3)	79,388	79,388	0.0000%
Eutrophication ($kgPO_4eq$)	505,501	505,640	0.0276%
Human Toxicity (kg1,4-DBeq)	558,840	558,921	0.0145%
Acidification ($kgSO_2eq$)	11,683	11,696	0.1088%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	161,089	0.0117%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0129	0.0000%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	418	0.0562%
Respiratory Inorganics ($kgPM_{10},eq$)	1,995	1,998	0.1054%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	657	0.0763%
Micropollutants (kg)	60	12	-80%

Table 66 presents the economic performance of the baseline and after the implementation of the micropollutants removal technology. The investment and operation and management costs faced by the actor municipality reduce the total value added of the system accordingly, by about 1.2 Mio Euro.

Table 66: Economic performance of baseline and with technology CS4T2 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	134	0
Municipality	92,568	-1,090,319	-1,182,886
Domestic water users	1,451,193	1,451,193	0
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	1,325,737	-1,182,886

Table 67 presents the eco-efficiency performance indicators of the baseline and after the implementation of the micropollutants removal technology. The eco-efficiency decreases in all indicators except in the micropollutants removal, where the environmental benefits overweight the economic costs. In this case, the eco-efficiency rises significantly compared to the baseline.

Table 67: Eco-efficiency performance indicators of baseline and with technology CS4T2

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO2eq)	372.86	196.85	-47%
Fossil Fuels Depletion (€/MJ)	0.03	0.01	-47%
Freshwater Resource Depletion (€/m3)	32	17	-47%
Eutrophication (€/kgPO4eq)	4.96	2.62	-47%
Human Toxicity (€/kg1,4-DBeq)	4.49	2.37	-47%
Acidification (€/kgSO2eq)	215	113	-47%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.6	8.2	-47%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	1,308,830	-47%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	3,170	-47%
Respiratory Inorganics (€/kgPM10,eq)	1,257	664	-47%
Photochemical Ozone Formation (€/kgC2H4,eq)	3,822	2,018	-47%
Micropollutants (€/kg)	41,810	110,478	164%

Figure 30 shows the eco-efficiency performance of the micropollutants removal technology compared to the baseline of the whole system. As discussed before, only the micropollutants emissions indicator is changing for the better, while other eco-efficiency indicators decrease.

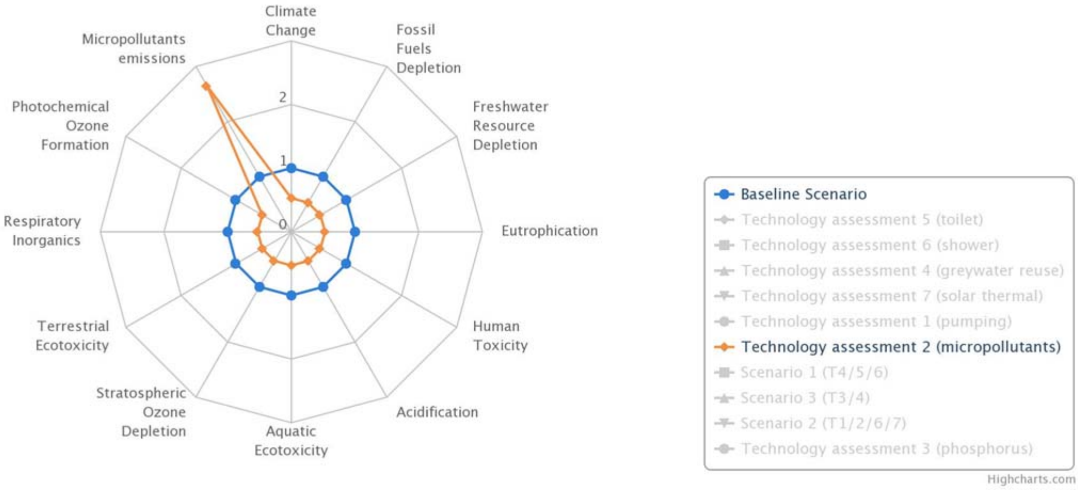


Figure 30: Eco-efficiency performance comparison of the whole system

The powdered activated carbon adsorption technology reduces the environmental impact of the water supply chain by removing micropollutants from the effluent which impose a potential risk for aquatic ecosystem and human health. However, the technology is also connected to additional environmental impacts in form of energy consumption and consumption of materials, in this case PAC. In this technology case, the additional energy and material consumption will be allocated to the background processes, but environmental benefits will be obtained at the end of the water value chain, thus in the receiving water body.

Despite the overall negative eco-efficiency change due to implementation of this technology, this measure will be implemented due new legislation. On the short term, the costs have been allocated to the operator of the WWTP, thus the municipality. On the long term, these costs will be passed on to the domestic and non-domestic water users through the increase of wastewater discharge prices. This is due to the fact that the wastewater treatment systems have to cover the operation costs. The TVA decreases with this technology, as there are no short-term economic benefits which would compensate for the increased capital and operational costs at the WWTP. At best, this technology has the potential to reduce drinking water treatment costs, as the water resources are taken from Lake Zurich and the micropollutants are eliminated at the water treatment stage at the moment.

3.2.3 Advanced phosphorus recovery technologies (CS4T3)

Short description

From 2015 on in the Canton of Zurich the sludge from most municipal WWTP will be collected and incinerated in one centralised mono-incineration plant to allow recovering of phosphorus from the ash of the sludge. This mono-incineration plant is now being build. However, the technology for recovery of phosphorus is still in an evaluation stage. It is planned to store the ash until an economically viable technology will be found. Two technologies are at the moment under consideration, the so-called LEACHPHOS system and the Ash-Dec method. With both methods phosphorus can be recovered from the ash and the end product is a powder. As there was no sufficient literature available on the LEACHPHOS method, in the following the Ash-Dec method will be described. With the Ash-Dec method the phosphorus is recovered from ash by leaching with acid and/or alkaline. The ash is treated in a rotary kiln at 850 to 1,000°C. During the process magnesium and calcium chloride are dosed into the rotary kiln. Under these conditions heavy metals which are contained in the ash will form volatile heavy metal chlorides. Another way to recover the phosphorus is the thermochemical removal of heavy metals from ash to produce P-fertilizer raw material (Havukainen, Horttanainen, & Linnanen, 2012).

Main assumptions

Proposed technical implementation

Only the phosphorus which is removed in the WWTP from the wastewater into the sludge is available for a recovery. In Waedenswil, this amount is estimated to about 18,000 kg of phosphorus per year (data from EcoWater Deliverable 3.3).

Environmental performance

A phosphorus recovery process from sludge can significantly reduce the primary resource depletion, but it implies additional consumption of energy, chemicals, etc. as shown in Table 68. The phosphorus recovery process will however not lead to reduced environmental impact in the foreground system. This is due to the fact that phosphorus concentrations in the treated and discharged wastewater will not be affected through the implementation of this technology, as they underlie certain thresholds imposed by legislation, which have to be respected at all times.

Table 68: Estimated parameters for Ash-Dec technology to recover phosphorus from 1 t of ash

Parameter	Value	Unit
Electricity consumption	118	kWh/t_{ash}
Fuel energy consumption (natural gas or biogas)	520	kWh/t_{ash}
NaCl consumption	46	kg/t_{ash}
MgO consumption	39	kg/t_{ash}
$NaHCO_3$ consumption	49	kg/t_{ash}
End product yield	1.1	t/t_{ash}

Source: (Havukainen, Horttanainen, & Linnanen, 2012)

According to the data from Office of Waste, Water, Energy and Air of Canton Zurich, the sludge from WWTP has an ash content of 462 g of ash per kg of dried sludge. According to data from the WWTP, the dry matter content of the sludge is about 23%. In case of Waedenswil with 2,200 t of sludge production, the amount of dried matter is 506 t per year. This leads to an annual ash production of 234 t. With data from Table 68 , estimated values of resources for Waedenswil were calculated in Table 69.

Table 69: Estimated values for Ash-Dec technology for Waedenswil

Parameter	Value	Unit
Electricity consumption	28,000	kWh/year
Fuel energy consumption (natural gas or biogas)	120,000	kWh/year
NaCl consumption	11,000	kg/year
MgO consumption	9,000	kg/year
$NaHCO_3$ consumption	11,000	kg/year
End product yield	260	t/year

However, as the phosphorus recovery process will take place in a centralised plant for the whole Canton of Zurich, the consumptions of the resource will occur outside of the case study system boundaries. The 260 t of end product obtained contain 18 t of phosphorus. This means that the phosphorus content in the end product is around 7%.

Economic performance

According to data from the EcoWater Deliverable 3.3, the costs for phosphorus recovery with the Ash-Dec process were estimated by Sartorius (Sartorius, 2011) and Dockhorn (Dockhorn, 2012). At present, the costs of the process are about 2.2 Euro per kg of phosphorus while the benefits of the process are around 2 Euro per kg. This means that the total benefits of this process are at the moment negative, with around 0.2 Euro per kg of phosphorus. The costs and benefits are summarized in Table 70.

Table 70: Specific costs for phosphorus recovery with Ash-Dec process

Economic data	Value	Unit
Cost of the process	2.2	€/kg$_P$
Benefit of the process	2	€/kg$_P$
Costs of phosphorus production	0.2	€/kg$_P$

Source: EcoWater Deliverable 3.3

The challenge with the phosphorus recovery technology is that the environmental impact of the recovery process is generated outside the system boundaries of the case study. However, the financial benefits will be accounted inside the boundaries of the system, for the actor municipality. As at the moment the costs of the recovery process overweight the benefits, the application of this technology will be taken up not earlier than in about 10 years, after the recovery is assumed to be more viable. Therefore, in the future scenario the municipality might benefit from the recovery.

Results

Table 71 presents the environmental performance indicators of the baseline and after the introduction of the phosphorus recycling technology. As the technology causes neither benefits nor costs from the covered environmental perspective of the setup indicator system, the changes are zero for all environmental impact indicators.

Table 71: Environmental performance indicators of baseline and with technology CS4T3

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6'728.01	6'728.01	0%
Fossil Fuels Depletion (MJ)	95,093,418	95,093,418	0%
Freshwater Resource Depletion (m^3)	79,388	79,388	0%
Eutrophication (kgPO_4eq)	505,501	505,501	0%
Human Toxicity (kg1,4-DBeq)	558,840	558,840	0%
Acidification (kgSO_2eq)	11,683	11,683	0%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	161,070	0%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0129	0%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	418	0%
Respiratory Inorganics (kgPM_{10},eq)	1,995	1,995	0%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	656	0%
Micropollutants (kg)	60	60	0%

Table 72 presents the economic performance of the baseline and after the implementation of the phosphorus recycling technology. If the actor “municipality” decides to recover phosphorus at the given moment, it will face costs of around 3,500 Euro per year, which would lead to the corresponding reduction of the total value added.

Table 72: Economic performance of baseline and with technology CS4T3 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	134	
Municipality	92,568	88,980	-3,588
Domestic water users	1,451,193	1,451,193	
Non-domestic water users	964,729	964,729	
Total Value Added	2,508,623	2,505,035	3,588

Table 73 presents the eco-efficiency performance indicators of the baseline and after the implementation of the phosphorus recycling technology. The eco-efficiency decreases in all indicators equally due to the decreased TVA and unchanged environmental impacts.

Table 73: Eco-efficiency performance indicators of baseline and with technology CS4T

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO_2eq)	372.86	372.33	-0.14%
Fossil Fuels Depletion (€/MJ)	0.0264	0.0263	-0.14%
Freshwater Resource Depletion (€/m^3)	31.60	31.55	-0.14%
Eutrophication (€/kgPO_4eq)	4.96	4.96	-0.14%
Human Toxicity (€/kg1,4-DBeq)	4.49	4.48	-0.14%
Acidification (€/kgSO_2eq)	215	214	-0.14%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57	15.55	-0.14%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	2,473,090	-0.14%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	5,994	-0.14%
Respiratory Inorganics (€/kgPM_{10},eq)	1,257	1,255	-0.14%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	3,822	3,817	-0.14%
Micropollutants (€/kg)	41,810	41,751	-0.14%

Figure 31 shows the eco-efficiency performance of the phosphorus recycling technology compared to the baseline of the whole system. No changes occur.

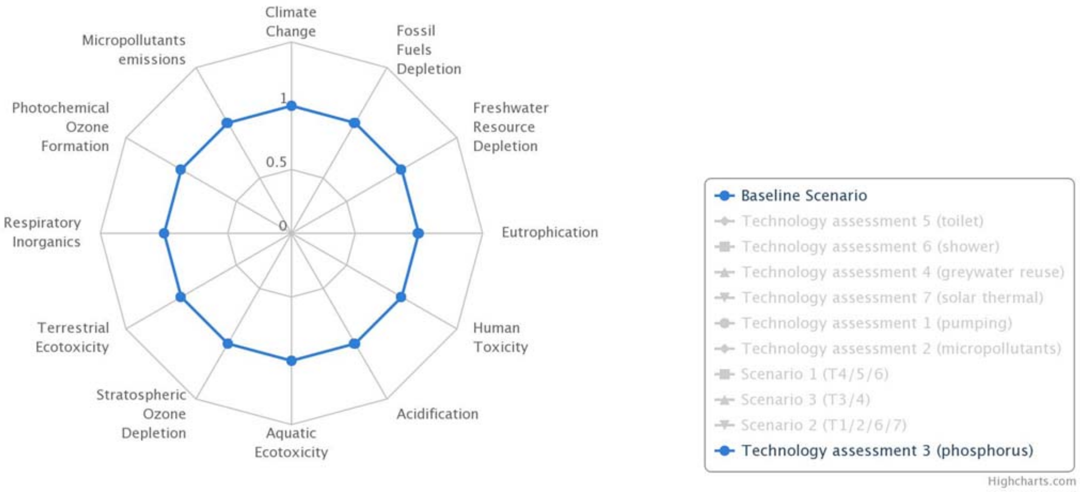


Figure 31: Eco-efficiency performance comparison of the whole system

Figure 32 shows the eco-efficiency performance of the phosphorus recycling technology for the actor municipality with a slight decrease compared to the baseline.

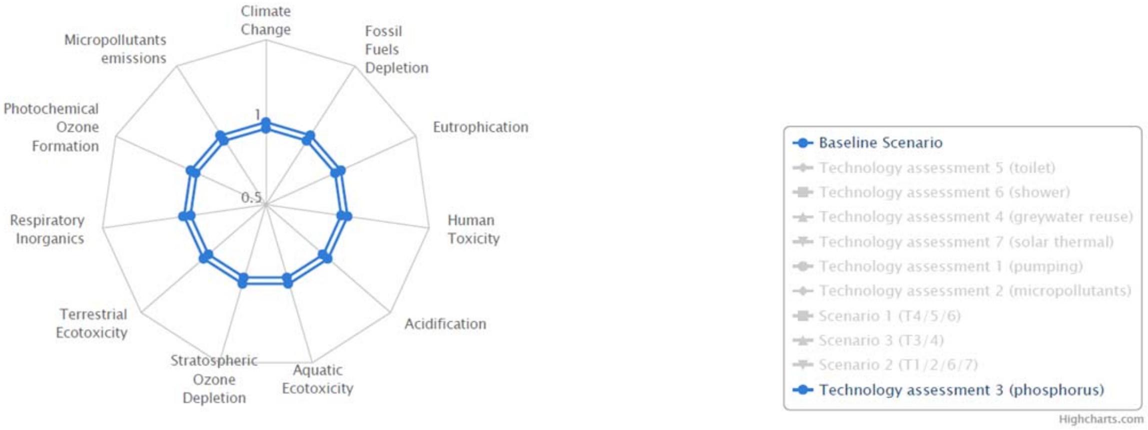


Figure 32: Eco-efficiency performance for the actor municipality

To sum up, the implementation of the phosphorus recovery at the moment is on the way, but still not economically viable. While a cantonal incineration plant is already being build, the technology for the recovery of phosphorus from sludge is still under evaluation. Additionally, the recovery process is with the current phosphorus prices economically not worthwhile. However, as these prices are expected to rise in the future, it should be an interesting option in some years, additionally, for a value to be attributed to the future independence from foreign phosphorus resources.

3.2.4 Water reuse for domestic water users (CS4T4)

Short description

Households are the main users of drinking water and accordingly the main producers of wastewater. Water reuse systems for households are suitable to recycle the so-called greywater from domestic water users. Greywater includes wastewater from washing machines, showers, baths and washbasins, see Figure 33.

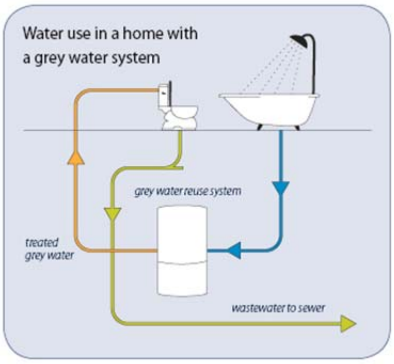


Figure 33: Example for a greywater reuse system (Guelph, 2013)

Main assumptions

Proposed technical implementation

To assess the potential of this technology, it is assumed that all water collected from showers and wash basin is used for flushing toilets, while the grey water overflow goes directly to the WWTP.

Water reuse systems require more energy and chemical consumption than water saving appliances according to Bello-Dambatta (Bello-Dambatta, et al., 2012). Energy and cost efficiency depend strongly on type of greywater reuse system and the number of users. More complex greywater systems with several treatment steps cause more carbon emissions than the production of a corresponding amount of drinking water. However, greywater reuse systems offer the potential of saving up to 30-40% of primary drinking water and the corresponding amount of wastewater, additionally to possibly used water saving appliances (Bello-Dambatta, et al., 2012).

One of the most common individual greywater reuse system consists in collecting the water from showers at households and recycle it for flushing toilets. For the non-domestic users, water can be collected from hand basins and reused for flushing toilets with the same result (Zadeh, Lombardi, Hunt, & Rogers, 2012), see Figure 34.

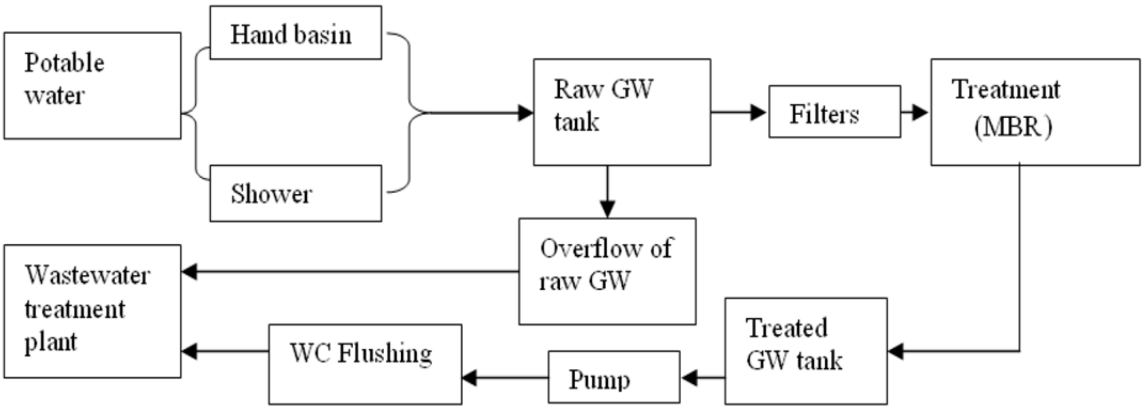


Figure 34: Component parts of grey water recycling system, source: (Zadeh, Lombardi, Hunt, & Rogers, 2012)

The greywater is treated by a membrane bioreactor (MBR). The MBR consists of a compact unit which combines activated sludge treatment for the removal of biodegradable pollutants and a membrane for solid/liquid separation. MBR is commonly used in large buildings. The main barrier is its high energy requirement (1.4 kWh/m3 of treated greywater). Chemicals for disinfection and desludging will not be considered in the assessment, as there is not enough data for their environmental impacts. The energy needed for pumping the treated water is not considered because it is too small compared with energy requirement of the MBR (less than 0.1%).

Environmental performance

According to the data from Schweizerischer Verein des Gas- und Wasserfaches (SVGW) cited in EcoWater Deliverable 3.3 (Hugi, et al., 2013), the water consumption in Waedenswil is assumed with 162 litres per person and day, from which about 48 L/person/day are used to flush the toilets, 32 L/person/day are used in bath or shower, and 21 L/person/day for wash basin.

With the implementation of the new technology, the water used for flushing toilets is 100% reused, which means that no primary water is demanded for flushing toilets. With the implementation of this technology, 42% of the cold water could be saved, as shown in Table 74.

Table 74: Water and energy consumption comparison for grey water reuse

Parameter	Baseline	After technology implementation	Unit	Water saved in %
Primary water used flushing toilets per person	48	0	L/day	100
Water used in bath or shower per person	32	32	L/day	-
Water used in wash basin per person	21	21	L/day	-
Drinking water demand per person	162	114	L/day	30
Waste water produced per person	145.8	102.6	L/day	30
Total water demand by domestic users	1,168,000	824,608	m^3/year	30
Cold water demand by domestic users	817,600	474,208	m^3/year	42
Warm water demand by domestic users	350,400	350,400	m^3/year	0
Electricity consumption by domestic users	0	1.4	kWh/m^3	-

Economic performance

The cost-effectiveness of greywater systems is as variable as the systems themselves. The amount of money saved will depend on volume of water saved, price of the mains, water replaced and costs of installing, running and maintaining the greywater system. Payback times for one single household can reach up to more than 50 years, well beyond most technologies life time (according to the citations in EcoWater Deliverable 3.3).

The costs for a grey water reuse system like the one depicted in Figure 34 (Zadeh, Lombardi, Hunt, & Rogers, 2012) are shown in Table 75 in the second column. In the investment costs, the costs for tanks, pipes, filters, pumps and the MBR are included. A design life of 15 years was assumed for the system. The annual operational costs include maintenance, chemicals, replacements of equipment and desludging. These costs were roughly transferred to the Waedenswil case study assuming that the investment and operational costs are in the same range per household as in for 200 households found in literature and that 100% of households implement the greywater reuse technology. The cost for electricity were estimated on the basis of the consumption of 1.4 kWh/m^3 of treated greywater and 48 L per day required for toilet flush as shown in Table 74. The costs for Waedenswil are shown in the third column of Table 75. As area-wide greywater reuse is considered a new technology for Waedenswil, no baseline costs are considered.

Table 75: Cost components for grey water reuse systems from literature values and extrapolation to households in Waedenswil for the actor domestic water users

Parameter	Greywater reuse for 200 households	Greywater reuse for 9,091 households in Waedenswil	Unit*
Investment costs			
Investment cost	102,000	4,600,000	€
Lifetime	15	15	years
Discount rate	2.5	2.5	%/year
Annualised investment costs	8,200	371,526	€/year
Annual operation and maintenance costs			
Fixed costs (incl. maintenance)	3,400	112,500	€/year
Cost of productive inputs - electricity	1,400	73,582	€/year
Annual savings (-)			
Savings in costs for drinking water	n.a.	-418,938	€/year
Savings in costs for wastewater	n.a.	-451,217	€/year
Total annual additional costs (+)/ savings (-)			
Total savings	n.a.	- 312,548	€/year

*To convert the cost from the literature source (Zadeh, Lombardi, Hunt, & Rogers, 2012), the average exchange in 2012 was used (1£=1.23€) and rounded

Results

Table 76 presents the environmental performance indicators in the baseline and after the implementation of the greywater reuse technology. While the fossil fuels depletion and eutrophication indicators increase slightly, the remaining indicators decrease or stay the same. The increase in the environmental performance indicators can be attributed to the increased energy consumption after implementation of the greywater reuse system. The decrease in the environmental performance indicators can be attributed mainly to the lower freshwater consumption, with a significant decrease in environmental impact of the freshwater resource depletion indicator by more than 20%.

Table 76: Environmental performance indicators of baseline and technology CS4T4

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6'728.01	6'732.40	0.065%
Fossil Fuels Depletion (MJ)	95,093,418	95,099,478	0.006%
Freshwater Resource Depletion (m^3)	79,388	62,218	-21.628%
Eutrophication ($kgPO_4eq$)	505,501	505,635	0.027%
Human Toxicity (kg1,4-DBeq)	558,840	558,539	-0.054%
Acidification ($kgSO_2eq$)	11,683	11,683	-0.001%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	160,015	-0.655%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0128	-0.012%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	418	-0.036%
Respiratory Inorganics ($kgPM_{10},eq$)	1,995	1,995	-0.032%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	656	0%
Micropollutants (kg)	60	60	0%

Table 77 presents the economic performance in the baseline and after the implementation of the greywater reuse technology. While the value added of the actors Zweckverband and municipality drops due to the lower revenues caused by decreased water consumption, the value added of the domestic water users increases due to the cost savings in water consumption, which compensate for the investment and operation and management costs. However, the total value added of the whole system decreases compared to the baseline.

Table 77: Economic performance of baseline and technology CS4T4 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	-72,668	-72,802
Municipality	92,568	-631,903	-724,471
Domestic water users	1,451,193	1,763,741	312,548
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	2,023,898	-484,725

Table 78 shows the eco-efficiency performance indicators for the baseline and after the implementation of the greywater reuse technology. An improvement in eco-efficiency can only be observed in the freshwater resource depletion indicator with around 3%. All other indicators decrease by around 20%.

Table 78: Eco-efficiency performance indicators of baseline and technology CS4T4

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO$_2$eq)	372.86	300.62	-19.37%
Fossil Fuels Depletion (€/MJ)	0.03	0.02	-19.33%
Freshwater Resource Depletion (€/m^3)	32	33	2.94%
Eutrophication (€/kgPO$_4$eq)	4.96	4.00	-19.34%
Human Toxicity (€/kg1,4-DBeq)	4.49	3.62	-19.28%
Acidification (€/kgSO$_2$eq)	215	173	-19.32%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	16	13	-18.79%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	1,998,326	-19.31%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	4,844	-19.29%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	1,015	-19.30%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	3,084	-19.32%
Micropollutants (€/kg)	41,810	33,732	-19.32%

Figure 35 shows the eco-efficiency performance of the greywater reuse technology compared to the baseline for the whole system. As discussed, an improvement is estimated only in the indicator freshwater resource depletion.

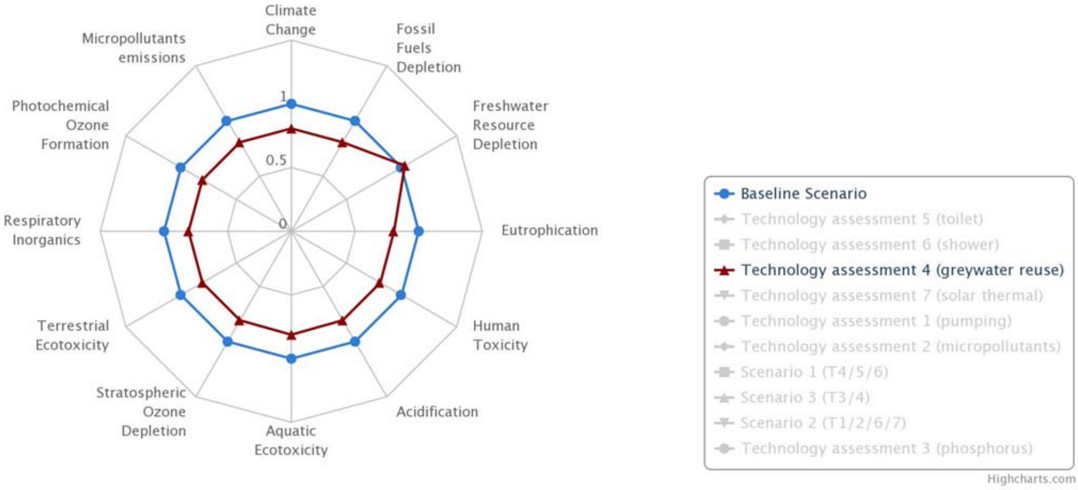


Figure 35: Eco-efficiency performance comparison of the whole system

Figure 36 shows the eco-efficiency of the greywater reuse technology for domestic water users. This actor faces the investment as well as operation and management costs, but also profits from the savings through reduced freshwater consumption and wastewater generation. This economic performance seems to compensate for the decrease in the environmental impact indicator, so that the eco-efficiency for the domestic water users increases in all categories.

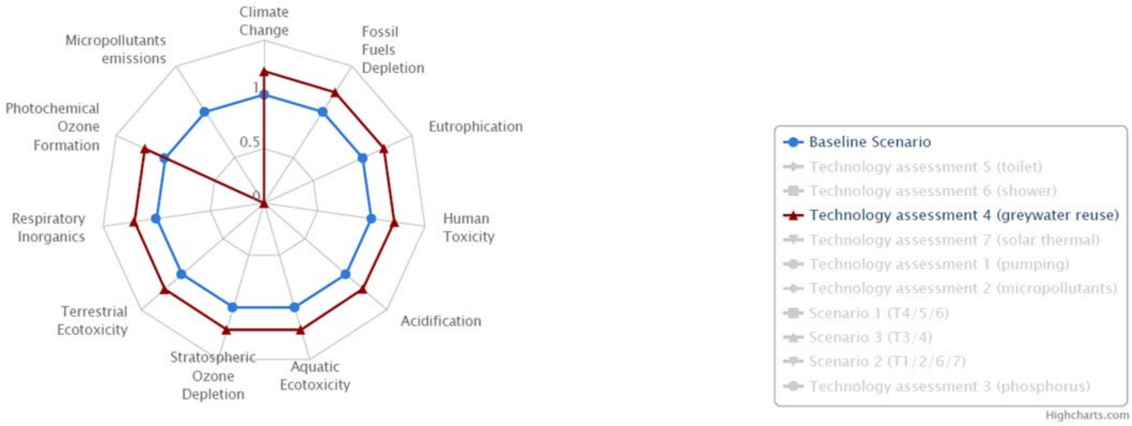


Figure 36: Eco-efficiency performance for domestic water users

The results of the economic performance show that this technology seems not to be very attractive for the whole system at the moment. The TVA drops by around 20% and the water provider has economic losses in the short term. As the water services have to be cost-covering, on the long term the water operator will raise the tariff, so that the drinking water price per m^3 for the water users will increase.

3.2.5 Water saving appliances for domestic water users – cold water (CS4T5)

Short description

One of the main use purposes of cold water is the flushing of toilets. To reduce the amount of drinking water used for this purpose, ultra-low-flush toilets can be implemented in households. This new type of toilet works with the principle of tank type siphoning toilet, reducing the required water volume per flush to below 4 litres.

Main assumptions

Proposed technical implementation

According to data, in Waedenswil are 9,091 households. The amount of 2.2 people per household and of 1.5 toilets per household is assumed. The average consumption for flushing toilet per person is 47.8 L/person per day (calculated in EcoWater Deliverable 3.3). It was further assumed that each person flushes the toilet about 5 times per day.

For Waedenswil it was assumed that households have different toilets with different tank capacities. To be coherent with previous numbers, the following assumptions were made:

- Number of households with 12 L tank toilet: 4,091 HHs (45%)
- Number of households with 8L tank toilet: 4,545 HHs (50%)
- Number of households with 4L tank toilet: 455 HHs (5%)

For the assessment of the potential of the ultra-low-flush toilets, it was assumed that 100% of households use ultra-low flush toilets, as shown in Table 79.

Environmental performance

The low flush toilet technology reduces the environmental impacts connected with drinking water production and wastewater treatment. Water saving will decrease the amount of fresh water consumed (freshwater resource depletion) and energy used for drinking water generation. The use of this technology implies not only water saving as a resource, but also the energy and chemicals savings involved in the drinking water treatment and in the wastewater treatment. With the implementation of the 4-litres toilets, and according with assumptions set before, the amount of water saved for flushing toilets is 58%. It represents a saving of 18% of total drinking water consumption.

Table 79: Water consumption comparison for full potential of low flush toilet technology

	Baseline				With new technology fully implemented			
Kind of toilet	Number of HHs	%	Total water consumption	units	Number of HHs	%	Total water consumption	units
12 L toilet	4,091	45%	540,012	L/day	-	-	-	L/day
8 L toilet	4,545	50%	400,048	L/day	-	-	-	L/day
4 L toilet	455	5%	20,020	L/day	9,091	100%	400,004	L/day
Consumption for flushing			350,500	m^3/year	146,000			m^3/year

Economic Performance

According to data from EcoWater Deliverable 3.3 (Hugi, et al., 2013) the costs for a 4-liters toilet are in the range from 110 - 340 €. In the following, average costs of 250 € are assumed, which means that the prices are similar as for common toilets. On the other hand, the considerable savings of water and the smaller volumes of generated wastewater reduce operation cost significantly. As a conservative assumption, the same maintenance costs as the standard toilets will be considered.

Table 80: Costs of ultra-low flush toilets technology for the actor domestic water users

Parameter	After technology implementation per device	After technology implementation for 95% of households	Unit
Investment cost			
Investment costs for replacement of 12L toilets (1/3)	83	511,375	€
Investment costs for replacement of 8L toilets (1/2)	125	852,375	€
Total investment costs	-	1,363,750	€
Lifetime	30	30	years
Interest rate	2.5	2.5	%/year
Annualised investment costs	12	65,157	€/year
Annual operation and maintenance cost			
Fixed costs (incl. maintenance)	0	0	€/year
Cost of productive inputs	0	0	€/year
Annual savings			
Savings in drinking water costs	n.a	249,368	€/year
Savings in wastewater costs	n.a	268,582	€/year
Total annual additional costs (+)/ savings (-)			
Total savings	n.a	452,793	€/year

Source: EcoWater Deliverable 3.3

To calculate the investment costs of domestic water users, an average of 1.5 toilets per household was assumed. According to Table 79 for the baseline it is assumed that 5% of the households have currently already ultra-low flush toilet. This means that to estimate the full potential of the technology the remaining 95% of households (8,636) will have to change their toilets to low-flush technology too. As all households have already toilets, only the additional costs for the toilets renewal are taken into account. These are calculated according to the expected point in time of change. It is assumed that households with 12 L toilets will change to the new technology after 20 of 30 years lifetime of the toilet, while the households with 8 L toilet will change after 15 of 30 years of lifetime. Therefore, only additional cost for the new technology, of one third or one half of the initial price of 250 €, respectively, will be considered. The expected costs are presented in Table 80.

Results

In Table 81 the environmental performance indicators of the baseline and after the implementation of the low-flush toilet technology are presented. All indicators, except the micropollutants indicator decrease due to the reduced amount of freshwater used and the corresponding reductions in energy and material consumption for drinking water supply and wastewater treatment. The biggest change of around 13% concerns the indicator freshwater resource depletion.

Table 81: Environmental performance indicators of baseline and technology CS4T5

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6'728.01	6'705.72	-0.3%
Fossil Fuels Depletion (MJ)	95,093,418	94,987,855	-0.11%
Freshwater Resource Depletion (m^3)	79,388	69,168	-12.87%
Eutrophication ($kgPO_4eq$)	505,501	505,633	0.03%
Human Toxicity (kg1,4-DBeq)	558,840	558,354	-0.09%
Acidification ($kgSO_2eq$)	11,683	11,635	-0.41%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	160,371	-0.43%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0128	-0.01%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	417	-0.23%
Respiratory Inorganics ($kgPM_{10},eq$)	1,995	1,987	-0.42%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	654	-0.29%
Micropollutants (kg)	60	60	0%

Table 82 presents the economic performance per actor in the baseline and after the implementation of the low-flush toilet technology. While the economic performance decreases for the actors Zweckverband and municipality, it increases for the domestic water users. The overall TVA decreases slightly by around 1%.

Table 83 present the eco-efficiency indicators for the baseline and after the implementation of the low-flush toilet technology. The indicator freshwater resource depletion rises by about 14%, all other indicators decrease very slightly, all below 1%.

Table 82: Economic performance of baseline and technology CS4T5 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	-43,201	-43,335
Municipality	92,568	-338,665	-431,233
Domestic water users	1,451,193	1,903,986	452,793
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	2,486,849	-21,774

Table 83: Eco-efficiency indicators of baseline and technology CS4T5

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO_2eq)	372.86	370.85	-0.5%
Fossil Fuels Depletion (€/MJ)	0.0264	0.0262	-0.76%
Freshwater Resource Depletion (€/m^3)	31.60	35.95	13.78%
Eutrophication (€/kgPO_4eq)	4.9626	4.9183	-0.89%
Human Toxicity (€/kg1,4-DBeq)	4.4890	4.4539	-0.78%
Acidification (€/kgSO_2eq)	214.72	213.74	-0.46%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57	15.51	-0.44%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	2,455,309	-0.86%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	5,964	-0.64%
Respiratory Inorganics (€/kgPM_{10},eq)	1,257	1,251	-0.45%
Photochemical Ozone Formation (€/kgC_2H_4,eq)	3,822	3,800	-0.58%
Micropollutants (€/kg)	41,810	41,447	-0.87%

Figure 37 shows the eco-efficiency performance in the baseline and after the implementation of the low-flush toilet technology for the whole system. As discussed, only the freshwater resource depletion indicator improves, while other indicators almost remain the same.

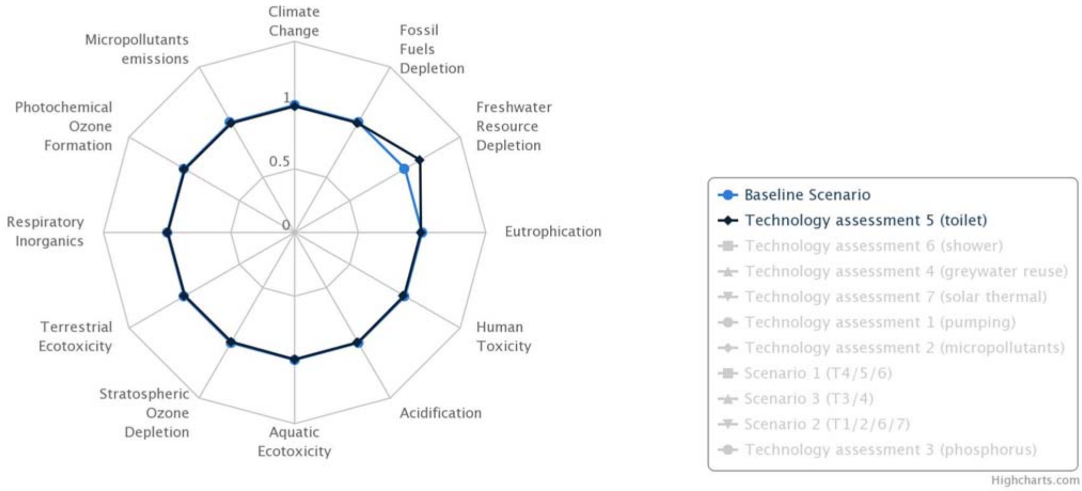


Figure 37: Eco-efficiency performance comparison of the whole system

Figure 38 shows the eco-efficiency in the baseline and after the implementation of the low-flush toilet technology for domestic water users. All indicators show an improvement in the eco-efficiency for this actor.

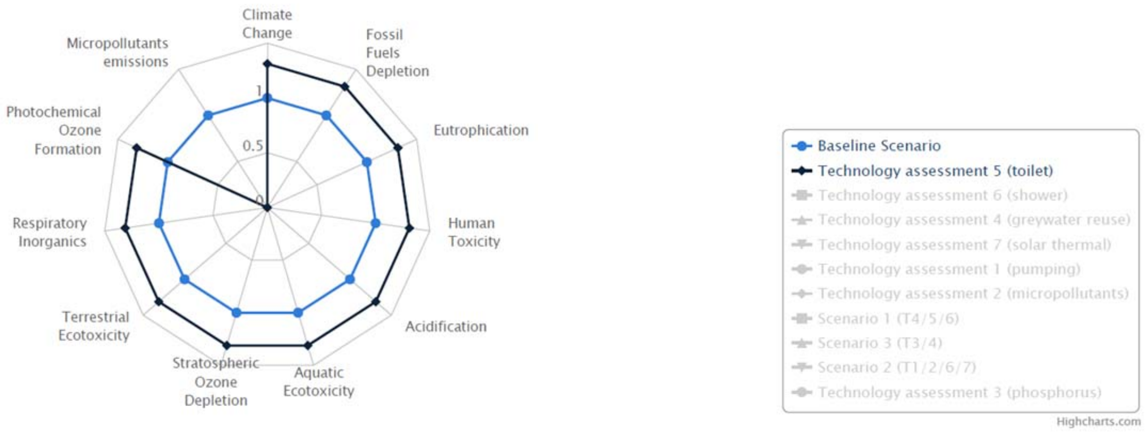


Figure 38: Eco-efficiency performance for domestic water users

To sum up, the ultra-low-flush toilet technology is an efficient technology for the domestic water users. It can be anticipated that the technology will be implemented subsequently by the domestic water users whenever old toilets flushing systems have to be replaced. As in other cases already shown, the water and wastewater tariff will be however increased in the long run which will reduce the benefits for the domestic water users.

3.2.6 Water saving appliances for domestic water users – warm water (CS4T6)

Short description

Innovative showerheads reduce the volume flow required by including a flow regulator; other showerhead models use air to improve the shower performance at lower water consumption. These technologies could be applied in all households to reduce the warm water consumption.

Main assumptions

Proposed technical implementation

According to data from the baseline, average consumption for bath or shower is 31.8 L/person/day. It is assumed that 30% of households have already new shower heads implemented. It means that in the baseline, 70% of the households use 34.8 L/person/day (old shower heads) and 30% of the households use 24.8 L/person/day (new shower heads). With total implementation of the technology proposed, 100% of households will use 24.8 L/person/day as shown in Table 84.

Table 84: Water consumption comparison for new shower head technology

	Baseline				**After technology implementation**			
Kind of shower hear	Number of HHs	%	Average water consumption	units	Number of HHs	%	Average water consumption	units
Old	6,364	70%	34.8	L/p/day	0	0%	-	
New	2,727	30%	24.8	L/p/day	9,091	100%	24.8	L/p/day
Consumption for shower			232,140	m^3/year	181,040			m^3/year

Environmental performance

The water saving shower head saves 10 litres/person/day, which leads to warm water savings of 22% in shower or bath. Compared with the total amount of warm water used per household (for different uses as dishwasher or washing machine) the water saved is around 15%, which leads to 4% of water saving from total drinking water distributed to the domestic users. Compared to the total water distributed to all the consumers (domestic and non-domestic) the savings represent 3.2% of total. Warm water savings in bath or shower are also connected with the energy saving, as showering requires around 35-70 kWh/m3, according to Beal et al., 2012 cited in (Hugi, et al., 2013).

Economic performance

To calculate the total investment cost of implementation of new shower heads for domestic water users, an average of one showerhead per household was assumed. According to baseline assumed in Table 84, 30% of the households currently have already water saving shower heads, which means that for a total implementation 70% of households (6,364) will change their shower heads to the suggested new technology. It is assumed that the water saving shower heads have the double price than the conventional shower heads. Therefore, only the additional investment costs were taken into account. The costs are presented in Table 85.

Table 85: Costs of new shower heads technology for 6,364 households for the actor domestic water users

Parameter	In Baseline per device	After technology implementation per device	After technology implementation for total area	Unit
Investment cost				
Investment costs	10	20	63,640	€
Lifetime	10	10	10	years
Interest rate	2.5	2.5	2.5	%/year
Annualised investment costs	1.14	2.29	7,271	€/year
Annual operation and maintenance cost				
Fixed costs (incl. maintenance)	-	-	-	€/year
Cost of productive inputs	-	-	-	€/year
Annual savings (-)				
Savings in energy costs	n.a.	n.a.	-244,350	€/year
Savings in drinking water costs	n.a.	n.a.	-64,123	€/year
Savings in wastewater costs	n.a.	n.a.	-69,064	€/year
Total annual additional costs (+)/ savings (-)				
Total savings	n.a.	n.a.	370,265	€/year

Source: EcoWater Deliverable 3.3

Results

Table 86 presents the environmental performance in the baseline and after implementation of the new shower heads technology. All indicators except the micropollutants indicator show a decrease in the environmental impact which is due to the reduced drinking water and even more due to the saved energy for water heating.

Table 86: Environmental performance indicators of baseline and technology CS4T6

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6'728.01	5'840.72	-13%
Fossil Fuels Depletion (MJ)	95,093,418	81,637,255	-14%
Freshwater Resource Depletion (m^3)	79,388	76,760	-3%
Eutrophication (kgPO_4eq)	505,501	430,860	-15%
Human Toxicity (kg1,4-DBeq)	558,840	476,790	-15%
Acidification (kgSO_2eq)	11,683	10,138	-13%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	138,089	-14%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	0.8665	-14%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	359	-14%
Respiratory Inorganics (kgPM_{10},eq)	1,995	1,731	-13%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	566	-14%
Micropollutants (kg)	60	60	0%

Table 87 presents the economic performance in the baseline and after the implementation of the new showerhead technology. While the economic performance of domestic water users, rises, the economic performance of Zweckverband and municipality drops. Nevertheless, the total value added rises by almost 10%. In this case, additional value is created due to the fact that the savings on energy are higher than on water. The value generated by the energy market is outside the system boundaries. So, if the consumption of outside materials such as energy can be reduced, more value can be created inside the system.

Table 87: Economic performance of baseline and technology CS4T6 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	-11,009.	-11,143
Municipality	92,568	-18,321	-110,888
Domestic water users	1,451,193	1,821,459	370,265
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	2,756,857	248,234

Table 88 presents the eco-efficiency in the baseline and after implementation of the new showerhead technology. Due to the increase of the total value added and almost all environmental impact indicators, all eco-efficiency performance indicators improve by 10 to 30%.

Table 88: Eco-efficiency performance indicators of baseline and technology CS4T6

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO$_2$eq)	372.86	472.01	26.59%
Fossil Fuels Depletion (€/MJ)	0.026	0.034	28.01%
Freshwater Resource Depletion (€/m^3)	32	36	13.66%
Eutrophication (€/kgPO$_4$eq)	5.0	6.4	28.93%
Human Toxicity (€/kg1,4-DBeq)	4.5	5.8	28.81%
Acidification (€/kgSO$_2$eq)	215	272	26.65%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	16	20	28.18%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	3,181,773	28.47%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	7,669	27.76%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	1,593	26.70%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	4,867	27.32%
Micropollutants (€/kg)	41,810	45,948	9.90%

Figure 39 shows the change in the eco-efficiency performance from baseline to the situation after the new showerhead technology implementation for the whole system. As discussed before, all indicators are improved after technology implementation.

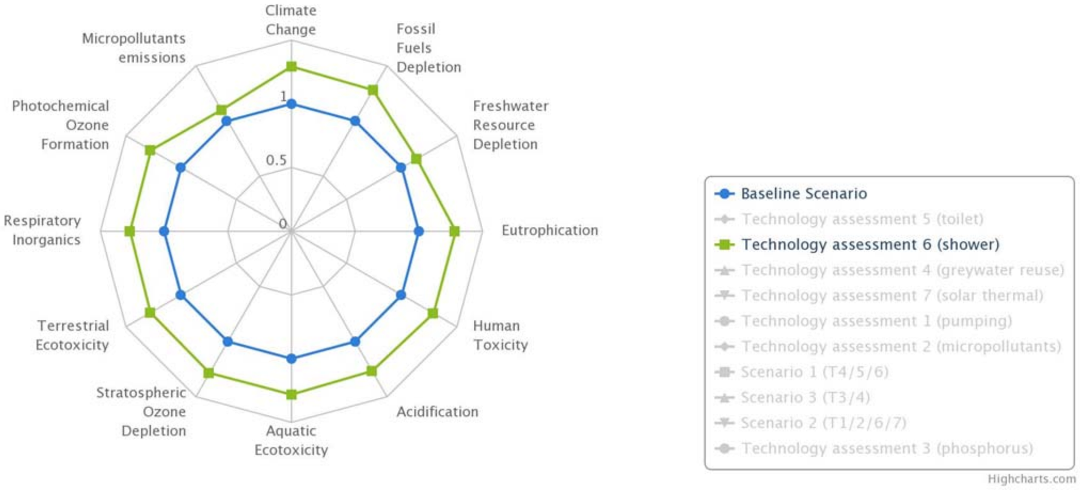


Figure 39: Eco-efficiency performance comparison of the whole system

Figure 40 shows the change in the eco-efficiency performance from baseline to the situation after the new showerhead technology implementation for domestic water users. Similarly as for the whole system, all indicators are improved.

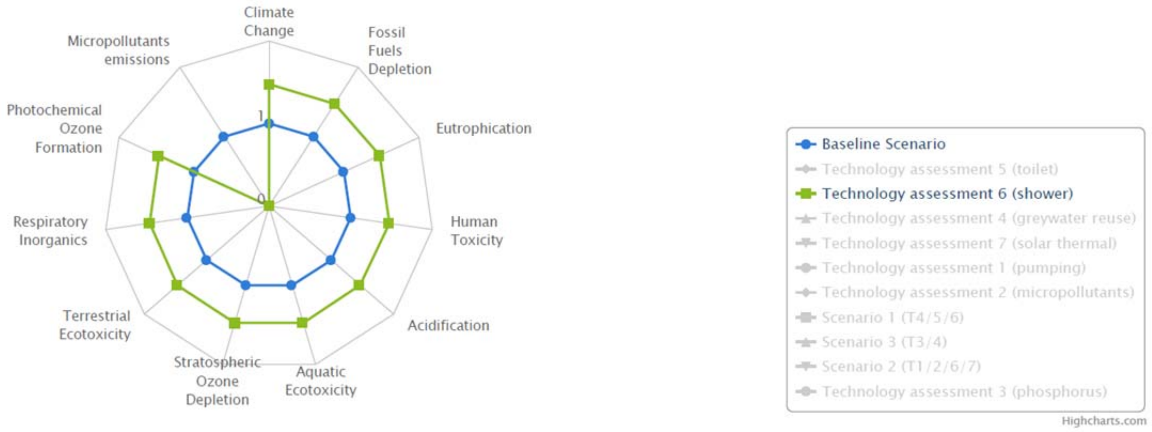


Figure 40: Eco-efficiency performance for domestic water users

The special aspect of the showerhead technology is that it does not only save water, but also energy for heating the water. Although some actors face losses and some gains, the total value added to the system rises. This is because more additional value is created due to the savings on energy than lost due to the lower water consumption. As the value generated by the energy market is outside the system boundaries, more value can be created inside the system if the consumption of outside materials such as energy can be reduced.

3.2.7 Solar thermal water heating (CS4T7)

Short description

Solar water heating systems use solar collectors to capture sunlight to heat water that is then moved from the collector to storage and then to its point of use. Solar collectors can be combined with every other type of heat production equipment, such as wood-fired ovens, heat-pumps, oil or gas-fired boilers. These backup heating systems can be used at times when the sun does not provide enough energy. Solar thermal installations can be used for several purposes - for heating up domestic hot water, for the heating of swimming pools and many other applications (Swissolar, 2014).

Main assumptions

According to the Municipal Energy Plan (Waedenswil, 2009) domestic water users are subdivided in four clusters according to the source of energy for water heating: domestic water users with electric water heating (5% of households), with gas water heating (37%), with oil water heating (55%) and with alternative water heating (3%) as shown in Table 89. Solar water heating is included in the alternative water heating and represents at the moment less than 1%.

Table 89: Energy consumption for domestic water heating in the baseline (annual values)

Parameter	Unit	Electric water heating	Gas water heating	Oil water heating	Alternative water heating
Share of energetic source for water heating	%	5	37	55	3
Number of households	amount	455	3,363	5,000	273
Inputs					
Total drinking water consumption	m^3	58,394	432,117	642,336	35,036
Cold water consumption (70%)	m^3	40,876	302,482	449,635	24,526
Hot water consumption (30%)	m^3	17,518	129,635	192,701	10,511
Electricity for direct water heating	kWh	1,064,774	0	0	0
Gas for water heating	kWh	0	7,879,329	0	0
Oil for water heating*	kWh	0	0	11,334,696	0
Electricity for alternative water heating	kWh	0	0	0	127,800
Solar energy for alternative water heating	kWh				511,148
Total amount of energy for water heating	kWh				21,000,000

*The energy content of oil is was calculated with 1kg=12kWh, given 944,558kg*12

Environmental performance

For the technology assessment it is assumed that all households will use the maximum theoretical potential and implement a solar thermal water heating technology. As the solar thermal systems have to be supported by conventional ones in case that there is not enough solar radiation, 10% of energy for water heating will be supplied by gas and oil further on.

Table 90: Energy consumption for domestic water heating technology scenario (annual values)

Parameter	Gas water heating	Oil water heating	Solar thermal water heating	Unit
Share of energetic source for water heating	5	5	90	%
Number of households	455	455	8,182	amount
Inputs				
Drinking water consumption	58,401	58,401	1,051,211	m^3
Cold water consumption (70%)	40,880	40,880	735,847	m^3
Hot water consumption (30%)	17,520	17,520	315,363	m^3
Electricity for direct water heating	-	-	-	kWh
Gas for water heating	1,064,891	-	-	kWh
Oil for water heating*	-	1,030,536	-	kWh
Electricity for solar thermal water heating			3,833,609	kWh
Solar energy for alternative water heating	-	-	15,334,436	kWh
Total amount of energy for water heating	-	-	21,000,000	kWh

*The energy content of oil is was calculated with 1kg=12kWh, given 85,878kg*12

Additionally, it is assumed that solar thermal water heating systems requires around 20% of electricity/energy compared to a conventional system to heat one m^3 of water. The rest of the energy is supplied by the sun (about 80%). To cover 90% the required energy by solar thermal water heating, the required amount of electric energy in Waedenswil is around 4 Mio kWh per year, using more than 15 Mio kWh from the sun.

Economic

It is assumed that one square meter ($1m^2$) of solar water heating collector produces 350 kWh of heat energy per year. To cover the amount of solar energy required in Waedenswil for water heating, a total area of around 44,000 m^2 will be required. The investment costs per m^2 of collector area are around 1,300 Euro, including hardware and installation costs, as additional cost compared with a conventional solution. Subsidies and tax reductions have already been subtracted from these costs. This is done because the subsidies and tax reductions are paid mainly outside the system boundaries by cantonal or even national actors. So while reducing the investment costs inside the system boundaries, these costs still occur outside. It is further assumed that the conventional water heating systems will be replaced after the first half of their lifetime of 25 years, therefore only half of the investment costs for the new solar thermal water heating system are taken into account. The lifetime of the collectors is indicated to be 25 years. The investment, operational and total costs are given in Table 91.

Table 91: Costs of solar water heating (Swissolar, 2014)

Parameter	Baseline costs for conventional systems	Additional costs after technology implementation per m^2	After technology implementation for 100% of households	Unit*
Investment cost				
Investment costs	30,000,000	1,300/2	28,000,000	€
Lifetime	25	25	25	years
Interest rate	2.5	2.5	2.5	%/year
Annualized investment costs	1,628,278	70	1,519,726	€/year
Annual operation and maintenance cost				
Fixed costs (incl. maintenance)	600,000	14	same as in baseline	€/year
Cost of productive inputs (electricity)	n.a.	n.a.	548,726	€/year
Annual savings (-)				
Savings electricity	n.a.	n.a.	-160,308	
Savings gas	n.a.	n.a.	-341,990	€/year
Savings oil	n.a.	n.a.	-987,252	€/year
Total annual additional costs (+)/ savings (-)				
Total costs	n.a.	n.a.	606,261	€/year

The investment costs of this technology are rather high. However, after the implementation of solar thermal water heating in all households, the cost for oil and gas for water heating are reduced considerably. The investment cost per household are around 3,000 Euro and the maintenance and electricity cost around 56 Euro per household per year each. The savings on gas and oil are about 145 Euro per year.

Results

Table 92 presents the environmental performance indicators in the baseline and after the implementation of the thermal water heating technology. All environmental impacts, except for the micropollutants and the freshwater resource depletion are decreased in this case. This is due to the fact that the consumption of fossil fuels has been considerably reduced and substituted by solar energy. The increase in electricity consumption does not seem to have a considerable negative effect on the environmental impact indicators.

Table 92: Environmental performance indicators of baseline and technology CS4T7

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (tCO_2eq)	6,728.01	1,783.64	-73%
Fossil Fuels Depletion (MJ)	95,093,418	16,573,380	-83%
Freshwater Resource Depletion (m^3)	79,388	79,388	0%
Eutrophication ($kgPO_4eq$)	505,501	54,874	-89%
Human Toxicity (kg1,4-DBeq)	558,840	74,768	-87%
Acidification ($kgSO_2eq$)	11,683	3,063	-74%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	24,168	-85%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	0.1467	-86%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	78	-81%
Respiratory Inorganics ($kgPM_{10},eq$)	1,995	514	-74%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	145	-78%
Micropollutants (kg)	60	60	0%

Table 93 represents the economic performance per actor in the baseline and after implementation of the thermal water heating technology. The technology implementation reduces the value added of the domestic water users and the total value added of the system considerably, by almost 25%. This is due to the very high investment costs and the maximum implementation rate assumption.

Table 93: Economic performance of baseline and technology CS4T7 per actor in € per year

Actor	Baseline Scenario	Technology assessment	Change
Zweckverband	134	134	0
Municipality	92,568	92,568	0
Domestic water users	1,451,193	844,932	-606,261
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	1,902,362	-606,261

Table 94 presents the eco-efficiency performance indicators in the baseline and after the thermal water heating technology implementation. The indicators show different tendencies. While the eco-efficiency in freshwater resource depletion and micropollutants indicators decreases by 24%, it improves very differently in other indicators.

Table 94: Eco-efficiency performance indicators of baseline and technology CS4T7

Indicator	Baseline Scenario	Technology assessment	Change
Climate Change (€/tCO$_2$eq)	372.86	1'066.56	186%
Fossil Fuels Depletion (€/MJ)	0.03	0.11	335%
Freshwater Resource Depletion (€/m^3)	32	24	-24%
Eutrophication (€/kgPO$_4$eq)	5	35	599%
Human Toxicity (€/kg1,4-DBeq)	4	25	467%
Acidification (€/kgSO$_2$eq)	215	621	189%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	16	79	405%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	12,967,360	424%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	24,338	305%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	3,704	195%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	13,132	244%
Micropollutants (€/kg)	41,810	31,706	-24%

Figure 41 shows the change in the eco-efficiency performance from baseline to the situation after thermal water heating technology implementation in the whole system. As discussed before, the indicators show very diverse tendencies.

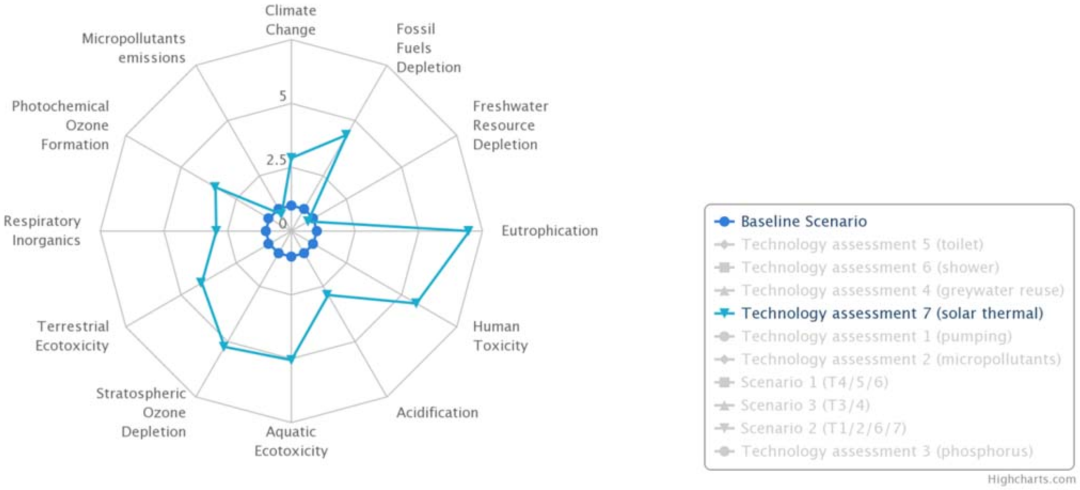


Figure 41: Eco-efficiency performance comparison for the whole system

Figure 42 shows the eco-efficiency performance for the baseline and after the implementation of the thermal water heating technology for domestic water users. Here all the eco-efficiency is higher in all indicators, except the micropollutants emissions, as the technology does not have any influence on it.

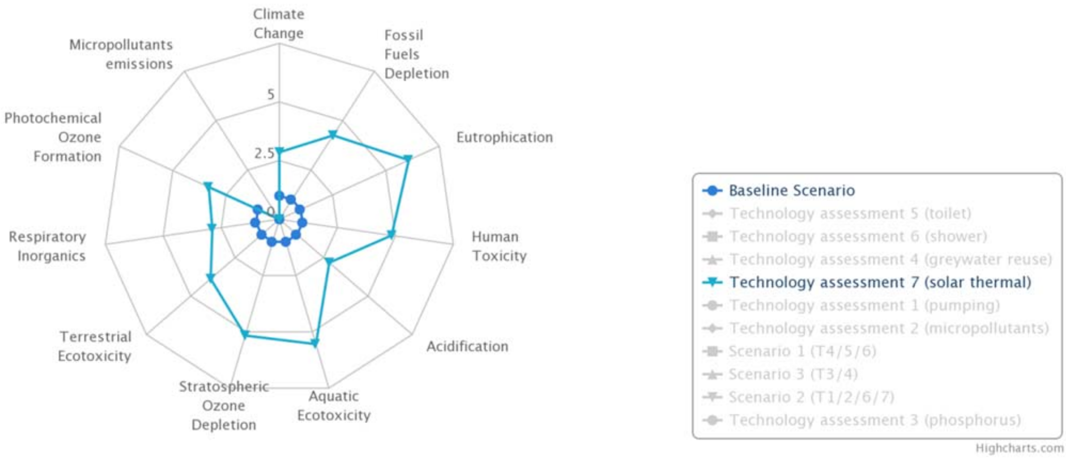


Figure 42: Eco-efficiency performance for domestic water users

With the high penetration rate the solar thermal heating technology does not seem to be efficient in economic terms. However, the technology brings considerable environmental improvements. This leads to an increase in eco-efficiency for the whole system as well as for the domestic water users.

3.3 Assessment of technology scenarios

In the project it was agreed that the future scenarios shall follow three different goals: resource efficiency, pollution prevention and circular economy. The technologies assessed in the previous section have been assigned to serve one or more of these goals according to their performance regarding the influence on specific environmental impact indicators. Two of the twelve indicators used, namely the freshwater and the fossil fuels depletion indicators are representing the **resource efficiency** dimension for the foreground system. The background values for all indicators may refer to both, **resource efficiency** and **pollution prevention**. None of the indicators given represents directly the issue of **circular economy**. The assessed technologies have been assigned to the given goals as shown in Table 95, although there were manifold combinations to assign the technologies to the goals of the three scenarios.

Table 95: Scenarios and assigned technologies in case study 4

Scenario	Technologies CS4
1. Resource efficiency	• SC4T6 Water saving appliances (warm water) • SC4T5 Water saving appliances (cold water) • SC4T4 Water reuse and recycling technologies
2. Pollution prevention	• SC4T6 Water saving appliances (warm water) • SC4T7 Solar water heating • SC4T2 Micropollutants removal technologies • SC4T1 Smart pumps
3. Circular economy	• SC4T4 Water reuse and recycling technologies • SC4T3 Advanced phosphorus recovery

The “Resource efficiency”- scenario aims at a more efficient use of resources, which are in this case water and fossil fuels. Both are represented by the indicators freshwater resources and fossil fuels depletion. The assessed technologies “greywater reuse” and “water saving toilets” could improve both the indicator freshwater resources depletion by up to 22% or 13%, respectively. The assessed “shower heads” technology could improve the indicator fossil fuels depletion by up to 14%. All three technologies are therefore assessed under the scenario 1, which aims at resource efficiency.

The “Pollution prevention” scenario aims at protection of the environment against pollution. Ten out of twelve indicators show the change in environmental pollution or negative effects on human health. All technologies assigned to the scenario 2 in Table 95 have mainly a positive effect on these indicators. Therefore in this scenario, the technologies solar water heating, micropollutants removal at WWTP, smart pumping for water distribution and warm water saving appliances are studied. The first technology reduces environmental pollution of water heating processes, replacing gas, oil and electric water heating with the less pollutant solar water heating. The micropollutants removal technology reduces the direct emissions of micropollutants into treated wastewater receiving water bodies. Smart pumping reduces pollution through reduction of electricity consumption and the more efficient shower heads prevent pollution from water heating.

The “Circular economy” scenario aims at closing the loops of energy and resources and or at treating waste as potential resource. In the urban water cycle this can be achieved if drinking water is reused or recycled or if the phosphorus contained in the sewage sludge of WWTP is recovered.

For all scenarios the time frame of ten years is used. This means that the scenarios are studied for the year 2021 compared to the baseline of 2011.

3.3.1 Technology scenario focusing on resource efficiency

The “Resource efficiency” scenario focuses in the more efficient use of resources, which are in this case water and fossil fuels. Therefore, in this scenario the greywater reuse technology and water saving appliances are included. All of these technologies reduce primarily the used amount of drinking water resources. The time horizon for the implementation of the technologies is the year 2021.

Environmental performance

For ultra-low flush toilets, the assumption for the scenario 1 is that the use of 12-litres toilets will be abandoned, the share of households with 8-litres toilets will decrease from 50% to 30% of total and 70% instead of 5% of households will introduce 4-litres toilets (see Table 96).

Table 96: Assumption for toilets (CS4T5)

Toilet	Baseline	Scenario
12 litres toilet	45%	0%
8 litres toilet	50%	30%
4 litres toilet	5%	70%

With these assumptions the water used for flushing toilets drops from 48 litres per person per day in the baseline to 26 litres per person per day in scenario 1. This leads to savings of 20% of cold water used by the domestic users and a reduction of 14% of total drinking water demand of domestic water users.

For new showerheads, it is assumed that 60% of the population, instead of 30% in the baseline, will use the new technology until 2021; therefore 40% of them will still use old showerheads.

Table 97: Shower heads assumptions (SC4T6)

Shower head	Average water consumption		Baseline		Scenario	
Old shower heads	34.8	[l/person/day]	70%	hh	40%	hh
New shower heads	24.8	[l/person/day]	30%	hh	60%	hh

With this assumption, the average amount of water used for shower and bath decreases by 9%, from 31.8 litres per person and day in the baseline, to 28.8 litres per person and day in the scenario 1. This saves 2% of total drinking water demand of domestic water users. The implementation of this technology leads also to a decreased consumption of fossil fuels as less warm water is used (see paragraph 3.2.6).

As the investment costs for the greywater reuse technology are still very high, it is assumed that only 10% of households will implement it. This means that 90% of households will still use drinking water for flushing the toilet.

In Table 98, the main water flows affected in scenario 1 after the application of the three chosen technologies with the assumption explained, are shown.

Table 98: Main water changes in Scenario 1

Water use	Baseline	Scenario	Units	Water saved in %
Water used for flushing toilets	48	23	L/person/day	51
Water used in bath/shower	32	29	L/person/day	9
Cold water demanded	113	89	L/person/day	22
Warm water demanded	49	46	L/person/day	6
Waste water produced	146	121	L/person/day	17

As it was explained in section 3.2.4, greywater reuse systems need extra electricity for the operation of the MBR. In this scenario, the amount of electricity demanded for the technology implementation is 3 kWh per household and year, which means that 1% more electricity than in the baseline is used.

As in this scenario the total water demand decreases, the water needed in the previous stages like water abstraction, water treatment and water distribution is decreasing, together with the energy consumption for pumping and amount of chemicals used for water treatment.

The reduction in the amount of wastewater from the domestic users affects also to the WWTP. Less wastewater produced per year means less energy and chemicals consumption for the water treatment.

Economic performance

For the water saving toilets technology, like in the technology assessment, it is assumed that all households already have toilets, therefore only the additional costs for the toilets renewal are taken into account. These are calculated according to the expected point in time of change. For the scenarios the time horizon of 10 years from baseline is modelled. Therefore, it is assumed that households will change their toilet flushing technology after a 20 to 30 years lifetime. As stated above, it is further assumed that all 12-liter households and only 50% of the 8-liter households will change the technology. Therefore, only additional cost for the new technology like in technology assessment, of one third of the initial price of 250 € were taken into account.

To calculate the investment cost of implementation of new shower heads for water domestic users in the scenario, an average price of one showerhead per household was assumed, like in baseline, whereas the water saving shower heads cost double the conventional shower heads. Therefore, only the additional investment costs were taken into account. As stated above, for new showerheads, it is assumed that 60% of the population, instead of 30% in the baseline, i.e. additional 2,728 households will change their shower heads to the suggested new technology until 2021.

As it was assumed above, 10% of households only will implement a greywater reuse technology. Therefore, the investment and operational cost for 909 households were considered in the scenario 1. The overall expected investment and operational costs as well as additional costs and savings in the scenario 1 are presented in Table 99Table 80.

Table 99: Expected costs in scenario 1

Parameter	T5 toilets	T6 showers	T4 greywater	Unit
Investment cost				
Investment costs	850,000	27,300	764,000	€
Lifetime	30	10	15	years
Interest rate	2.5	2.5	2.5	%/year
Annualised investment costs	40,611	3,119	61,706	€/year
Annual operation and maintenance cost				
Fixed costs (incl. maintenance)	0	0	11,000	€/year
Cost of productive inputs (electricity)	0	0	3,982	€/year
Annual savings				
Savings in costs for drinking water	-195,934	-26,718	-19,166	€/year
Savings in costs for wastewater	-211,031	-28,777	-20,643	€/year
Savings in costs for energy	n.a.	-103,790	0	€/year
Total annual additional costs (+)/ savings (-)				
Total saving			-485,641	€/year

Results

Table 100 represents the environmental performance indicators in the baseline and in the scenario focusing on resource efficiency. The environmental impacts are decreasing in all indicators except micropollutants, with the highest decrease in freshwater resource depletion with 13%.

Table 101 represents the economic performance of scenario 1 compared to the baseline. While the value added for the actors Zweckverband and municipality decreases, it increases for the domestic water users. As the latter is greater, the total value added to the system increases by around 10%.

Table 102 represents the eco-efficiency performance indicators of technology scenario 1 compared to the baseline. These show an increase in all indicators, especially for freshwater resource depletion of more than 15%.

Table 100: Environmental performance indicators of baseline and technology scenario 1

Indicator	Baseline Scenario	Scenario 1	Change
Climate Change (tCO$_2$eq)	6'728.01	6'341.26	-6%
Fossil Fuels Depletion (MJ)	95,093,418	89,405,149	-6%
Freshwater Resource Depletion (m^3)	79,388	69,438	-13%
Eutrophication (kgPO4eq)	505,501	474,476	-6%
Human Toxicity (kg1,4-DBeq)	558,840	524,260	-6%
Acidification (kgSO$_2$eq)	11,683	11,002	-6%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	150,895	-6%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	0.9518	-6%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	393	-6%
Respiratory Inorganics (kgPM$_{10}$,eq)	1,995	1,879	-6%
Photochemical Ozone Formation (kgC$_2$H$_4$,eq)	656	617	-6%
Micropollutants (kg)	60	60	0%

Table 101: Economic performance of baseline and technology scenario 1

Actor	Baseline Scenario	Scenario 1	Change
Zweckverband	134	-42,054	-42,188
Municipality	92,568	-327,256	-419,823
Domestic water users	1,451,193	1,936,834	485,641
Non-domestic water users	964,729	964,729	0
Total Value Added	2,508,623	2,532,253	23,629

Table 102: Eco-efficiency performance indicators of baseline and technology scenario 1

Indicator	Baseline Scenario	Scenario 1	Change
Climate Change (€/tCO$_{2e}$q)	372.86	399.33	7.10%
Fossil Fuels Depletion (€/MJ)	0.03	0.03	7.36%
Freshwater Resource Depletion (€/m^3)	32	36	15.41%
Eutrophication (€/kgPO4eq)	4.96	5.34	7.54%
Human Toxicity (€/kg1,4-DBeq)	4.49	4.83	7.60%
Acidification (€/kgSO$_2$eq)	215	230	7.19%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	16	17	7.75%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	2,660,409	7.42%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	6,446	7.40%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	1,348	7.21%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	4,101	7.30%
Micropollutants (€/kg)	41,810	42,204	0.94%

Figure 43 shows the eco-efficiency performance of scenario 1 compared to the baseline of the whole system.

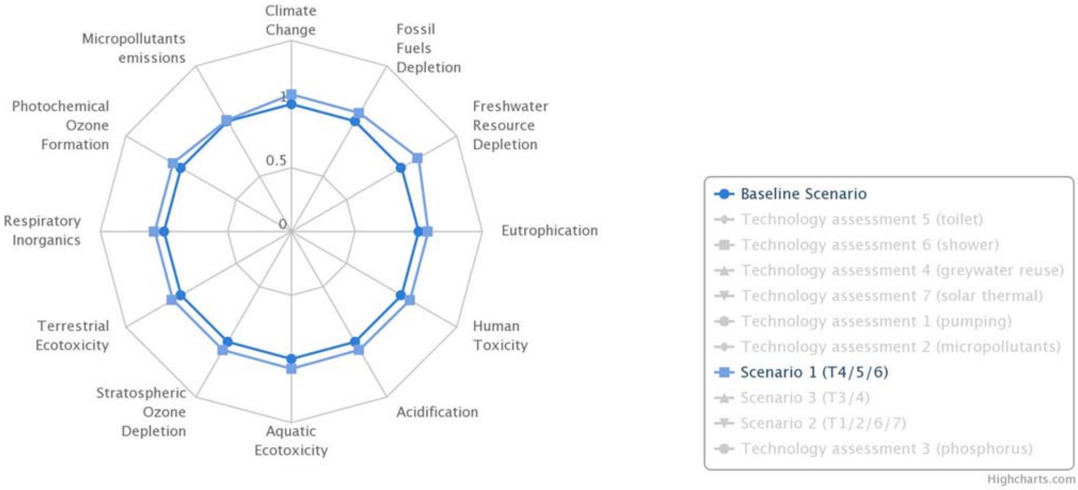


Figure 43: Eco-efficiency performance comparison for scenario 1 for the whole system

Figure 44 show the eco-efficiency performance of scenario 1 compared to the baseline for the actor domestic water users.

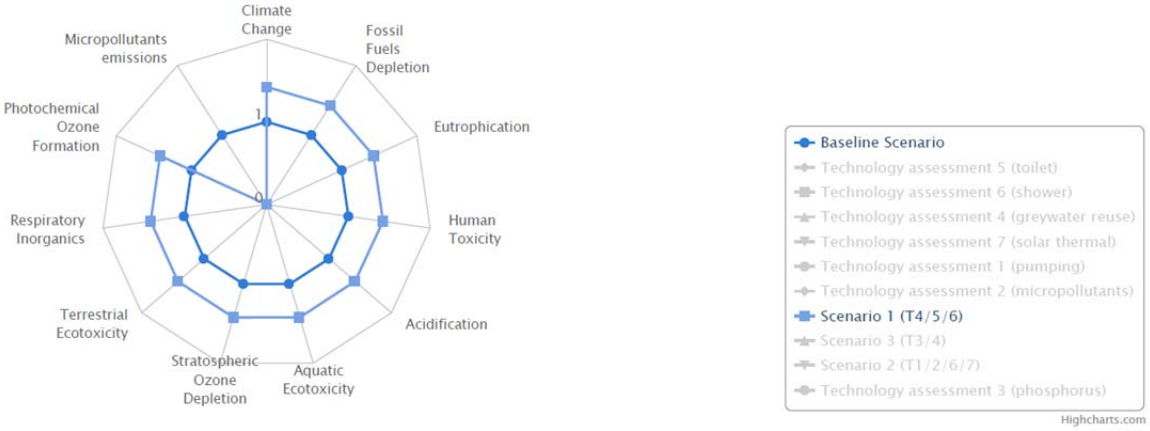


Figure 44: Eco-efficiency performance for the actor domestic water users in scenario 1

For the implementation of this scenario the financial losses faced by the actors Zweckverband and municipality will be passed on to the domestic water users as their value added increases. As the scenario has significantly positive environmental impacts, this compensation flows should be established to guarantee the implementation of technologies proposed.

3.3.2 Technology scenario focusing on pollution prevention

The “Pollution prevention” scenario aims primarily at protection of the environment against pollution. In this scenario, smart pumps, micropollutants removal technology, water saving appliances for warm water and solar water heating were combined to be studied. The time horizon for the implementation of the technologies is the year 2021.

Environmental performance

As it was presented in the technology assessment for smart pumping systems, the main assumption for this technology in scenario 2 is that specific measures will be implemented in the drinking water distribution network which will lead to potential electricity savings of up to 10% as shown in Table 103.

Table 103: Smart pumping assumptions for scenario 2

Water flow affected	In baseline	Scenario 2	Unit
Electricity used at Water Distribution Network	952,650	846,032	kWh/year

For the micropollutants removal technology, it is assumed that it will be implemented until 2021 and will be functioning as it was explained in section 3.2.2. This means that 80% of the micropollutants will be eliminated from the outflow of WWTP using powdered activated carbon (PAC technology). However, this technology implies an increase in sludge production, electricity consumption and PAC consumption.

For the technology shower heads, it is assumed like in the scenario 1, that 60% of the households will use new showerheads, reducing the warm water demand by about 6%, leading to drinking water saving of 2% in total.

Swissolar formulated a goal of 20% of solar heating for water and heat of households, which is assumed to be the technical potential of this technology. This goal and corresponding assumptions are based on the analysis of potential for use of solar thermal heating in Swiss buildings from the Swiss Federal Office of Energy (BFE, 2012). Similarly to the goal of Swissolar and considering thermal heating for warm water only, for the scenario 2 it will be assumed that the fraction of alternative water heating will rise to 30%, electric water heating will disappear and the gas and oil water heating will be reduced to 30% and 40% respectively (Table 104).

Table 104: Energy consumption for domestic water heating in scenario 2 (annual values)

Parameter	HH with gas water heating	HH with oil water heating	HH with solar thermal water heating	Unit
Share of total households (HH)	30%	40%	30%	%
Number of households	2,727	3,636	2,727	amount
Inputs				
Drinking water consumption	344,093	458,790	344,093	m^3
Cold water consumption	245,280	327,040	245,280	m^3
Hot water consumption	98,813	131,750	98,813	m^3
Gas for water heating	6,027,581	-	-	kWh
Oil for water heating	-	7,746,924	-	kWh
Electricity for alternative water heating	-	-	1,172,727	kWh
Solar energy for alternative water heating			4,690,908	kWh

*The energy content of oil is was calculated with 1kg=12kWh, given 645,577kg*12

In Table 105, main affected flows in scenario 2 after the application of the chosen technologies are presented.

Table 105: Main water demand changes in Scenario 2

Flow	Baseline	Scenario 2	Unit
Total drinking water for HHs with electric water heating	58,400	0	m^3/year
Warm water for HHs with electric water heating	17,520	0	m^3/year
Total drinking water for HHs with gas water heating	432,160	344,093	m^3/year
Warm water for HHs with gas water heating	129,648	98,813	m^3/year
Total drinking water for HHs with oil water heating	642,400	458,790	m^3/year
Warm water for HHs with oil water heating	192,720	131,750	m^3/year
Total drinking water for HHs with alternative water heating	35,040	344,093	m^3/year
Warm water for HHs with alternative water heating	10,512	98,813	m^3/year
WW from domestic users	1,051,200	1,032,278	m^3/year
Total WW	3,098,975	3,080,053	m^3/year
Micropollutants emissions to lake	60	12	kg/year

Economic performance

The investment costs in scenario 2 are assumed to be 11,500 Euro for the smart pumping, staying the same as already introduced in the technology assessment for the micropollutants removal technology.

Table 106: Expected costs in scenario 2

Parameter	T1 pumps	T2 micropoll.	T6 showers	T7 solar thermal	Unit
Investment cost					
Investment costs	11,500	10,000,000	63,640	9,500,000	€
Lifetime	15	15	10	25	years
Interest rate	2.5	2.5	2.5	2.5	%/year
Annualised investment costs	930	807,886	7,270	515,621	€/year
Annual operation and maintenance cost					
Fixed costs (incl. maintenance)	300	290,000	0	same as in baseline 600,000	€/year
Cost of productive inputs (electricity)	0	10,780	0	170,299	€/year
Cost of productive inputs (PAC)	n.a.	73,921	n.a.	n.a.	€/year
Annual savings (-)					
Savings in costs for drinking water	0	0	-25,649	0	€/year
Savings in costs for wastewater	0	0	-27,626	0	€/year
Savings in costs for electricity	-15,993	0	-11,353	-160,308	€/year
Savings in costs for gas	0	0	-19,237	-74,810	€/year
Savings in costs for oil	0	0	-47,388	-296,176	€/year
Total annual additional costs (+)/ savings (-)					
Total saving	-14,763	1,182,527	-123,983	154,626	€/year

The annual operation and maintenance costs are assumed to stay the same as in the respective technology scenarios. For the showerheads technology, the same costs are taken as in scenario 1, with 2,728 households implementing the technology. To heat 30% of water with solar thermal heating, the installed collector area should be around 14,600 m^2. The overall costs in scenario 2 are given in Table 106.

Results

Table 107 represent the results of the environmental performance of scenario 2 compared to baseline. In all indicators significant improvements can be observed.

Table 107: Environmental performance indicators of baseline and technology scenario 2

Indicator	Baseline Scenario	Scenario 2	Change
Climate Change (tCO$_2$eq)	6'728.01	5'047.20	-25%
Fossil Fuels Depletion (MJ)	95,093,418	69,543,212	-27%
Freshwater Resource Depletion (m^3)	79,388	78,336	-1%
Eutrophication (kgPO$_4$eq)	505,501	352,155	-30%
Human Toxicity (kg1,4-DBeq)	558,840	401,619	-28%
Acidification (kgSO$_2$eq)	11,683	8,624	-26%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	113,685	-29%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	0.7419	-27%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	299	-28%
Respiratory Inorganics (kgPM$_{10}$,eq)	1,995	1,467	-26%
Photochemical Ozone Formation (kgC$_2$H$_4$,eq)	656	481	-27%
Micropollutants (kg)	60	12	-80%

Table 108 represents the economic performance of technology scenario 2 compared to the baseline. All actors face a reduced total value added which, accordingly, leads to a reduced total value added for the whole system.

Table 108: Economic performance of baseline and technology scenario 2

Actor	Baseline Scenario	Scenario 2	Change
Zweckverband	134	-4,323	-4'457
Municipality	92,568	-1,121,564	-1'214'132
Domestic water users	1,451,193	1,417,181	-34'012
Non-domestic water users	964,729	964,729	-
Total Value Added	2,508,623	1'256'022	-1'252'601

Table 109 represents the eco-efficiency performance of scenario 2 compared to the baseline. This scenario is not eco-efficient for the system because of the high investment costs faced by all relevant actors.

Table 109: Eco-efficiency performance indicators of baseline and technology scenario 2

Indicator	Baseline Scenario	Scenario 2	Change
Climate Change (€/tCO$_2$eq)	372.86	248.86	-33%
Fossil Fuels Depletion (€/MJ)	0.0264	0.02	-32%
Freshwater Resource Depletion (€/m^3)	31.60	16.03	-49%
Eutrophication (€/kgPO$_4$eq)	4.96	3.57	-28%
Human Toxicity (€/kg1,4-DBeq)	4.49	3.13	-30%
Acidification (€/kgSO$_2$eq)	215	145.64	-32%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57	11.05	-29%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	1'692'922	-32%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	4'195	-30%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	856.10	-32%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	2'612	-32%
Micropollutants (€/kg)	41,810	104'668	150%

Figure 45 shows the eco-efficiency performance of technology scenario 2 compared to the baseline for the whole system.

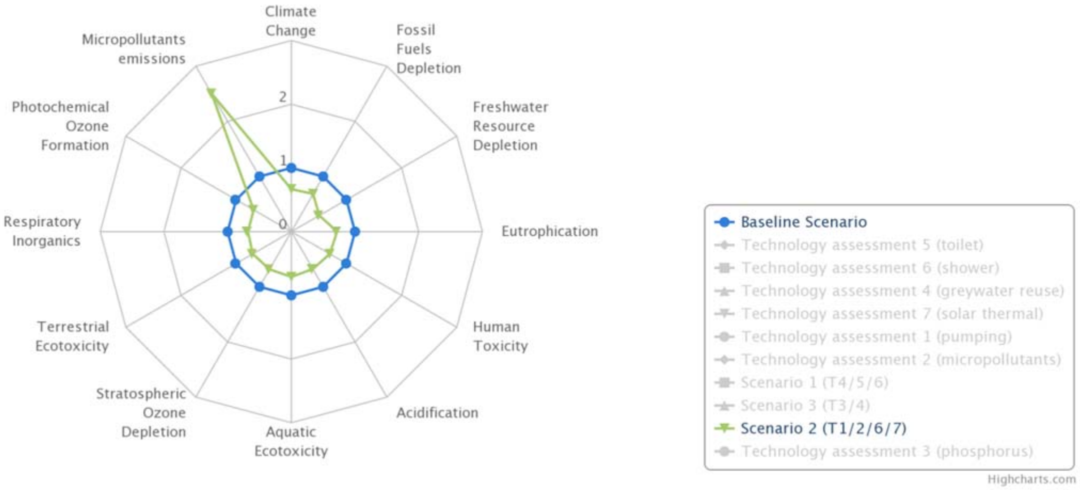


Figure 45: Eco-efficiency performance comparison for scenario 2 of the whole system

Figure 46 shows the eco-efficiency performance of scenario 2 compared to the baseline for the actor domestic water users. From this perspective an improvement in eco-efficiency can be observed, as the overall environmental benefits compensate the reductions in value added for the domestic water users.

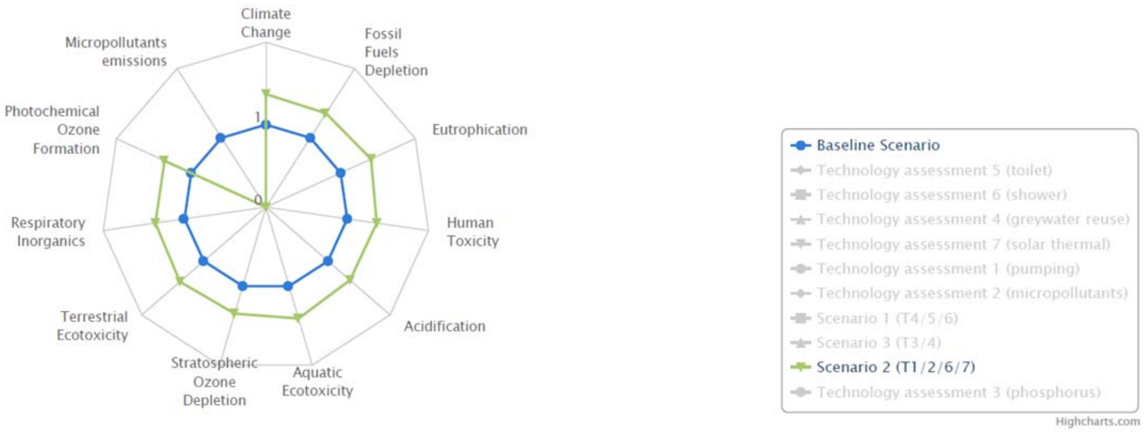


Figure 46: Eco-efficiency performance for the actor domestic water users in scenario 2

In scenario 2 the eco-efficiency for the whole system and for the actor municipality is reduced, while an increase can be shown for the actor domestic water users.

3.3.3 Technology scenario focusing on circular economy

The “Circular economy” scenario is focused at closing the loops of energy and resources and treating waste as potential resource. In the urban water cycle this can be achieved if drinking water is reused or recycled (with water reuse and recycling technologies) or if the phosphorus contained in the sewage sludge of WWTP is recovered. The time horizon for the implementation of the technologies is the year 2021.

Environmental performance

Like in Scenario 1, the assumption for greywater reuse system is that only 10% of the households will implement this technology. With this assumption drinking water for flushing toilets will be saved. The detailed data is shown in Table 110.

Table 110: Water saving with water reuse system

	Baseline	Scenario	Units	Water saved (%)
Drinking water used flushing toilets	48	43	L/person/day	10
cold water demanded	113	109	L/person/day	4
drinking water demand per person	162	157	L/person/day	3
waste water produced per person	146	142	L/person/day	3

For the phosphorus recovery technology which was described in section 3.2.3, it is assumed that by the year 2021 not only the mono-incineration plant is build, but also that the phosphorus technology is applied. Moreover the phosphorus prices are expected to rise so that the negative value of recovered phosphorus assumed in the technology assessment rises to a positive value of 0.2 Euro per kg of phosphorus. Like in the technology assessment, no environmental impacts from applying the technology are considered because these occur mainly outside the set system boundaries.

Economic performance

As it was already assumed above, 10% of households only will implement the greywater reuse technology. Therefore, the investment and operational cost for 909 households were considered in the scenario 1. The overall expected costs for scenario 1 are presented in Table 111.

Table 111: Expected costs in scenario 3 for greywater reuse technology

Parameter	T4 greywater	Unit
Investment cost		
Investment costs	764,000	€
Lifetime	15	years
Interest rate	2.5	%/year
Annualised investment costs	61,706	€/year
Annual operation and maintenance cost		
Fixed costs (incl. maintenance)	11,000	€/year
Cost of productive inputs (electricity)	7,364	€/year
Annual savings		
Savings in costs for drinking water	39,899	€/year
Savings in costs for wastewater	42,973	€/year
Total annual additional costs (+)/ savings (-)		
Total savings	2,803	€/year

Table 112: Expected costs in scenario 3 for phosphorus recovery with Ash-Dec process

Economic data	Value	Unit
Cost of the process	2.2	€/kg_P
Benefit of the process	2.4	€/kg_P
Benefits of phosphorus production	0.2	€/kg_P

Results

Table 113 represents the environmental performance indicators in the baseline and after implementation of grey water reuse and phosphorus recovery technologies in scenario 3. It can be observed that all indicators change. However, most of the changes are below 0.02% and either positive or negative. Most important change is the improvement of Freshwater Resource Depletion indicator by around 2%.

Table 113: Environmental performance indicators of baseline and technology scenario 3

Indicator	Baseline Scenario	Scenario 3	Change
Climate Change (tCO_2eq)	6'728.01	6'728.63	0.0092%
Fossil Fuels Depletion (MJ)	95,093,418	95,094,882	0.0015%
Freshwater Resource Depletion (m^3)	79,388	77,752	-2.0598%
Eutrophication ($kgPO_4eq$)	505,501	505,639	0.0273%
Human Toxicity (kg1,4-DBeq)	558,840	558,814	-0.0047%
Acidification ($kgSO_2eq$)	11,683	11,684	0.0032%
Aquatic Ecotoxicity (kg1,4-DBeq)	161,070	160,970	-0.0620%
Stratospheric Ozone Depletion (kgCFC-11eq)	1.0129	1.0129	-0.0011%
Terrestrial Ecotoxicity (kg1,4-DBeq)	418	418	-0.0018%
Respiratory Inorganics ($kgPM_{10},eq$)	1,995	1,995	0.0002%
Photochemical Ozone Formation (kgC_2H_4,eq)	656	656	0.0023%
Micropollutants (kg)	60	60	0%

Economic performance in the baseline after implementation of the technologies proposed in scenario 3 is presented in Table 114. It can be observed that the value added of actor Zweckverband and Municipality decrease and increase for the domestic water users slightly (less than 1%). The total value added decreases by less than 3%.

Table 114: Economic performance of baseline and technology scenario 3 per actor in € per year

Actor	Baseline Scenario	Scenario 3	Change
Zweckverband	134	-6,800	-6,934
Municipality	92,568	27,159	-65,409
Domestic water users	1,451,193	1,453,996	2,803
Non-domestic water users	964,729	964,729	-
Total Value Added	2,508,623	2,439,083	-69,540

Table 115 represents the eco-efficiency performance indicators in the baseline and after implementation of technologies from scenario 3. All eco-efficiency indicators decrease slightly (around 3%), except for freshwater resource depletion, which decreases by around 1%.

Table 115: Eco-efficiency performance indicators of baseline and technology scenario 3

Indicator	Baseline Scenario	Scenario 3	Change
Climate Change (€/tCO$_2$eq)	372.86	362.49	-2.78%
Fossil Fuels Depletion (€/MJ)	0.0264	0.0256	-2.77%
Freshwater Resource Depletion (€/m^3)	31.60	31.37	-0.73%
Eutrophication (€/kgPO$_4$eq)	4.96	4.82	-2.80%
Human Toxicity (€/kg1,4-DBeq)	4.49	4.36	-2.77%
Acidification (€/kgSO2eq)	215	209	-2.78%
Aquatic Ecotoxicity (€/kg1,4-DBeq)	15.57	15.15	-2.71%
Stratospheric Ozone Depletion (€/kgCFC-11eq)	2,476,632	2,408,006	-2.77%
Terrestrial Ecotoxicity (€/kg1,4-DBeq)	6,002	5,836	-2.77%
Respiratory Inorganics (€/kgPM$_{10}$,eq)	1,257	1,222	-2.77%
Photochemical Ozone Formation (€/kgC$_2$H$_4$,eq)	3,822	3,716	-2.77%
Micropollutants (€/kg)	41,810	40,651	-2.77%

Figure 47 shows the eco-efficiency performance in the baseline and after implementation of Scenario 3. As exposed above, the negative changes are minimal from this perspective.

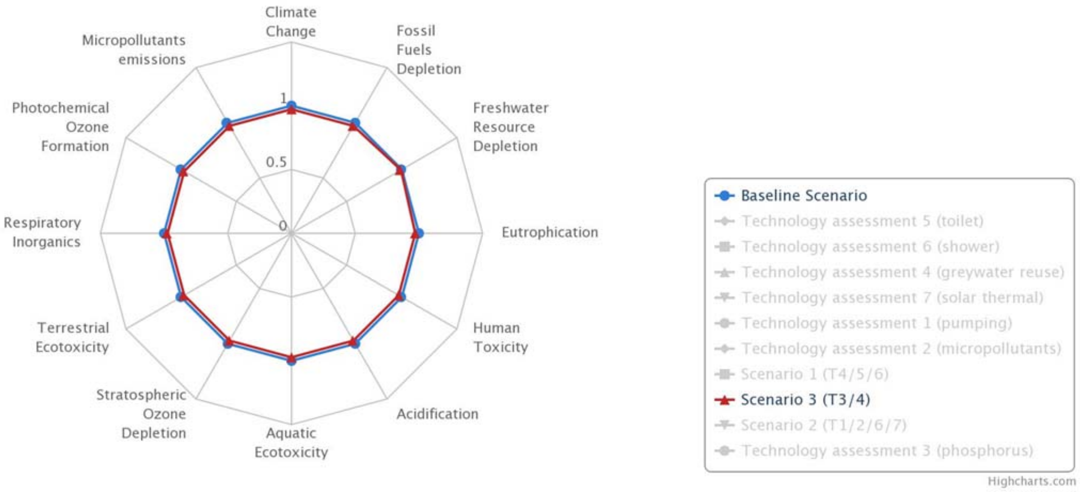


Figure 47: Eco-efficiency performance comparison for scenario 3

Figure 48 shows the eco-efficiency performance in the baseline and after implementation technologies selected for scenario 3 from the perspective of the actor municipality, which would introduce the technologies. Here, a bigger change to the negative can be observed.

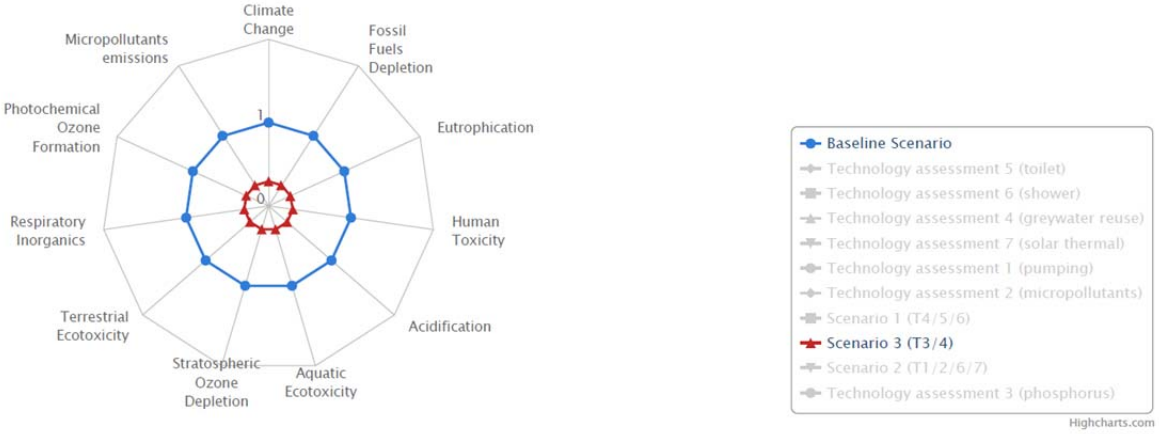
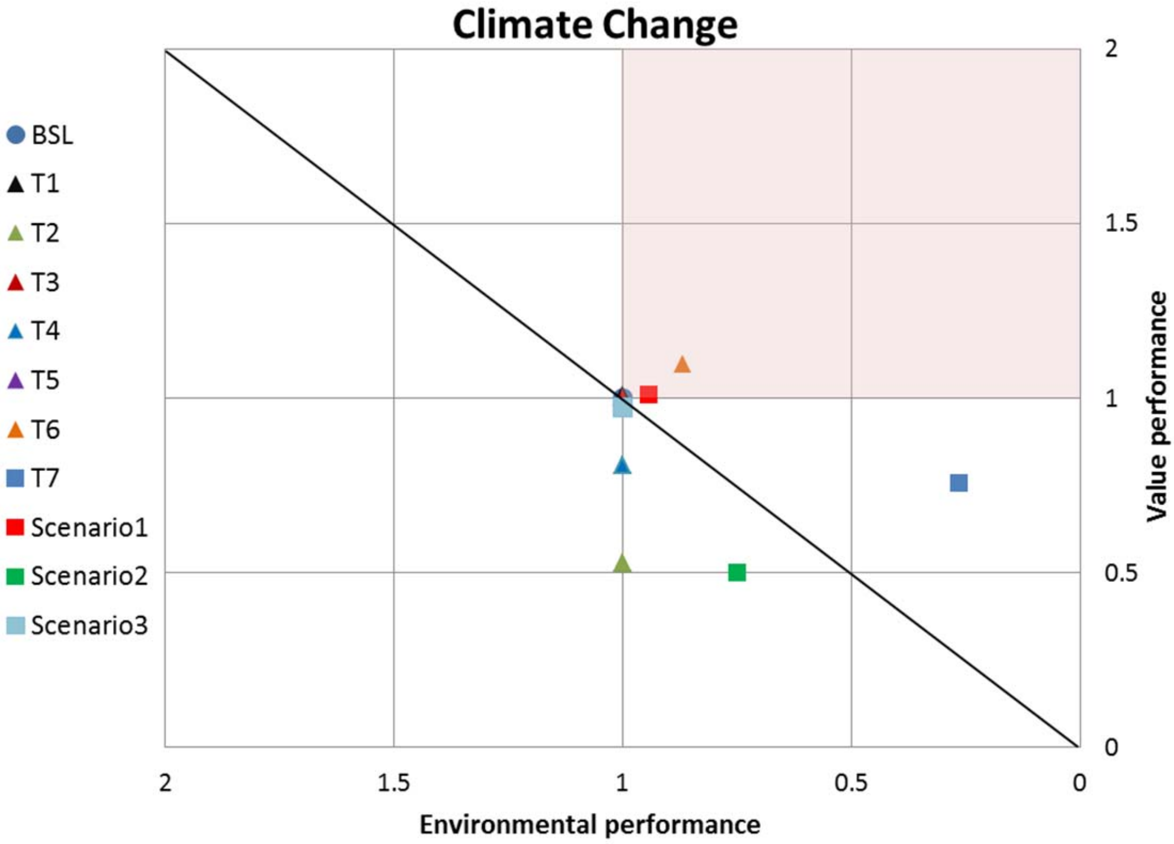


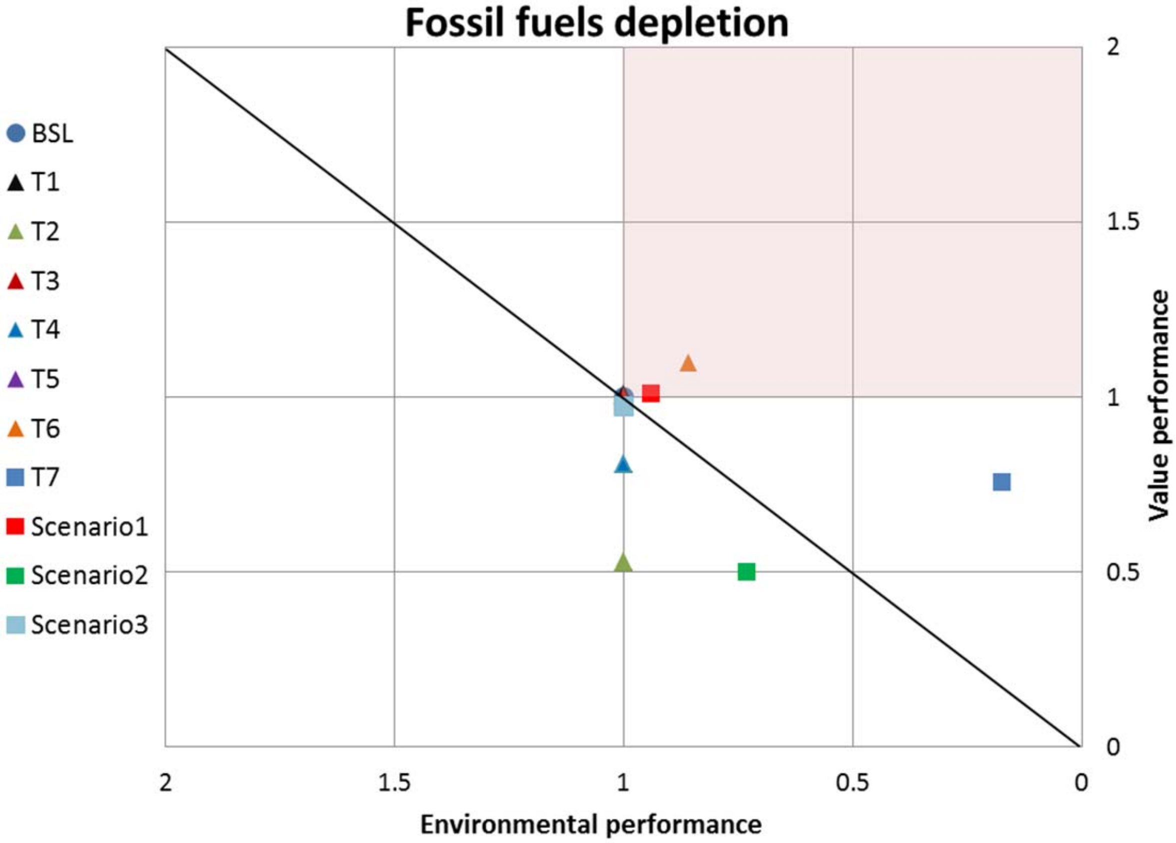
Figure 48: Eco-efficiency performance the actor municipality in scenario 3

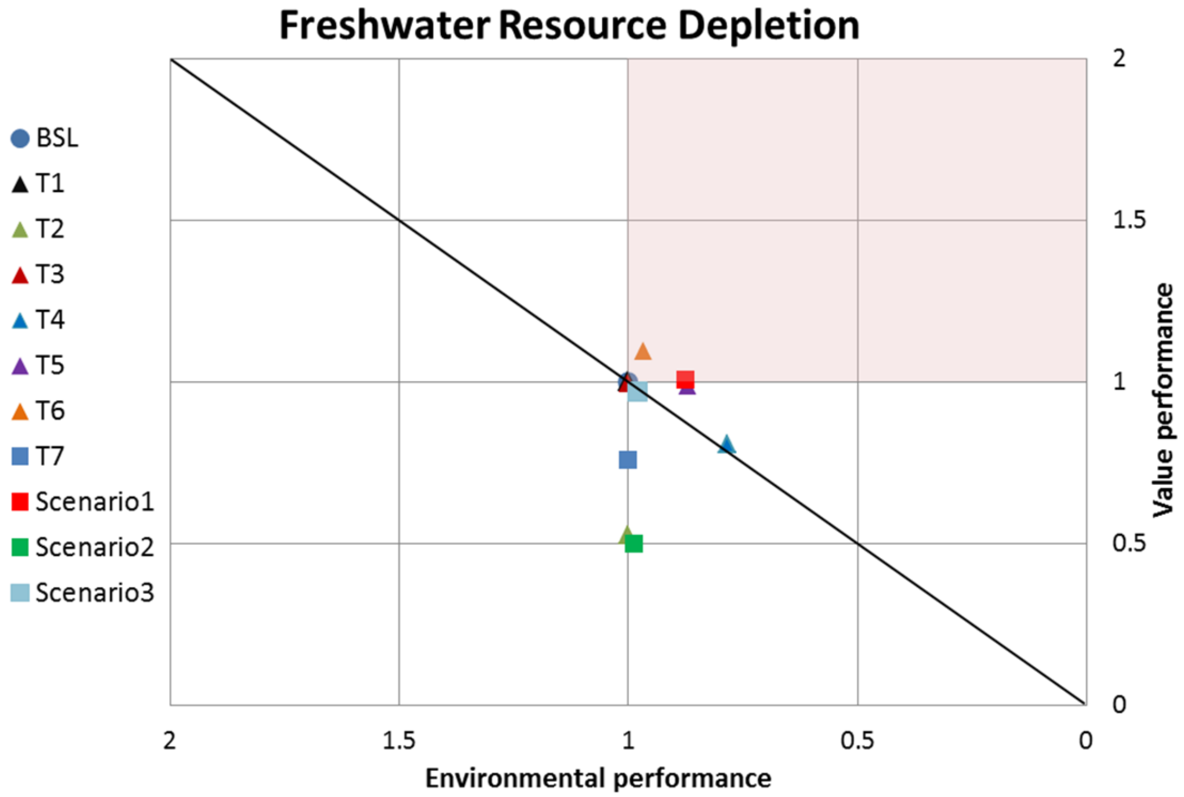
The technology scenario 3 leads to a decrease in the total value added as well as to a decrease, even if it is small, in eco-efficiency. However, it the greywater reuse technology leads to a positive total value added and a positive eco-efficiency assessment from the perspective of the domestic water users. In this case the greywater reuse technology will probably be implemented by the domestic water users. From the perspective of the municipality, the gains lost from lower water consumption of households will be passed on to the domestic water users in the long term. However, if the price of phosphorus keeps rising, this will generate additional income for the municipality and the price increase for water users could be reduced accordingly.

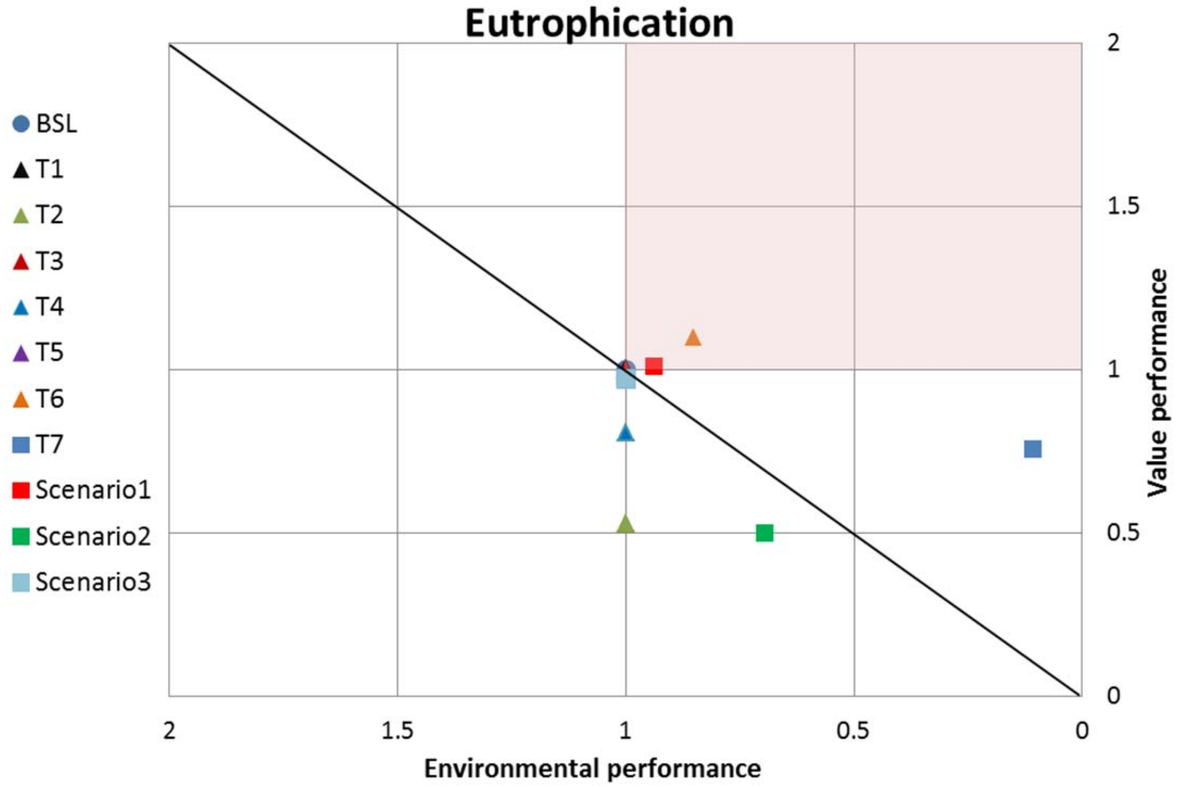
3.4 Discussion and conclusions for Zurich urban case study

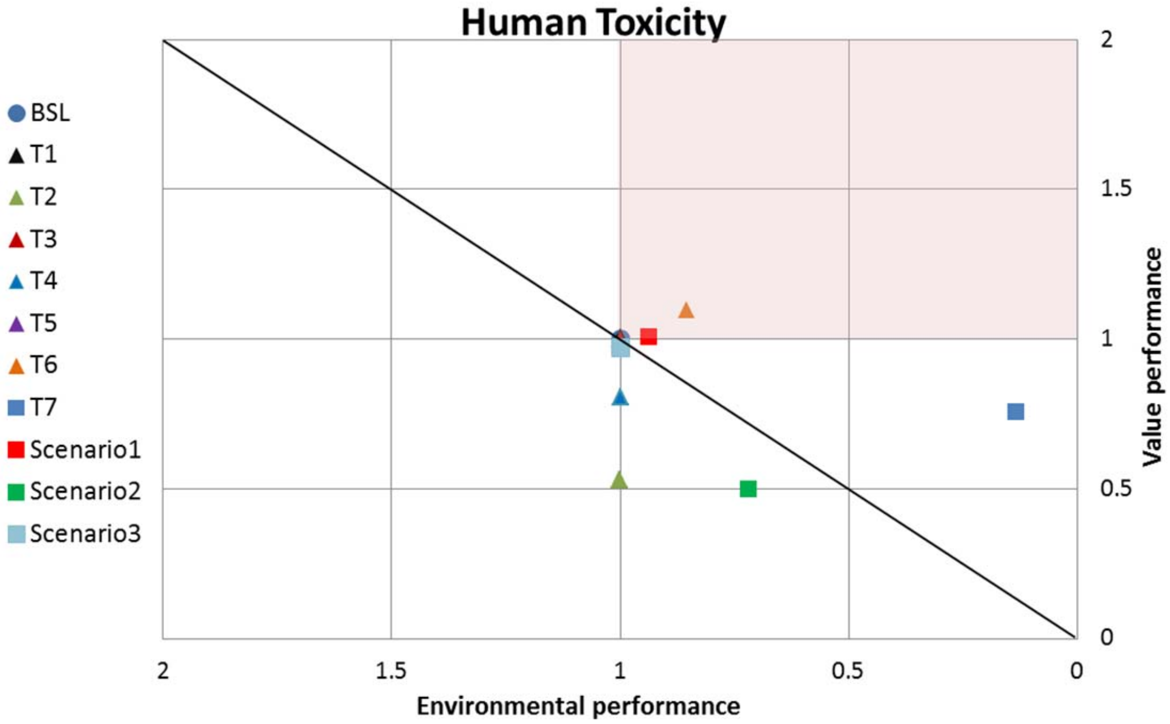
In the text above, the eco-efficiency was calculated as a ratio of the value added and environmental performance. Another way of presentation of the results is by using X-Y diagrams as shown in Figure 49 below. This presentation facilitates drawing conclusions on potential trade-offs between environment and economy, because of the simultaneous visualisation of both parameters – value performance and environmental performance.

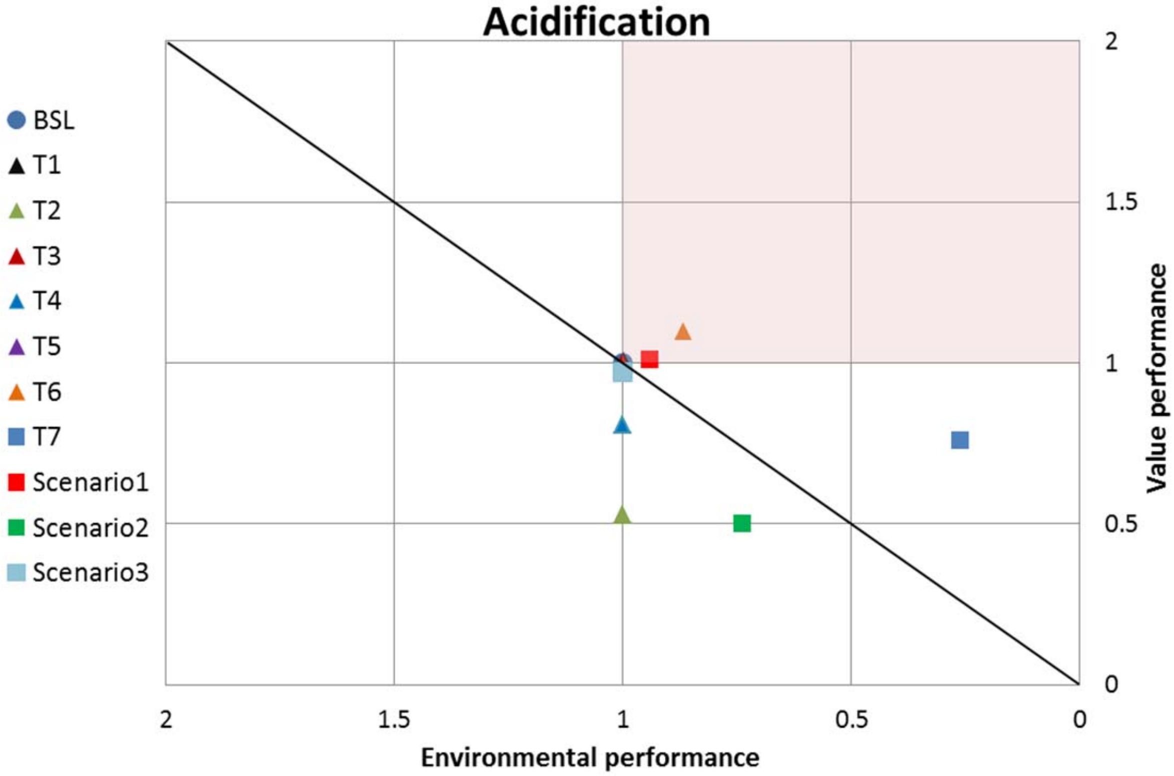


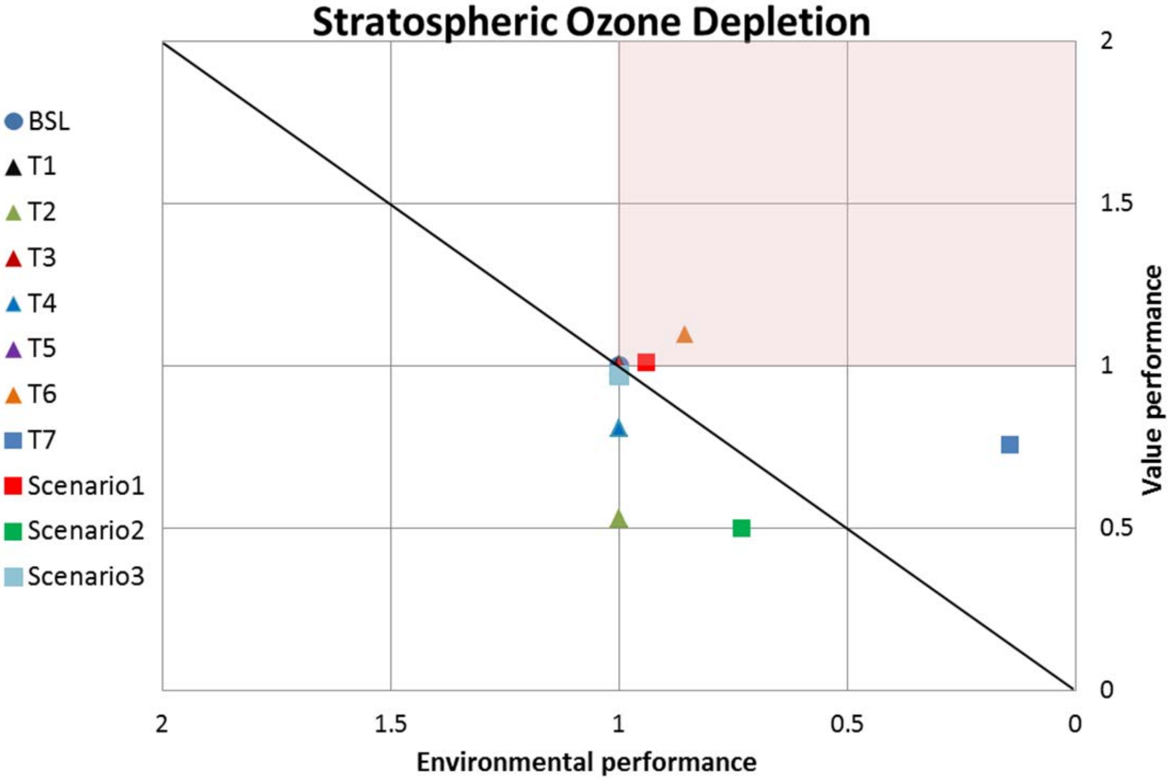


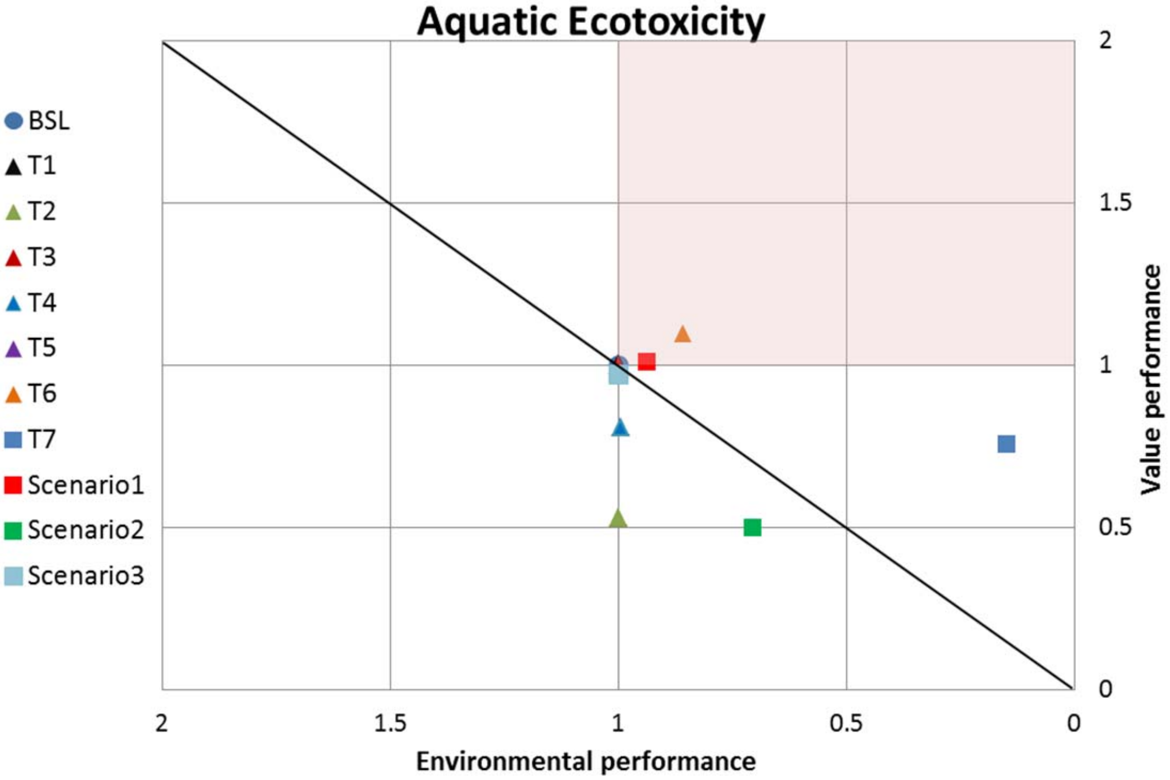

Freshwater Resource Depletion
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Value performance
2
1.5
1
0.5
0
Environmental performance

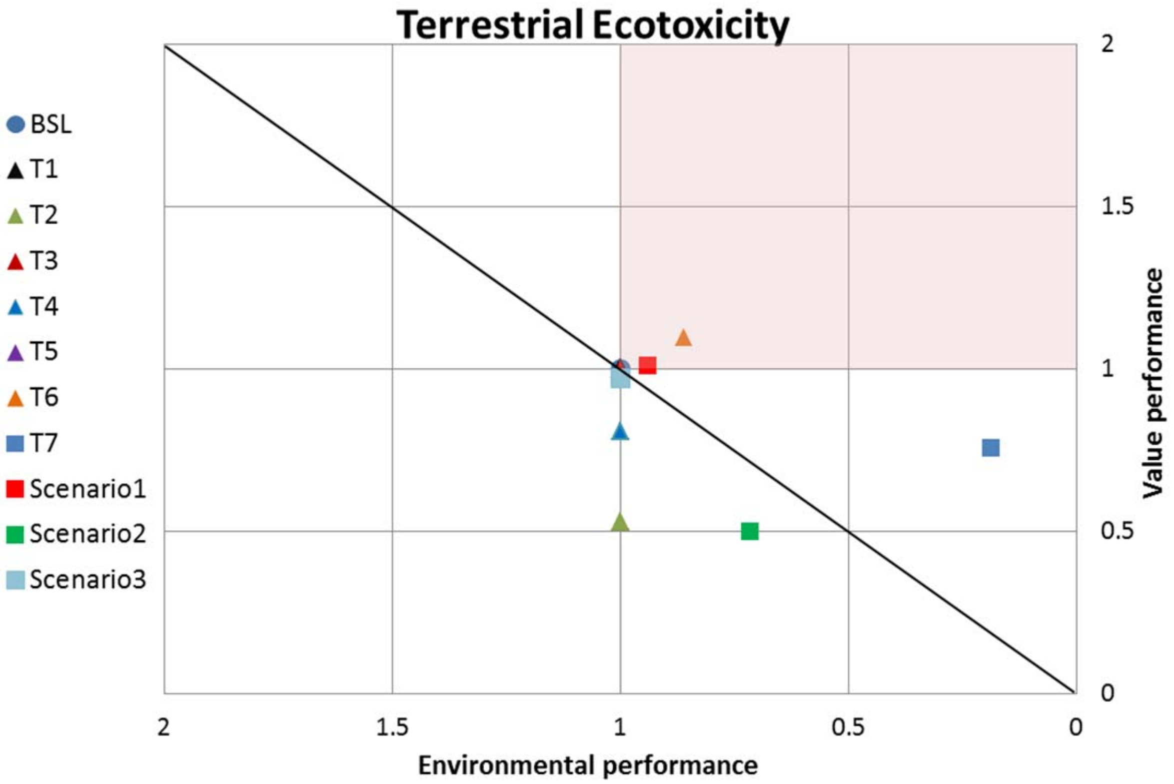

Eutrophication
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Value performance
2
1.5
1
0.5
0
Environmental performance

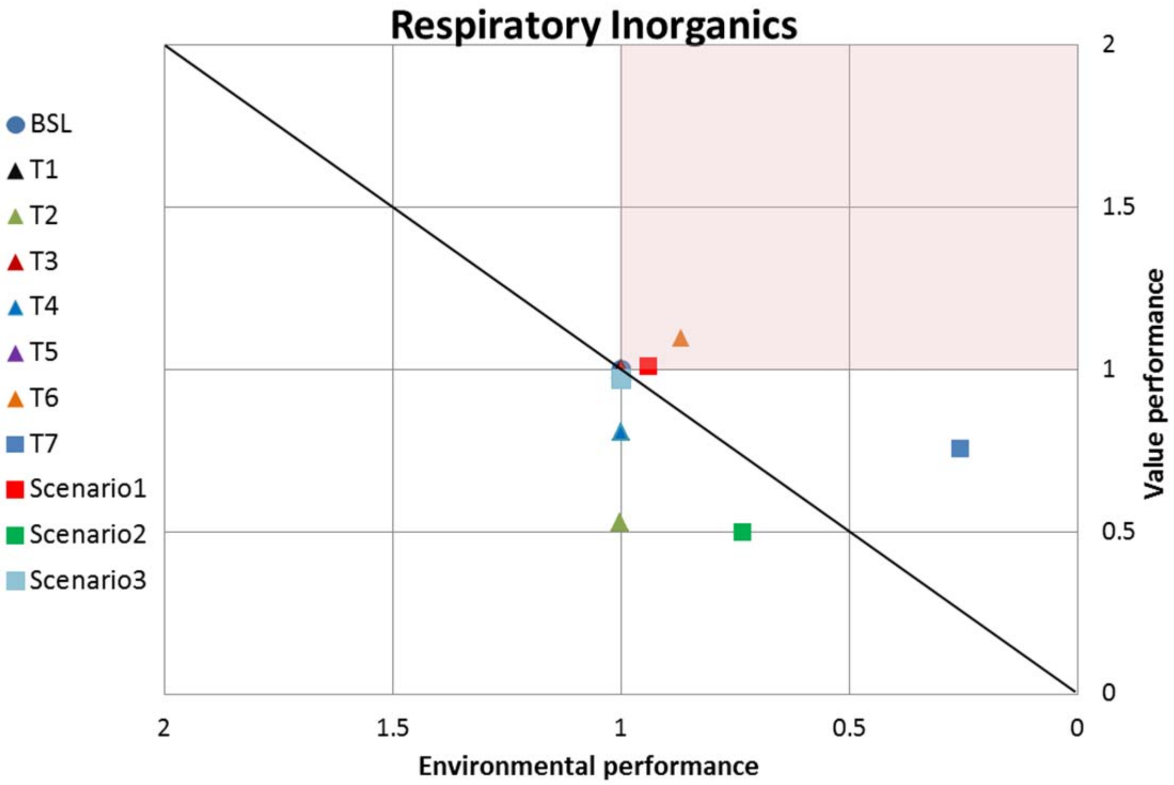

Human Toxicity
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Environmental performance
2
1.5
1
0.5
0
Value performance

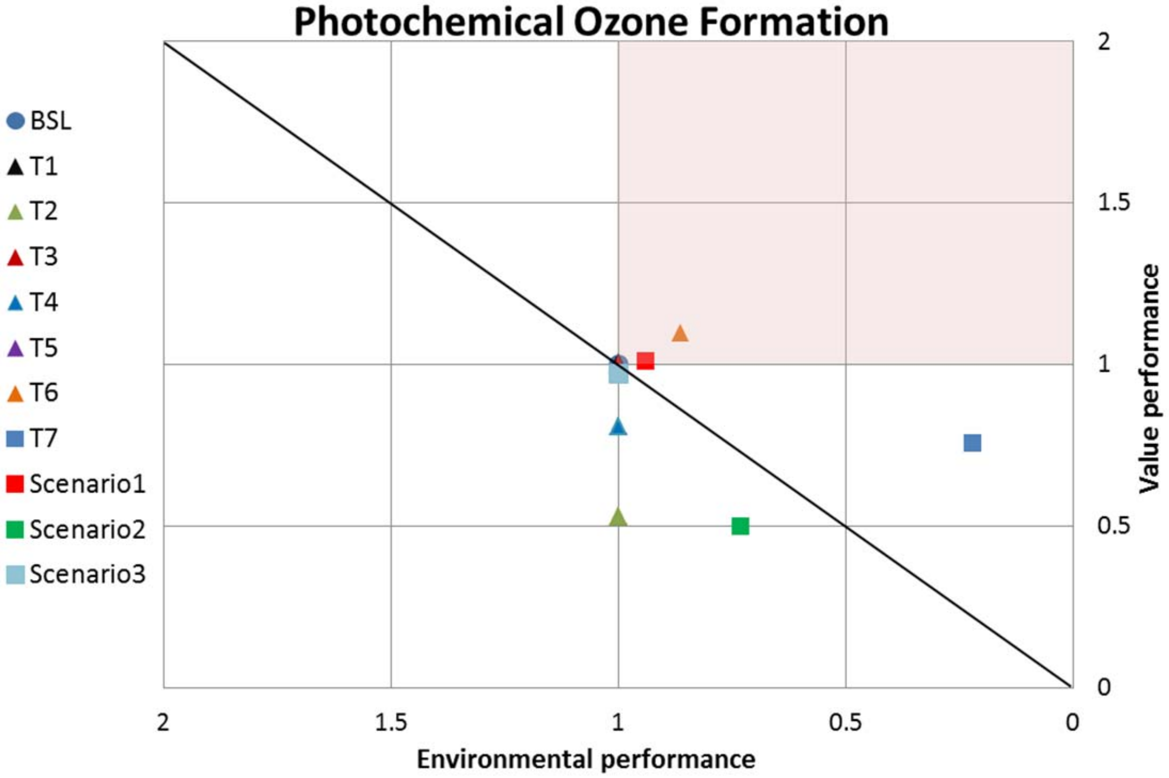

Acidification
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Environmental performance
2
1.5
1
0.5
0
Value performance


Stratospheric Ozone Depletion
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Value performance
Environmental performance


Aquatic Ecotoxicity
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Value performance
Environmental performance


Terrestrial Ecotoxicity
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Environmental performance
Value performance


Respiratory Inorganics
BSL
T1
T2
T3
T4
T5
T6
T7
Scenario1
Scenario2
Scenario3
2
1.5
1
0.5
0
Environmental performance
Value performance



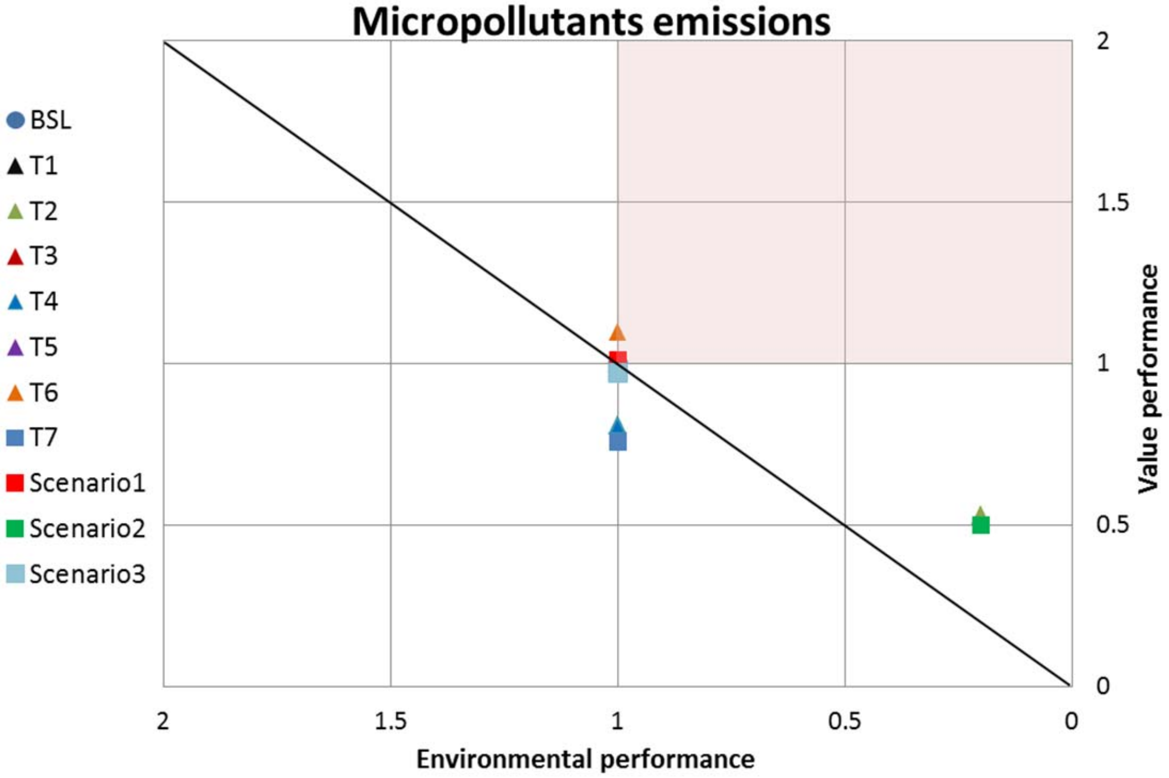


Figure 49: Eco-efficiency performance comparison for all scenarios per environmental impact indicator

In the following paragraphs, conclusions from the assessment of the individual technologies and the three future scenarios are drawn and discussed.

The results of the assessment of the **smart pumping technology (CS4T1)** show that this technology should be implemented by a rational actor municipality because it increases its individual net economic output. The annual investment and operational costs are in this case less than the yearly savings in energy costs. No compensations or incentives from other actors should be required. The actor municipality in Waedenswil has already recognised the improvement potential of such measures in water distribution system, so that the efficiency of the water distribution network has been continuously improved in the last years and this practice will be pursued in the years to come as it was stated by the persons in charge. For this type of measure no whole system analysis would be required to improve the system.

The **powdered activated carbon adsorption technology (CS4T2)** reduces the environmental impact of the water supply chain by removing micropollutants from the effluent which impose a potential risk for aquatic ecosystem and human health. At the same time this technology is connected to additional environmental impacts in form of energy consumption, consumption of materials and an increased sludge production. While the impacts of the additional energy and material consumption are allocated to the background processes, environmental benefits are allocated to the foreground processes as they are obtained at the end of the water value chain, thus in the receiving water body. Regardless of an anticipated overall negative eco-efficiency change, based on the applied impact indicators due to implementation of this technology, this measure will be implemented due to new legislation. As the long-term effects of micropollutants on aquatic ecosystems and human health cannot be adequately estimated at the moment and are therefore also not adequately represented in the applied impact indicators, this measure is used as precautionary action. In the technology assessment the costs have been allocated to the operator of the WWTP, thus the municipality. On the long term however, these costs will be passed on to the domestic and non-domestic water users through an increase of wastewater tariffs. This is due to the fact that the wastewater treatment systems are obliged to cover operating costs according to the polluters-to-pay principle. The total value added decreases after implementation of this technology, as there are no short-term economic benefits and no quantifiable long-term economic benefits which would compensate for the increased capital and operational costs at the WWTP. At best, this technology has the potential to reduce drinking water treatment costs, as the water resources in Waedenswil are taken from the Lake Zurich and I is already a requirement that the micropollutants should be eliminated at the water treatment stage. The used assessment framework would not favour this measure based on the used definition of eco-efficiency, but this serves to stress the important issue of background and foreground impact and the rise of trade-offs between the protection of different environmental compartments.

The implementation of the **phosphorus recovery technology (CS4T3)** is on its way in Canton Zurich, but at the moment is still not economically viable. While a cantonal mono-incineration plant is already being built, which allows storing the ash separately for later recovery, the technology for the recovery of phosphorus from sludge is still under evaluation. The actual recovery plant will be built not earlier than in some years. Additionally, the recovery process considering current phosphorus prices is economically not worthwhile. However, as phosphorus prices are expected to rise in the future, it can become an interesting option in some years, additionally, if a value is attributed to increased independence from foreign phosphorus resources and a circular economy. The applied framework would not favour such a measure and indicates that additional aspects need to be taken into account besides eco-efficiency for a holistic system assessment and improvement.

The **greywater reuse technology (CS4T4)** seems not to be attractive for the whole system at the moment from the economic and environmental point of view. The total value added drops by around 20% and the water provider has economic losses in the short term. As the water services have to be cost-covering, on the long term the water operator will raise the tariff to cover the high fixed costs, and the specific drinking water price per m^3 for the water users will increase. Although the greywater reuse technology has financial benefits for the domestic water users, there is little motivation to implement this technology, as the water solely the cold water consumption, only minor energy is saved on pumping. On the contrary, more energy is used to operate the required membrane technology. Overall, as long as there are enough water resources available in Switzerland and in particular in the case study area, this technology should not be implemented area-wide or needs to be improved. Also because the environmental impacts show different tendencies (some of them rise, some fall and some stay the same), an overall statement about environmental impacts increase or reduction cannot be made. To make this statement, an aggregation of the indicators would be needed, which would require some kind of weighting of the different indicators. Therefore, a further development of the applied framework should be considered to account for these additional aspects.

The **ultra-low-flush toilet technology** is an efficient technology for the domestic water users. It can be anticipated that this technology will be implemented subsequently by the domestic water users whenever old toilets flushing systems have to be replaced or new are built. As in other cases already shown, the specific long-term water and wastewater tariff per m^3 will however increase to cover the fixed costs, which will reduce the benefits for the domestic water users. For these types of measures standards might prove most efficient to improve the market uptake. If such standards are applied with other possible water saving technologies on the users` side, which would lead to further reduction in water consumption, a re-dimensioning of the water system should be considered by the actor municipality in the long term to reduce the fixed cost of the system.

The distinct benefit of the **showerhead technology** is that it does not only save water, but also energy for heating the saved water. Although the municipality faces losses in the value added, the domestic water users` value increases so that the total value added to the system rises as well. This is due to the fact that more added value is created due to the savings on energy than lost due to the lower water consumption. As the value generated by the energy market is outside the system boundaries, more value can be created inside the system if the consumption of outside materials such as energy can be reduced. Even if the municipality will increase the specific water tariffs to cover their costs, the system and especially the domestic water users will still benefit overall from the technology. This technology seems to be a good example for an eco-efficient measure with the assessment framework applied.

The **solar thermal heating technology** with the assumed penetration rate of 90% does not seem to be efficient in economic terms with the applied model; however it is expected to create economic benefits regionally for the providers and installers of the systems and decreased fuel dependence not covered in the framework. Additionally, the technology brings considerable environmental improvements. This leads to an increase in eco-efficiency for the whole system as well as for the domestic water users. If increasing costs for gas and oil in the long term would be considered, the economic performance of this technology will rise and will probably become efficient someday.

In the **scenario 1**, which aims at an increased **resource efficiency**, water saving appliances for warm and cold water as well as water reuse and recycling technology have been assessed for the year 2021. For the implementation of this scenario the financial losses faced by the actors Zweckverband and municipality would have to be passed on to the domestic water users, as their value added increases. As the scenario has significantly positive environmental impacts and therefore leads to an increase in resource efficiency, this compensation flows should be established to guarantee the implementation of technologies proposed.

In the **scenario 2**, which aims at **pollution prevention**, water saving appliances for warm water, solar water heating, micropollutants removal smart pumping technologies have been assessed. In this scenario, the eco-efficiency for the whole system as well as for the actor municipality is reduced, while an increase can be shown for the actor domestic water users. For pollution prevention focus the applied model would need to be extended to cover for additional aspects and weightings.

In the technology **scenario 3**, which aims towards **circular economy**, water reuse and recycling and the advanced phosphorus recovery technology are assessed. The implementation of these technologies leads to a decrease in the total value added as well as to a decrease, even if a small one, in eco-efficiency. However, the greywater reuse technology leads to a slightly positive total value added and a positive eco-efficiency assessment from the perspective of the domestic water users. This is due to the implementation rate of 10% of the households which reduces the total investment costs compared to the technology assessment, where a 100% implementation rate for this technology was assumed. In the scenario case the greywater reuse technology will probably be implemented by the domestic water users. From the perspective of the municipality, the reduced income from lower water consumption of households will be passed on again to the domestic water users in the long term to cover for the costs. However, if the price of phosphorus keeps rising, this might generate additional income for the municipality and the price increase for water users could be reduced accordingly. Scenario 3 shows the limits of the applied framework with the set system boundaries. It is not fully clear how resources like phosphorus should be accounted for, as the sludge containing phosphorus leaves the system boundaries for recovery, so that the negative environmental impacts from the recovery process occur outside system boundaries. It is also not clear whether the positive environmental impacts from the replacement of natural phosphorus with the recycled product will occur inside or outside the system boundaries. Even if the recycled phosphorus is used in the case study area, in the urban system model set up at the moment, the agricultural sector is not included, so the benefits could not be accounted for.

All three scenarios assessed have the potential to achieve their respective key objectives. Scenario 1 is the best example of all. As this scenario aims at resource efficiency, costly resources are saved, which reduces not only the environmental impact for the whole system, but also the costs for the actors. As the scenario 2 aims at pollution prevention and for many ecosystem services no external costs are being considered at the moment, this scenario leads to financial losses. Although the negative environmental impacts are reduced, the overall eco-efficiency is declining in this scenario compared to the baseline. The goal of circular economy of the scenario 3 can be achieved if the prices for goods and services in question will increase in the future. For all scenarios constant prices for resources have been considered, except for phosphorus.

To allow overall conclusions for the individual technologies assessed as well as for the scenarios, weighting of the environmental impact categories for their aggregation is required. At the moment the implicit weighting equals one for all impact categories. However, this does not allow statements whether a small change in the category climate change for example is as good as or as bad as a large change in the indicator eutrophication.

4 Common conclusions for urban case studies

The urban case studies assess the eco-efficiency of two urban water services and use systems – in Sofia (CS3) and in Waedenswil (CS4) before and after implementation of innovative technologies in two steps. In step 1 individual technologies were assessed on their full technological potential. In step 2 three scenarios, targeting three major goals of sustainable development were assessed.

Table 116 shows the comparison between the two case studies in regard to Step 1. The table provides the list of the investigated technologies, their corresponding stage in the system, as well as in which case study they were applied.

Table 116 Studied innovative technologies in CS3 and CS4

Individual technologies	CS3 Sofia	CS4 Waedenswil
Stage: Water supply system		
Pressure reduction turbines	CS3 -T1*	
Hydro power plant	CS3 -T2	
Smart pumping		CS4-T1
Stage: Water use		
Water saving appliances	CS3 -T4	CS4-T5, CS4-T6
Energy saving appliances	CS3 -T4	CS4-T6
Solar water heating	CS3 -T5	CS4-T7
Water reuse for domestic users		CS4-T4
Drain water heat recovery	CS3 -T6	
Stage: Sewerage system		
Solar sludge drying	CS3 -T3	
Advanced phosphorus recovery		CS4-T3
Micro pollutants removal		CS4-T2

*Corresponding number of the scenario in the toolbox.

Looking at Table 116, the first conclusion is that both case studies include innovative technologies for all of the three main stages of the system – water supply system, water use and sewerage system. The second similarity, respectively the second conclusion is that most of the technologies in both case studies are applied for the environmentally most relevant stage in both systems – “water use”. The third conclusion is that, due to the legislative differences and differences in the engineering systems, there are no similar technologies for the stages “Water supply system” and “Sewerage system”. The last conclusion for Step 1 concerns the water use stage. There is only one technology, assessed in both case studies - “Solar water heating”. Under the titles “Water saving appliances” and “Energy saving appliances” different innovative technologies were considered in Sofia and Waedenswil.

Table 117 shows the comparison of the two case studies with regard to Step 2 - scenarios, targeting three major goals of the sustainable development.

Table 117 Scenarios and corresponding technologies

Scenario	Technologies CS3	Technologies CS4
Scenario 1: Resource efficiency (with focus to freshwater depletion)	Water saving appliances Pressure reduction turbines	Water saving appliances (cold water) Water saving appliances (warm water) Water reuse and recycling technologies
Scenario 2: Pollution prevention	Water and energy saving appliances Drain water heat recovery Solar water heating Pressure reduction turbines Hydro power plant (before WTP)	Water saving appliances (warm water) Solar water heating Micropollutants removal technologies Smart pumping
Scenario 3: Circular economy	Solar sludge drying Pressure reduction turbines Hydro power plant (before WTP)	Water reuse and recycling technologies Advanced Phosphorus recovery

Table 117 shows the diversity of potential technologies, included in each of the three scenarios in the two case studies. Therefore, the conclusion is that comparison between two case studies of the magnitudes of the eco-efficiency improvements for these three scenarios could not be done. However, for both case studies all three scenarios show potential to improve against the key objectives given the fact that eco-efficiency of the system increases after implementation of the innovative technologies and/or their combination.

The eco-efficiency assessment proved to be a powerful tool for comparison of alternatives. Its test in the two urban case studies shows that:

i) it is applicable for urban water systems;
ii) it is a solid base for decision making and disputes among stakeholders, because it allows presentation of the results from the perspective of all actors;
iii) it might be visualised in a way, allowing comparison on the two elements – environmental and value performance;
iv) it shows co-benefits, generated simultaneously with achieving the main goal of the scenario.

A possible future improvement of the methodology is weighting of the environmental impact categories in order to compare the impact between different categories and to aggregate the results into one overall eco-efficiency indicator. At the moment the implicit weighting is 1, i.e. equally weighted, for all impact categories. However, this does not allow statements whether a small change in the category climate change for example is as good as or as bad as a large change in the impact indicator eutrophication.

On the eco-efficiency framework for urban cases the following can be finally concluded:

- **Eco-Efficiency Indicator** - Nominator - Economic benefit: Economic benefits can be difficult to estimate, but are important to guarantee long-term economic sustainability of the system;
- **Eco-Efficiency Indicator** - Nominator - Costs: To derive accurate cost estimates is in general feasible for public but more difficult for private institutions. To improve the metrics, Life Cycle Costing could be applied;
- **Eco-Efficiency Indicator** - Denominator - Environmental impact: Apply proven concepts: i.e. Life Cycle Assessment is the method to account for environmental impacts and should be used;

- **Aggregation of the different environmental impacts:** To support decisions in conflicting environmental impact results a weighting and aggregation might be needed.
- **Interpretation challenges:** The presented eco-efficiency indicator depends on economic benefit minus cost, i.e. margin changes and not on commonly applied costs per reduced impact metrics, i.e. not necessary least cost measures for reduction will be identified for different systems and measures might be eco-efficient in one system but not in another system that creates less margin.
- A facilitator or a price signal is needed to optimise the system in respect to the eco-efficiency metric: The existing actors of the value chain will not make system-optimal decision on their own.
- **Feasible and beneficial approach:** Eco-efficiency (EE) approach is feasible and beneficial for whole system optimisation, especially for asymmetric cost-benefit situations.
- Targeting decision makers for EE and interpretation of results may be challenging.
- **Shared services tend to be more optimised:** Water utilities (i.e. shared services) tend to be more optimised than water use stages under full cost recovery scheme.
- **Shared services could drive eco-efficiency improvements:** Shared services (e.g. water utilities) could become champions to facilitate system (EE) optimisation -> e.g. drive optimisation in households or industrial symbiosis programs. -> Additional benefit sharing concepts adjusted to decision makers are needed.

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