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

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Deliverable 3.2

Baseline eco-efficiency assessment in urban water systems

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Abstract

The “Baseline eco-efficiency assessment in urban water systems” summarizes the results of the baseline assessments in the case studies in Sofia, Bulgaria and in Canton of Zurich, Switzerland of the FP7 EcoWater project. These results are building up on the previous EcoWater report, “Value Chain Description of the Analysed Urban Water Systems”. In the report at hand a set of meso-level indicators has been derived to quantify the eco-efficiency of both current systems.

First, the case study areas are presented in a goal and scope definition and the inventory of relevant resources consumed and emissions produced by the water system is set up. This is followed by an assessment of environmental and economic performance of the water value chains.

For the environmental performance assessment a set of relevant environmental impact indicators is chosen followed by an estimation of these based on the derived resources consumption and generated emissions using corresponding characterisation factors commonly used in Life Cycle Assessments (LCAs).

For the economic performance assessment, the economic value from water use is estimated for domestic and non-domestic water users. Additionally, the total financial costs related to water supply and wastewater treatment are calculated for the case study areas. Based on the difference between the created economic value and the incurred costs, a total value added to the system from water use is estimated.

In a final step several eco-efficiency indicators are estimated as the ratio of the economic performance indicator and relevant environmental performance indicators.

The interpretation of the derived results will guide the selection of potential technologies to enhance the eco-efficiency of the system that will be assessed in a next phase. The next step will be an analysis of the expected effects of these innovative technologies and measures on the eco-efficiency of the urban water systems.

Contents

1 Introduction

This report, i.e. “Baseline eco-efficiency assessment in urban water systems”, summarizes the results of the urban case studies in Sofia, Bulgaria (Chapter 2) and in Canton of Zurich, Switzerland (Chapter 3) of the FP7 EcoWater project. A set of meso-level eco-efficiency indicators is derived and estimated to characterise the eco-efficiency of both investigated systems.

The proposed Eco-Efficiency Indicators (EEI) of the meso-level water use systems are defined as ratios of the economic performance of the system, i.e. economic benefits minus financial costs (a value chain related parameter) to the environmental performance of the system, i.e. environmental impact indicators relevant for the system (water supply chain and water use stage related environmental impact parameters) (see equation below).

$$EEI = \frac{Economic\ Benefits - Financial\ Costs}{Environmental\ Impacts}$$

The requirements of the ISO standard for assessment of the eco-efficiency were considered as a basic methodological framework (ISO14045, 2012). The EcoWater project has tried to apply this general standard framework to the specific case of an urban water system. The main challenges, which have been faced, were:

1) Determination of the product of an urban water system, i.e. what kind of goods or services are delivered;
2) Determination of the system boundary, if foreground and background processes need to be considered in a Life Cycle Assessment;
3) The way different users are considered, i.e. domestic and non-domestic;
4) Selection of a functional unit, e.g. m3 of used water, satisfied consumers, different water services;
5) Lack of agreed research method for the Life Cycle Assessment of water abstraction;
6) Assessment of the product system value.

The following assumptions were made to derive the presented results:

1) The material flows of reagents, wastes, and emissions in the WTP are proportional to the quantity of purified water;
2) The material flows of reagents, wastes, and emissions in the WWTP are proportional to the number of persons’ equivalent (p.e.) served. One p.e. corresponds to the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day (Directive 91/271);
3) Water losses in the drinking water distribution network are equal to the difference between the revenue water metered and the total water quantity supplied (physical and commercial losses are included);
4) The average temperature of the supplied potable water is 10°C degrees;

The report consists of five main parts for each case study: 1) goal and scope definition; 2) inventory analysis of the collected data, accomplished with core necessary calculations, assisting SEAT and EVAT modelling; 3) assessment of the environmental performance; 4) estimation of the economic performance and, 5) first results for the eco-efficiency assessment for the current system, i.e. baseline estimations. At the end initial conclusions are drawn from this baseline calculation.

2 Baseline eco-efficiency assessment for the city of Sofia, Bulgaria

2.1 Goal and scope definition

2.1.1 Objectives

The goal for Sofia case study, as required by the standard, is shown in Table 1.

Table 1 Definition of the goal of the study

Item	Content
Purpose of the eco-efficiency assessment	To promote innovative technology uptake in urban water systems by presenting the difference in eco-efficiencies between a baseline scenario and scenarios with new technology implemented
The intended audience	Research community, water operators
The intended use of the results	Provides indicators to decision makers when new technology is recommended to be implemented

The analysis is targeted on a meso-level that encompasses every stage of the urban water cycle and entails the consideration of the interrelations among the heterogeneous actors. Assessment will be performed in the baseline scenario which represents the reference point for benchmarking enhancements resulting from the upgrade of the value chain through the introduction of innovative technologies that will be examined in a later stage.

2.1.2 Product system

With respect to urban water systems, there is debate in the literature as to what the "product" is, i.e. whether water should be treated as a good or a service. Some authors state that the water in the urban water system is a good, because of its economic value (Rogers et al., 2002). An alternative interpretation is that the product in the urban water system is not the water itself, but the satisfied human water needs through the water services - "delivering water to the consumers with the required quality and quantity" and "transporting away the generated wastewaters". This understanding is in line with the core concept of the Water Framework Directive, namely "water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such" (EU Water Framework Directive, 2000). In this study the "product" of the urban water system will be the "water services".

2.1.3 System Boundaries

The studied system considers the entire life cycle of water from its origin as a natural resource until its release into the environment after being used in urban facilities, (Figure 1).

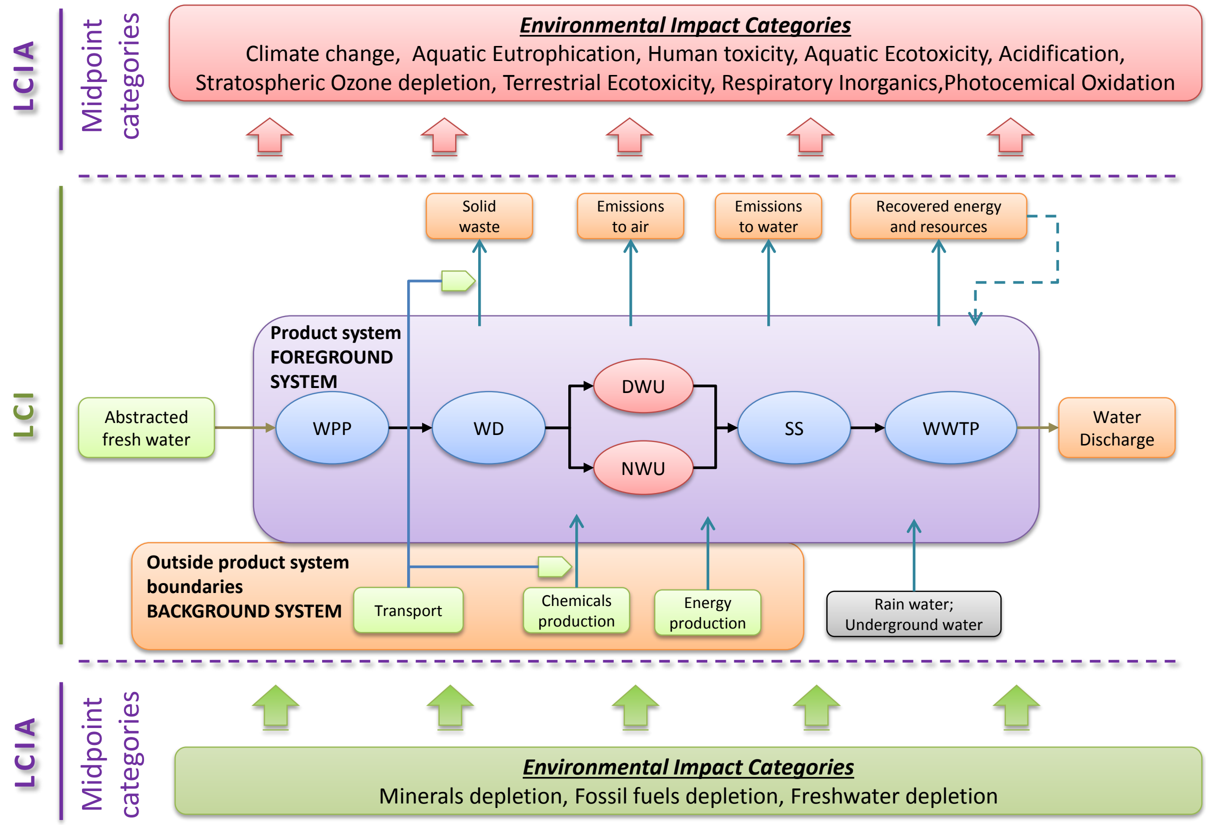


Figure 1 A conceptual model of the Sofia urban water system

Urban water systems have two major external material inflows – energy and chemicals. The determination of the system boundary requires clarification of the length of these chains, e.g. should the assessment include the production of these two groups of consumables (with their respective values and environmental impact). There are "pros" and "cons" for the two possible solutions – inclusion or exclusion. This was one of the challenges faced.

In this study we have decided to consider the accessory chains (production of energy, chemicals, transport, etc.), but to differentiate them from the main product system by adopting the terms "foreground system" and "background system".

- Foreground system is the product system, e.g. the system of direct interest and includes all the stages along the water value chain (the water abstraction and treatment stage, the distribution network, the water use in urban facilities and the wastewater treatment plant) where resources are used and emissions are generated directly.
- Background system is the one, which includes the production processes of the various resources entering the system which are not included in the boundaries of the study system (i.e. energy production, chemicals manufacturing, fuels production and distribution etc).

These systems are visualised in Figure 1. The summary of system processes and their characterization as Foreground or Background are described in Table 2.

Table 2 Foreground and Background processes for the City of Sofia

Type of Process	Process Name
Foreground	1. Water Treatment and Distribution
	2. Domestic Water Use
	3. Non-domestic Water Use
	4. Wastewater Transportation
	5. Wastewater Treatment
Background	1. Energy Production (Electricity mix for Bulgaria)
	2. Heat Production
	3. Chlorine (Cl_2) Production
	4. Aluminium Sulphate (Al_2SO_4) Production
	5. Iron (III) Chloride ($FeCl_3$) Production
	6. Flocculant Production*
	7. Transport

**Although there are flocculants used in the WWTP, they will not be considered, because no data is available in LCA databases.*

Compared to the Deliverable 3.1, in addition to the new concept for foreground and background systems, the value chain of Sofia urban water foreground system has been updated as a result of:

i. Gathering deeper knowledge on the system's performance and potential innovative technologies
ii. Literature review;
iii. Recommendations of the EcoWater midterm reviewer.

The changes are explained in Table 3.

2.1.4 Cluster Analysis

The case study includes different water users. The relative environmental impacts can be expressed considering them as reference points. Users with the same consumptive patterns (e.g. technology, socio-economic characteristics) can be grouped in clusters. The subdivision of the mass and energy flows of whole system on cluster scale will be performed on the basis of the water volumes at the point of consumption and discharged pollution load into the sewerage network for water supply and sewerage processes respectively.

The entire study area can be distinguished in two main types of urban water users - Domestic and Non-Domestic Customers.

Table 3 Justification of the changes in the updated value chain

Change	Reason for the change
System boundary – a functional extract of the users, which are served by the centralized sewerage system will be studied, the remaining 1.8% of the users (without sewerage) will be excluded	The initial plans were to estimate the eco-efficiency of the entire water supply and sewerage system of Sofia, including both centralized sewerage system and septic tanks. Due to the facts that the centralized sewerage system serves about 98.2% of the population and no technologies in the sewerage system will be applied, it has been decided to exclude users without centralized sewerage system (*see Data from National Statistical Institute in Deliverable 3.1*). They would complicate the model without added value on the final results.
Stage "WTP" – instead of having 3 separate WTPs, they are combined into one	New technologies for this stage have not been considered. The combination simplifies the model, without any negative impact on the results.
Stage "Water use"– "Domestic water use" is subdivided into "Households with local water heating", "Households with district water heating" and "Households with alternative water heating"	Heating of the water requires lots of energy. Flower et al. (2007) revealed that residential water use appliances are responsible for significantly more GHG emissions than all upstream and downstream operations. Water use pattern of centralized water heating is different compared to local water heating. This subdivision will allow more precise estimation of the energy used and respectively the emitted CO_2. "Alternative water heating" means heating through renewable energy sources, which do not generate green house gas emissions.
Stage "Water use" – "Non domestic water use" is subdivided into 3 categories, corresponding to the pollution load of each of them.	According to the WFD the principle "pollutant pays" is adopted in Sofia wastewater collection and treatment system. Correspondingly, 3 types of non – domestic water users are identified according to the level of the pollution of their effluents prior discharge into the municipal sewerage system. These 3 categories are considered in our model in order to determine p.e. coming from each of them.

Domestic users are further divided into 3 sub-clusters in relation to the way of water heating, respectively to: 1) domestic users with central water heating; 2) domestic users with local water heating and, 3) domestic users with alternative (from renewable energy sources) water heating.

How to consider the non-domestic water users was another challenge. While all domestic water users, nevertheless the way water is heated, have relatively similar pattern of the water use and wastewater discharge, there is no such pattern for the non-domestic users. Their water consumption and pollution load depends on the production needs and varies significantly from one user to another. In order to overcome this challenge, the approach of substituting non-domestic users with equivalent citizens in regard to their water consumption and BOD pollution was applied according to the Urban Wastewater Directive (Directive 91/271). In relation to the BOD pollution level, non-domestic water users are divided into 3 sub-clusters: 1) non-domestic 1st category; 2) non-domestic 2nd category; non-domestic 3rd category. However, electricity consumption and other pollution loads for non-domestic users will not be considered, because of the impossibility to assess them due to the variety of the industries and products.

2.1.5 Functional unit

According to ISO14045 the functional unit shall be measurable and clearly defined, so that to provide a reference for the environmental assessment and for the product system value assessment. Having in mind that the product of the system has already been defined as "water service", it is logical to select as a functional unit "satisfied consumer", e.g. the eco-efficiency assessment will be done based on the number of the consumers, satisfied with the water service (supplied with drinking water, collection of the generated waste water and its treatment). Consumers could be either citizens (p.e. for non-domestic users) or households, because there is direct correlation between them (Statistical Institute provides mean value of the number of citizens in a dwelling).

Another theoretically possible functional unit is m^3 of used water. However, it is not appropriate one, because its use could lead to wrong conclusions. An illustrating example is given in Table 4 for the environmental indicator "Freshwater depletion": When the amount of the used water is used as a functional unit for the new technology associated with reduction of the used water (Scenario 1) the environmental indicator "Freshwater depletion" could have higher value (1.6 in the example) than in the baseline scenario (1.3 in the example). This means that Scenario 1 has worse environmental performance compared to the baseline scenario, which is wrong conclusion, because in scenario 1 less water is abstracted from the nature. Table 4 illustrates that the use of citizens as a functional unit gives correct trend for this indicator (last row of the table).

Table 4 Illustrative example for misleading use of m^3 as a functional unit

Parameter	Unit	City A	City A after technology
Number of citizens	number	1,000,000	1,000,000
Water used per citizen per day	l/per cit. per day	300	150
Total water used by citizens (W_{used})	m^3	300,000	150,000
Losses in the distribution system	m^3	90,000	90,000
Total water abstracted ($W_{abs}=W_{used}+Loss$)	m^3	390,000	240,000
Freshwater depletion (W_{abs}/W_{used})	m^3/m^3	1.3	1.6
Freshwater depletion (W_{abs}/citizens served)	m^3/citizen	0.39	0.24

2.2 Inventory Analysis

The resources of the modelled system for CS3 are presented in Table 5.

Table 5 Resources of the Sofia Urban Water System (CS3)

Category	Symbol	Resource
Water service related materials	w_1	Water
Supplementary Resources	r_1	Electricity
	r_2	Heat
	r_3	Chlorine (Cl_2)
	r_4	Aluminium Sulphate (Al_2SO_4)
	r_5	Iron (III) Chloride ($FeCl_3$)
	r_6	Flocculants
	r_7	Transport
Emissions to air	e_1	Nitrous Oxides (N_2O)
Emissions to soil	e_2	Sludge
Emissions to water	e_3	Organic pollution measured as COD
	e_4	Organic pollution measured as BOD
	e_5	Nitrogen
	e_6	Phosphorus
	e_7	Water
Products	p_1	Satisfied Customers
By Products	p_2	Renewable energy

2.2.1 Elementary Flows

Year 2011 was chosen for assessment of the baseline scenario, because it was the closest year in which national census was performed. Part of the necessary information was extracted from the questionnaires, which every household filled in for the sake of the census.

Three main data sources were used:

- Local water operator “Sofiyska voda” AD;
- National Statistical Institute; and
- Literature data.

Data from Sofiyska voda

The following tables present the data, which were provided by Sofiyska voda (the Sofia water operator) either upon request or from their officially published documentation.

Table 6 Inventory of flows in the stage "Water treatment plant" (annual values)

Parameter	Unit	WTP Bistritsa	WTP Pancharevo	WTP Mala Tsarkva
Water quantity Inlet	m^3	87,195,313	77,334,440	13,031,690
Water quantity Outlet	m^3	85,485,601	76,544,505	12,578,852
Water Losses	m^3	1,709,712	789,935	452,838
Aluminium sulphate	kg	91,040	151,879	-
Sludge	kg	772,300	612,500	-
Electricity	kWh	877,725	448,681	23,280

Table 7 Inventory of flows in the stage "Wastewater treatment plant" (annual values)

Parameter	Unit	Value
Water quantity	m^3	147,942,306
Sludge	t	101,537
Produced electricity	kWh	13,915,000
Electricity used	kWh	20,213,179
Produced Methane gas	m^3	8,331,210
Exported electricity to the grid	kWh	556,768
Produced Heat	kWh	14,248,960
Flocculant	kg	156,700
$FeCl_3$	kg	2,419,000
BOD load inlet	kg	13,175,766
BOD load outlet	kg	2,256,799
Total N inlet	kg	2,991,644
Total N outlet	kg	1,555,744
P inlet	kg	391,168
P outlet	kg	139,281
N_2O outlet	kg	283,819
COD inlet	kg	31,544,547
COD outlet	kg	4,434,122

Table 8 Data for calculation of the flows, connected to transport associated with water treatment plant needs

	Unit	Aluminium sulphate	Cl_2	Sludge
Quantity reagent or sludge per delivery	t/delivery	22	4	15
Distance to provider/disposal place	km	300	700	18

Table 9 Data for calculation of the flows, connected to transport associated with wastewater treatment plans needs

	Unit	$FeCl_3$	Flocculant	Sludge
Quantity reagent or sludge per delivery	t/delivery	20	20	12
Distance to provider/disposal place	km	300	850	25

Data from the National Statistical Institute

Table 10 Data from the national census 2011

Total citizens	1,291,591
Dwellings (calculated)	576,603
Density	2.24 citizens per dwelling
Citizens connected to centralized sewerage system	98.2% or 1,268,342

2.2.2 Economic Data

Table 11 Economic data (from Sofiyska Voda)

Parameter	Value	Unit
Operation costs		
Aluminium sulphate	0.22	€/kg
Chlorine	0.22	€/kg
Electricity	0.06	€/kWh
Transport	0.075	€/t-km
Flocculant	2.45	€/kg
$FeCl_3$	0.11	€/kg
Water tariffs for domestic users		
Drinking water tariff	0.51	€/m^3
Wastewater collection and treatment tariff	0.25	€/m^3
Total	0.75	€/m^3
Water tariffs for Non-domestic users Category 1		
Drinking water tariff	0.51	€/m^3
Wastewater collection and treatment tariff	0.38	€/m^3
Total	0.88	€/m^3
Water tariffs for Non-domestic users Category 2		
Drinking water tariff	0.51	€/m^3
Wastewater collection and treatment tariff	0.48	€/m^3
Total	0.99	€/m^3
Water tariffs for Non-domestic users Category 3		
Drinking water tariff	0.51	€/m^3
Wastewater collection and treatment tariff	0.57	€/m^3
Total	1.07	€/m^3

Table 12 Additional data assisting calculations

Parameter	Unit	Value	Source
Cost for water abstraction	€/m^3	0.01	State Gazzete, 2011
Cost for water discharge	€//m^3	0.001	State Gazzete, 2011
Cost for central water heating	€//kWh	0.05	State Gazzete, 2011

2.3 Data processing

Prior to the assessment of the eco-efficiency, a number of assisting calculations was performed. They are explained in the following sub-sections.

2.3.1 SEAT input data

Domestic water use

The domestic water consumption is one of the most important parameters in the foreground urban water system. There are no reliable official data about this parameter for Sofia urban system. To estimate it, data from two sources were collected and analysed:

1) National Statistical Institute (NSI) – purchased data

These data include specific information for each of the studied residential buildings from the census in 2011 – total number of apartments, number of inhabitable apartments, number of inhabitants, use of water appliances (washing machines and dishwashers).

2) Water Operator “Sofiyska voda” – these data were kindly provided to us

Two types of data were collected: records of the water meters of the buildings and record of the individual water meters in the households. Both hot and cold water records were collected. These data were requested for the two main types of water users:

- Type 1 households - with district water heating;
- Type 2 households - with local water heating (electric boilers or alternative heaters);

Sofia has above 1,000,000 citizens and it would be too time and money consuming process to analyse all districts. Because of this, representative areas were selected – 8 DMAs, which are relatively independent elements of the water supply system and could be used for further analyses in regard to implementation of new technologies. The results could be than extrapolated for the entire urban water system.

Type 1 households - with district water heating

The studied extract includes 621 blocks with 54.380 inhabitants. In this area around 97% of the buildings are connected to district heating network thus most of the users take advantage of the district water heating service.

Some discrepancies between the data from NSI and Sofiyska voda and in each data set were found. The unreliable data were excluded and at the end only 90 blocks with population of about 16,000 inhabitants were selected for further analysis. The process with the justifications for exclusions of the records is presented in Figure 2.

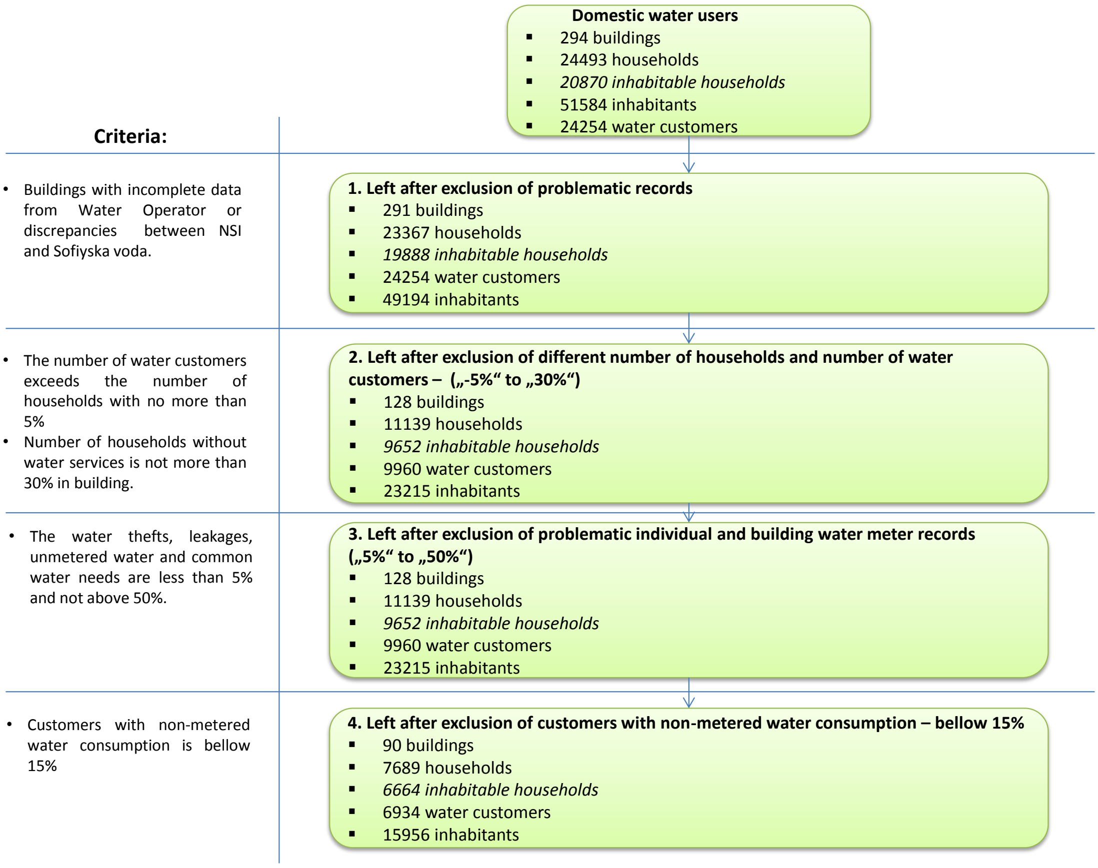


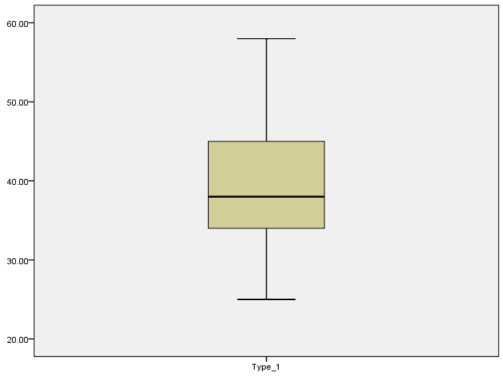
Figure 2 Selection of reliable data for further analysis

To check the representativeness of the extract, a normality test with Shapiro-Wilk method was done. The average water consumption per inhabitant in each block was tested. The result shows that the data have a normal distribution and thus the calculated mean value for water demand per inhabitant is a reliable parameter (Figure 3).

Total water use (cold plus hot) per capita in households with district water heating

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Type_1	.974	90	.068



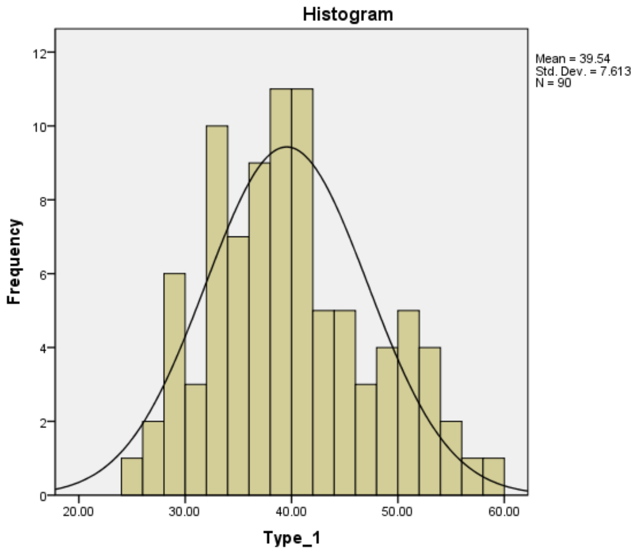


Figure 3 Tests of normality and calculation of mean value of water consumption (90 records)

The calculated average values of the representative extract of these 90 buildings are given in Table 13. These data will be used as input data in the SEAT model.

Table 13 Water use in households with district water heating

District water heating (Type 1)				
Water Demand	39.54	m3/ca.year	108	l/ca.day
Hot water demand (45%)	17.79	m3/ca.year	49	l/ca.day
Cold water demand (55%)	21.75	m3/ca.year	59	l/ca.day
Water demand per household	88.57	m3/hh.year	243	l/hh.day

Type 2 households - with local water heating

No statistical data were purchased for this type of households. They are situated mostly in the surrounding areas of Sofia where there is no district heating and where the density of inhabitants per household is lower than in the central areas. An average of 2.12 inh./hh (inhabitants/household) was assumed for calculations. For these users only data for total (sum of cold and hot) water consumption are available and were provided to us by Sofiyska voda. Similar to the Type 1 households, Shapiro-Wilk normality test was performed. The results of the test are satisfactory so the calculated values are considered to be reliable (Figure 4).

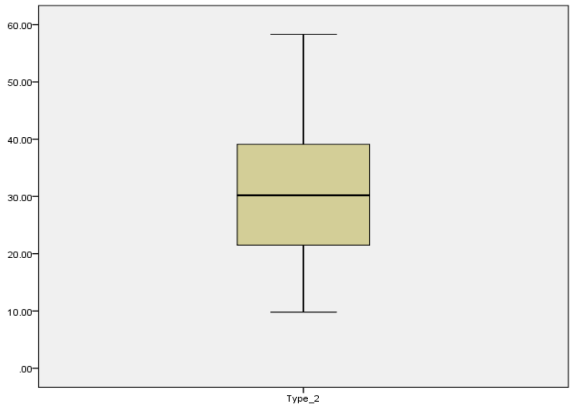
Table 14 Water use in households with local water heating

Local water heating (Type 2)				
Water Demand	31.38	m^3/ca.year	86	l/ca.day
Hot water demand (35%)	10.98	m^3/ca.year	30	l/ca.day
Cold water demand (65%)	20.40	m^3/ca.year	56	l/ca.day
Water demand per household	70.29	m^3/hh	193	l/ca.day

Total water use (cold plus hot) per capita in households with local water heating

Tests of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Type_2	.973	66	.152



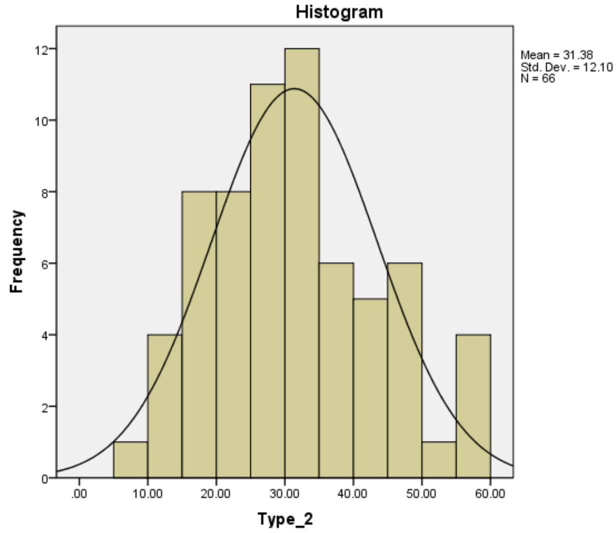


Figure 4 Tests of normality and calculation of mean value of water consumption (66 records)

Data in Table 13 and Table 14 show that the consumers with district water heating use more water than these with local water heating. Possible reasons for that are: 1) lost volumes of water when the circulation systems in buildings are not working properly; 2) there is no limit of hot water so people spend more time under the shower.

Another parameter, needed for SEAT calculations is the distribution of the total consumed water between hot and cold water. In households with district water heating hot and cold water meters are available, so calculations were performed, which show that hot water is around 45% of the total water consumption. The customers with local water heating have only water meter for the total water consumed. For them it is assumed 35% hot water and 65% cold water consumption from literature data.

The last set of the necessary data concerns the distribution of users in relation to the type of the water heating. These data were taken from the NSI and were available in Deliverable 3.1. For clarity, a table is shown here as well (Table 15).

Table 15 Distribution of users depending on type of water heating

Type of water heating	Part of dwellings *(Taken from D3.1)*	Number of Households	
Electric water heating	32%	181,192	hh
District water heating	63%	356,721	hh
Alternative water heating	5%	28,311	hh

Non - domestic water use

Sofiyska voda provided the total amount of the water used by non-domestic users. Its distribution among the 3 categories was assumed to be equal to the % distribution for the year 2012, for which data were available (SCEWM, 2013).

Table 16: Water use by different types of users

Stage	Water used (m^3/year)
Non-domestic use total	7,208,742 (100%)
Category 1	6,559,955 (91%)
Category 2	504,612 (7%)
Category 3	144,175 (2%)

Calculation of the person equivalents

The Sofia urban water operator has determined 3 categories of non-domestic users in dependence of their BOD_5 pollution, respectively:

- Category 1 – BOD_5 up to 200 mg/l;
- Category 2 – BOD_5 200 and 400 mg/l;
- Category 3 – BOD_5 above 400 mg/l.

Data about the water quantities, consumed by these three categories are available (Table 16).

According to the report of the water operator the wastewater is 90% of the water used (SCEWM, 2013). In order to perform the necessary calculations, the most common values from the measurements for the three categories were accepted as fixed characteristic values for these categories:

- Category 1 – BOD_5 =180 mg/l;
- Category 2 – BOD_5=300 mg/l;
- Category 3 – BOD_5=1,000 mg/l.

With these data and the assumptions that BOD per citizens is 60 g/d, the p.e. were calculated as follows (Table 17).

Table 17 Calculation of the person equivalents

Type of use	Waste water in m3/year	BOD concentration in gram/year	BOD Load in t/year	Person equivalents
Domestic use	57,571,600	-	27,777	1,268,342
Non-domestic use				
Category 1	5,903,960	180	1,063	48,526
Category 2	454,151	300	136	6,221
Category 3	129,757	1000	130	5,925
Total	64,059,468	-	29,105	1,329,014

Calculations related to material flows "Transport"

There are two major transport contributors in the system – the water purification plant and the wastewater treatment plant. Data about the quantity per delivery, number of deliveries and distance to the provider were requested and provided (Table 8 and Table 9) so the transport as t-km/year was calculated (Table 18 and Table 19).

Table 18 Calculation of the transport flow in the WTP

Item	Unit	Aluminium sulphate	Cl_2	Sludge
Quantity per delivery/disposal of sludge	t/delivery	22	4	15
Number of deliveries	deliveries	12	104	93
Distance to provider	km	300	700	18
Transport	t-km/year	79,200	291,200	25,110
Total Transport	t-km/year		370,400	25,110

Table 19 Calculation of the transport flow in the WWTP

Item	Unit	$FeCl_3$	Flocculant	Sludge
Quantity per delivery/disposal of sludge	t/delivery	20	20	12
Number of deliveries	deliveries	121	8	8,460
Distance to provider	km	300	850	25
Transport	t-km/year	726,000	136,000	2,538,000
Total Transport	t-km/year		862,000	2,538,000

Calculations related to heating of water with electric boilers for domestic use

The energy for heating 1 m^3 of cold water is calculated using equation 1 (Dimitrov, 2009):

$$N = \frac{Q.\rho.c.(t_h - t_c)}{3600.\tau.\eta} \qquad (1)$$

where:

- N is the energy for heating 1m^3 of water
- t_c the temperature of cold water
- t_h the temperature of hot water (56^{o}C for average boilers)
- ρ the density of water
- c the specific heat (4190 J/m^3)
- τ the heating duration
- η the heater efficiency

$$N = \frac{Q\cdot\rho\cdot c\cdot(t_h - t_c)}{3600\cdot\tau\cdot\eta} = \frac{1\cdot1\cdot4{,}190\cdot(56-10)}{3600\cdot1\cdot0.9} = 60kWh/m^3$$

Calculations of the energy used by water appliances (dish washers and washing machines)

In the domestic use of water, there are two more appliances beside water heating, which consume not only water, but energy as well. These are dishwashers and washing machines. Considering the cultural characteristics of Sofia citizens and the data, provided in the census questionnaires it is assumed that:

- There are two major types of households: households without dishwashers, which prevail being around 75% and households having dishwashers (the remaining 25%).
- The households without dishwashers are usually low-income ones, therefore their washing machines are old, here accepted being energy Class C;
- The households with dishwashers are usually high income ones, who replace regularly their sanitary appliances. Therefore, it is accepted that their appliances (both dishwashers and washing machines) are energy Class A.

The standard annual energy consumption (SAEc) of the household dishwasher is calculated using Equation 4 (COMMISSION DELEGATED REGULATION of 28.9.2010).

SAEc =25.2.ps +126 = 25.2.10+126 = 378kWh/year (4)

where ps is the average number of place settings. An average number of 10 place settings is assumed for most commonly used dishwashers.

According to literature data, the Energy Efficiency Index (EEI) of the dishwashers Class A is between 63 and 71 (COMMISSION DELEGATED REGULATION (EU) of 28.9.2010). Here a value of 67 is assumed, which gives energy efficiency of:

Energy efficiency dishwashers Class A = EEI.SAEc = 67%.SAEc = 253 kWh/year

The standard annual energy consumption (SAEc) of the household washing machine is calculated according Equation 5 (COMMISSION DELEGATED REGULATION (EU) of 28.9.2010):

SAEc =47.0.c +51.7 = 47.0.6+51.7 = 334 kWh/year (5)

where c = 6 kg average rated capacity of the household washing machine for the standard 60°C cotton programme at full load or the standard 40°C cotton programme at full load, whichever is the lower.

According to literature data, the Energy Efficiency Index (EEI) of the washing machines Class A is between 59 and 68, Class C between 77 and 87 (COMMISSION DELEGATED REGULATION (EU) of 28.9.2010). Here value of 53 is accepted for Class A and value of 80 is accepted for Class C, which gives energy efficiencies of:

- Energy efficiency Class A = EEI.SAEc = 53%.SAEc = 177 kWh/year
- Energy efficiency Class C = EEI.SAEc = 80%.SAEc = 267 kWh/year

These values are used for calculation of the energy, used by the households' sanitary appliances in the SEAT model.

Energy recovery

Since 2006 a cogeneration technology is introduced in WWTP Kubratovo. It is a technology that simultaneously generates both heat and electricity. Cogeneration utilizes about 82% of the energy content of the fuel (methane gas from digesters) and turns it into a useful/utilized energy. It consists of three co-generators each with 1 MW power rating.

The entire produced heat energy is used for WWTP needs. Most of the produced electricity is used on site and only about 560,000 kWh/y are sold to the grid. This way the purchased electricity from the electricity provider is reduced (Table 20).

Table 20 Energy balance of WWTP in kWh per year

Produced electricity	Produced Heat	Sold electricity to the grid	Total electricity use	Purchased electricity
13,915,000	14,248,960	556,768	20,213,179	6,854,947

Calculations of the Freshwater Ecosystem Impact (FEI)

Although many LCA studies consider fresh water use, there is no satisfactory and well accepted assessment method, especially when the production system is an urban water supply system. Some authors suggest that when water is abstracted from a river to provide drinking water for a city, there is no environmental concern. Urban water use is characterized as non-evaporative water use, because major part of the water returns back to the nature, nevertheless that 1) the discharge point is downstream of the abstraction point; 2) there is pollution associated with the discharge (Mila i Canals et al, 2009). Others state that when water is abstracted for human needs, the ecosystem equilibrium of the water source will be damaged between abstraction and discharge points. In our study the impact on the ecosystems due to abstraction of water is considered, because the discharge point is approximately 100 km downstream abstraction point. The methodology proposed by Milá i Canals (2009) will be applied, although they propose a constant value for the regional WTA (water withdrawal to availability) ratio, which does not correspond to the reality.

The Freshwater Ecosystem Impact (FEI) indicator is defined as:

$$FEI = f_{w,0-1} \times WTA \tag{6}$$

where:

$f_{w,0-1}$: flow of freshwater abstracted

WTA water withdrawal to availability ratio, defined as:

$$WTA = \frac{WU}{WR} \tag{7}$$

where:

WU: the total annual freshwater withdrawal in a river basin; and

WR: is the annual freshwater availability in the same basin.

The average WEI for Sofia is 0.43 (Ribarova, 2009). However, since the freshwater ecosystem impact indicator refers to the foreground river basin only foreground impacts are calculated. Flows of the freshwater abstracted per stages are as follows:

- WTP – process water and own consumption;
- Distribution network – water losses in it;
- Water use stage – recorded water use quantities;
- The entire system – sum of the losses and the used water.

2.3.2 EVAT input data

The economic performance of the system is estimated using equation 8:

$$\mathrm{TVA} = \mathrm{EVU} - \mathrm{TFC_{WS}} - \mathrm{TFC_{WW}} + \mathrm{VP_{BP}} - \mathrm{FC} \qquad (8)$$

where:

- EVU is the total economic value from water use,
- $\mathrm{TFC_{WS}}$ is the total financial cost related to water supply provision for rendering the water suitable for the specific use purpose,
- $\mathrm{TFC_{WW}}$ is the total financial cost related to wastewater treatment,
- $\mathrm{VP_{BP}}$ is the income generated from any by-products of the system, and
- FC is the annual equivalent future cash flow generated from the introduction of new technologies in the system.

For calculation of EVU it is assumed that the level of water services provided (the functional unit) will not change as a result of technology implementation (i.e. the application of a technology or management practice will not result in supply interruptions or render the quality of water unsuitable for the specific purpose) and that the total utility (the overall satisfaction of wants and needs) does not change between scenarios. The economic value from water use is given then by equation 9:

$$\mathrm{EVU} = \mathrm{EVU^{bl}} = \mathrm{WTP} \times \mathrm{f^{bl}_{w,2-3}} \qquad (9)$$

where:

- WTP is the customers' willingness to pay for the services provided (defined as the maximum amount a person would be willing to pay in order to receive a reliable and adequate water supply);
- $\mathrm{f}^{bl}_{\mathrm{w},2-3}$: the total quantity of water supplied to the processes of water use stage.
- The superscript bl indicates the baseline scenario.

The EVU in Sofia is generated from of the following services to the costumers:

- water supply service;
- water heating;
- wastewater discharge;

- wastewater treatment.

Table 21 shows how EVU for these services per household in Sofia was calculated.

Table 21 Calculation of EVU for domestic users (566,224 households)

EVU for water supply, waste water sewerage and treatment				
Average water consumption per household in baseline scenario	115.00	m^3/hh.year		
Water tarriff (water supply, waste water sewerage and treatment)	1.47	lv/m^3	0.75	€/m^3
Willingness to pay per m^3 (assumed, increased with 100%)	2.94	lv/m^3	1.50	€/m^3
EVU for water per household	**338.10**	**lv/hh.year**	**172.84**	**€/hh.year**
EVU for water per year	**191,440,334**	**lv/year**	**97,868,511**	**€/year**
EVU for water heating				
Hot water consumed in average household	42.00	m^3/hh.year		
Maximum costs for heating 1m^3 of water	6.60	lv/m^3	3.37	€/m^3
Willingness to pay for water heating (assumed, the higher cost is increased with 20%)	7.92	lv/m^3	4.05	€/m^3
EVU for water heating per household	**332.64**	**lv/hh.year**	**170.05**	**€/hh.year**
EVU for water heating per year	**188,348,751**	**lv/year**	**96,288,025**	**€/year**
Total EVU				
Total EVU per household	**670.74**	**lv/hh.year**	**342.90**	**€/hh.year**
		Assumed total willingness to pay per household	**350.00**	**€/hh.year**
		Total EVU per year	**198178,400**	**€/year**

For non-domestic users it is assumed that their willingness to pay per m^3 of water is the same as for domestic thus their EVU is calculated in Table 22 .

Table 22 Calculation of EVU for non-domestic users

EVU for water supply, waste water sewerage and treatment for non-domestic users				
Total water consumption of non-domestic Category 1 in BSL	6,559,955	m^3/year		
Total water consumption of non-domestic Category 2 in BSL	504,612	m^3/year		
Total water consumption of non-domestic Category 3 in BSL	144,175	m^3/year		
Willingness to pay per m3 (assumed, as domestic)	2.94	lv/m^3	1.50	€/m^3
EVU per year for non-domestic Category 1 users	19,286,268	lv/year	9,859,564	€/year
EVU per year for non-domestic Category 2 users	1,483,559	lv/year	758,428	€/year
EVU per year for non-domestic Category 3 users	423,875	lv/year	216,694	€/year
Total EVU per year	**21,193,701**	**lv/year**	**10,834,686**	**€/year**

2.4 Environmental performance

2.4.1 Assessment steps

Life cycle inventory

According to ISO 14045 the environmental assessment should be based on LCA. Life cycle inventory (LCI) is an obligatory step, while life cycle impact assessment (LCIA) could be optionally carried out. In this study first LCI was performed, followed by LCIA. The LCI for Sofia case study is well visualized in SEAT model for Sofia (Figure 5).

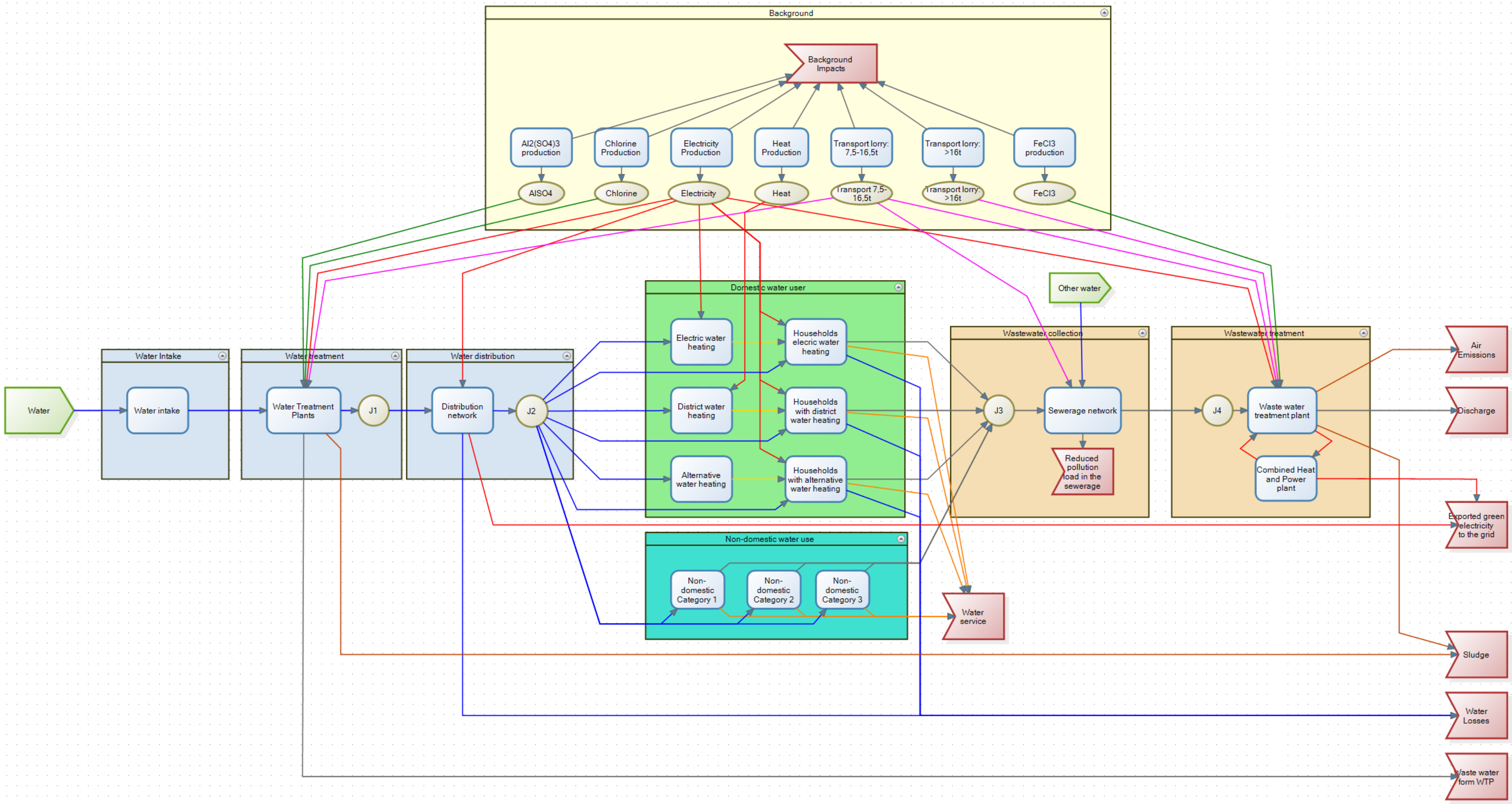


Figure 5 The SEAT model of Sofia urban water system

Life cycle impact assessment

In relation to the LCIA, the two mandatory steps were done, namely:

1) Selection of impact categories and classification;

2) Characterization (ISO 14044, 2006).

Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project (EcoWater, 2013), 12 impact categories are selected as the most representative for the environmental assessment of the system.

The characterization factors used for the estimation of the impact of the foreground system are presented in Table 23.

The environmental impact factors per unit of produced good in the background processes are presented in Table 24.

They are obtained from ELCD and Ecoinvent 2.2 databank with SimaPro 7 software using the following LCIA methods - CML 2001, TRACI and ReCiPe.

Table 23 Characterization Factors of Foreground Elementary Flows (Guinee et al., 2001)

Impact Category	Unit	COD (per kg)	N (per kg)	P (per kg)	N_2O (per kg)
Climate Change	kg $CO_{2,eq}$	-	-	-	298
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	0.022	0.42	3.06	0.27
Acidification	kg $SO_2^{-}{}_{,eq}$	-	-	-	-
Stratospheric Ozone Depletion	kg CFC-$11_{,eq}$	-	-	-	-
Human Toxicity	kg1,4-$DCB_{,eq}$	-	-	-	-
Freshwater Aquatic Ecotoxicity	kg1,4-$DCB_{,eq}$	-	-	-	-
Terrestrial Ecotoxicity	kg1,4-$DCB_{, eq}$	-	-	-	-
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	-	-	-	-

Table 24 Environmental Impact Factors for Background ProcessesResults

Impact category	Unit	Electricity mix BG (per kWh)	Transport, lorry 7.5-16t, (per tkm)	Transport, lorry 16-32t, (per tkm)	Chlorine (per kg)	Aluminium sulphate (per kg)	Iron (III) chloride (per kg)	Heat at CHP (per kWh)
Acidification	kg SO_2,eq	0.033003465	0.000830000	0.000635000	0.005290000	0.010100000	0.00423657	0.00077101
Eutrophication	kg PO_4^{-3},eq	0.000408298	0.000216102	0.000167264	0.003557898	0.001408591	0.00291287	0.00014983
Freshwater aquatic ecotoxicity	kg 1.4-DB,eq	0.000878382	0.017308751	0.014042314	0.612623681	0.638787702	0.58274349	0.00341698
Climate change	kg CO_2,eq	0.906527531	0.220936004	0.165091144	1.054946263	0.491834290	0.80061956	0.60601591
Human Toxicity	kg 1,4-DB,eq	0.062420999	0.032677433	0.025875140	0.442448207	0.168812133	0.79793335	0.00489735
Ozone layer depletion	kg CFC-11 eq	0.000000121	0.000000031	0.000000023	0.000002820	0.000000038	0.00000173	0.00000012
Photochemical Oxidation	kg C_2H_4,eq	0.001282044	0.000025825	0.000020167	0.000211724	0.000398556	0.00017938	0.00006254
Terrestrial Ecotoxicity	kg 1.4-DB.eq	0.000261121	0.000035779	0.000029188	0.002080718	0.000117068	0.00189525	0.00001150
Mineral Depletion	kg Fe eq	0.000162000	0.008980000	0.007850000	0.084800000	0.033300000	0.193000000	0.002140000
Fossil Depletion	kg oil eq	0.212000000	0.080700000	0.061100000	0.304000000	0.151000000	0.231000000	0.023000000
Respiratory Inorganics	kg PM10,eq	0.006480000	0.000175000	0.000131000	0.001210000	0.002170000	0.001110000	0.000077813

The results of the environmental impact of the background and foreground systems as well as their cumulative values are presented in Table 25 and Figure 15.

2.4.2 Results

The results of the environmental impact of the background and foreground systems as well as their cumulative values are presented in Table 25 and Figure 15.

Table 25 Environmental indicators results for CS3 baseline assessment

Impact category	Unit	Value (Unit)	Foreground Value (Unit)	Background Value (Unit)
Climate change	tn CO_2,eq	1,304,690	10,058	1,294,632
Fossil Fuels Depletion	GJ	6,027,939	0	6,027,939
Freshwater Resource Depletion	m^3	71,659,616	71,659,616	0
Eutrophication	kg PO_4^{-3},eq	2,046,825	1,620,563	426,262
Human Toxicity	kg 1.4-DB,eq	41,845,153	0	41,845,153
Acidification	kg SO_2,eq	18,507,535	0	18,507,535
Aquatic ecotoxicity	kg 1,4-DB,eq	6,903,629	0	6,903,629
Ozone layer depletion	kg CFC-11 eq	230	0	230
Terrestrial Ecotoxicity	kg 1,4-DB,eq	159,085	0	159,085
Respiratory Inorganics	kg PM10,eq	3,536,098	0	3,536,098
Photochemical Oxidation	kg C_2H_4,eq	762,612	0	762,612
Mineral Depletion	kg Fe eq	3,495,351	0	3,495,351

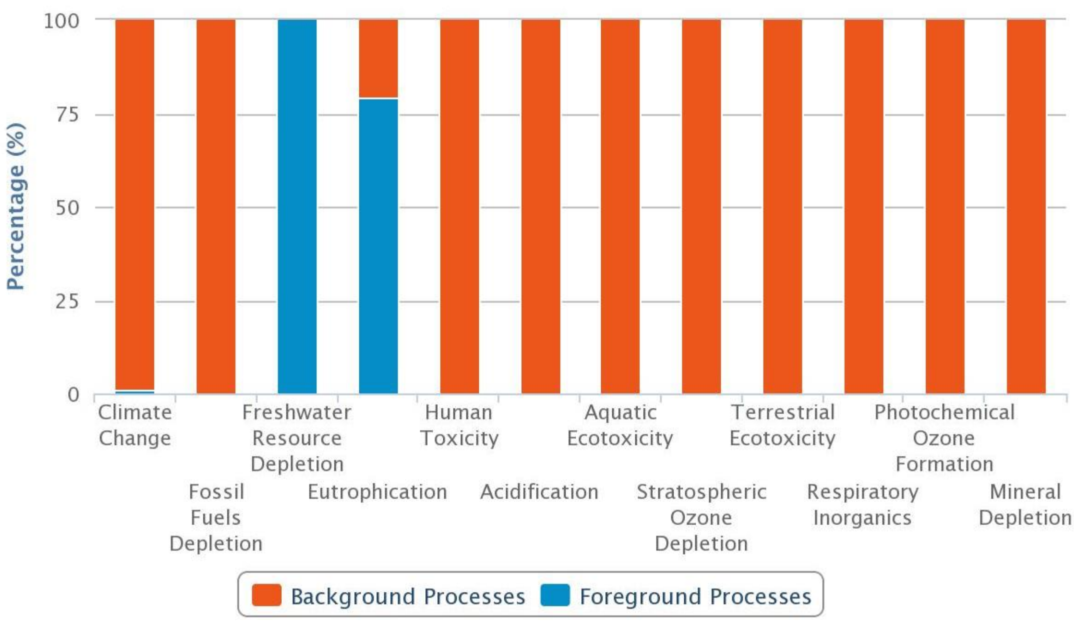


Figure 6 Contribution of Foreground and Background Systems in the environmental impact categories

Figure 6 shows that the foreground system has negative environmental impact only in regard to climate change, freshwater resource depletion and eutrophication. In addition to this analysis, it is useful to know what the contribution of each stage is. This will allow identification of the stages, which are environmentally weak as well as selection of technologies for their better performance. The environmental impact by stages is presented in two separate charts – one for the background system (Figure 7) and one for the foreground system (Figure 8).

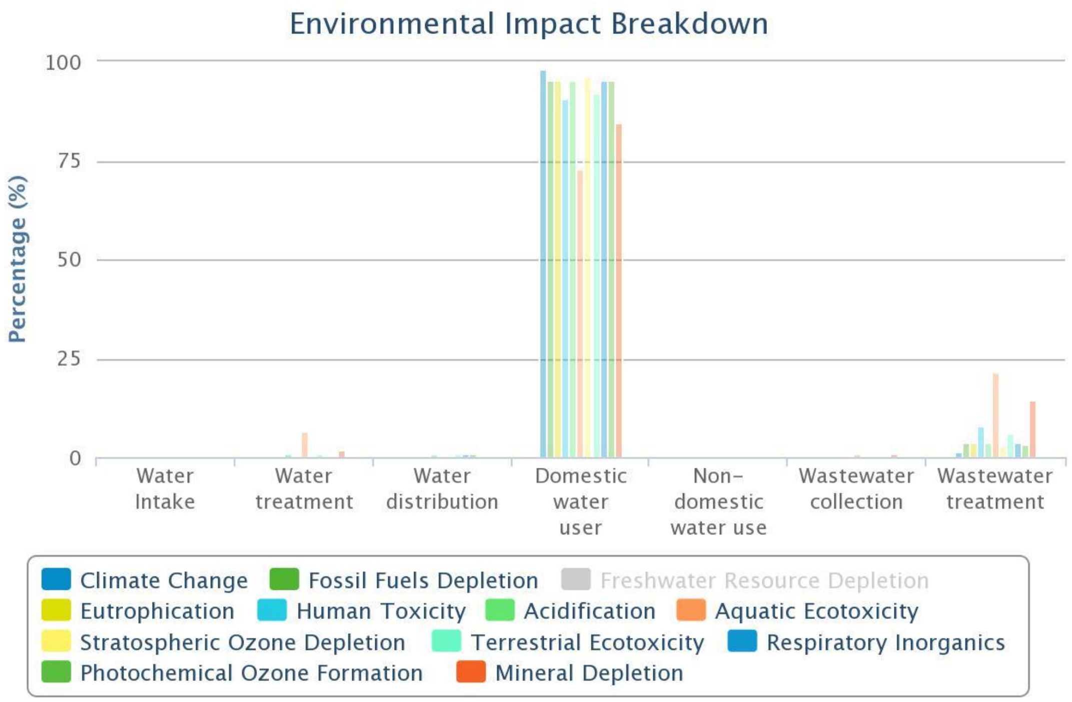


Figure 7 Environmental Impact Breakdown of the background system, percentage per stage

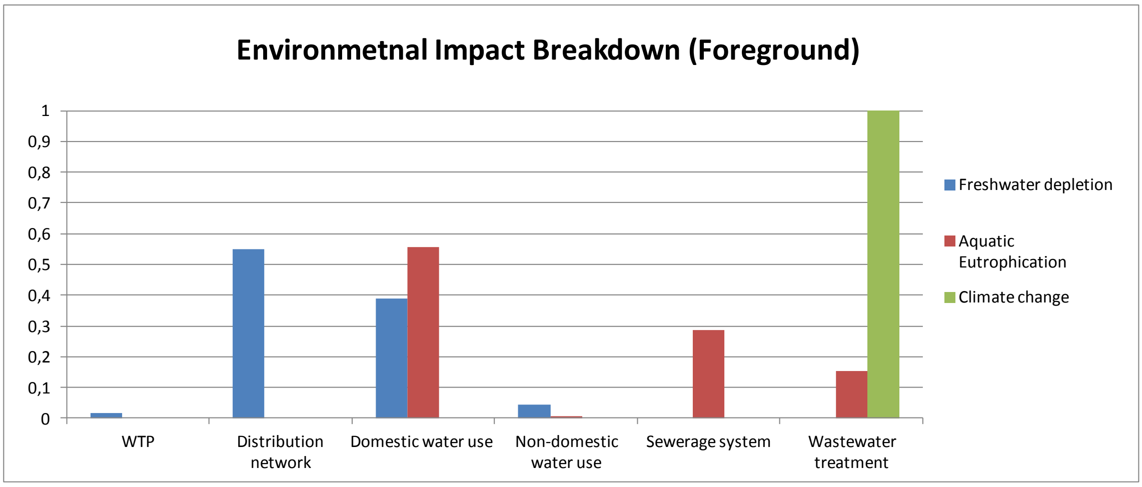


Figure 8 Environmental Impact Breakdown of the foreground system, percentage per stage

Figure 7 and Figure 8 show that for the background system the water use stage is the environmentally weakest one for all indicators. It is also the weakest stage in regard to one of the indicators of the foreground processes – the aquatic eutrophication. This confirms the conclusions, drawn from another studies that the most significant system component in terms of operational energy are the residential end uses of water due to heating the water and operation of dishwashers and clothes washers (Flower, DJM. et al., 2007). In the study of Flower, the mass of GHG emissions in an urban water system with gas storage hot water service was found to be 2088 kg CO_2-eq. per household per year. The value for households with electric storage hot water service was reported to be 6860 kg CO_2-eq. per household (Flower, DJM. et al., 2007). For Sofia urban water system these values are: 1814 kg CO_2-eq per household with electric water heating and 2410 kg CO_2-eq. per household connected to district water heating.

The second problematic stage is the wastewater treatment plant, which shows negative environmental impact in both foreground and background systems.

The third problematic stage is the distribution network, which shows the worst performance in regard to the most important indicator of the foreground system – the freshwater ecosystem impact.

The reasons for such performance of the stages should be well analysed in order to suggest appropriate innovative technologies, which will allow better environmental performance (will be done in Deliverable 3.3).

2.5 Economic performance

The ISO 14045 standard provides only general requirements for assessment of the product system value. The difficulty with its determination is that different stakeholders may attach different values to the same product system (ISO14045, 2012). Economics often determines the value of the product to the supplier (the water operator in our case) as a difference between income and cost, equal to the profit (ISO14045, 2012). For customers the value is called “surplus value” and is most often equivalent to willingness to pay (ISO14045, 2012).

After many discussions it has been decided that in EcoWater project product system value will be assessed through Total Value Added (TVA), which is explained in more details in chapter 2.3. In addition to it, the Sofia Case study applied the so called “One over cost” method, explained briefly below.

When comparable products are considered Monczka et al. (2005) suggest a value can be calculated as a ratio between function and costs:

$$Product\ system\ value = \frac{function}{costs} \qquad (10)$$

In the case of urban water systems, the product is unity - the water service to the customers, as indicated above. As in other studies using equation (10) the function may therefore be accepted as equal to 1, where “1” means that the product system fulfils its functions (Michelsen , 2006; Monczka et al., 2005). So, the product system value is:

$$Product\ system\ value = \frac{1}{costs} \tag{11}$$

This approach sidesteps the difficulty with the different valuations of the stakeholders, because it considers only the associated costs of operation of the system and is not interested in the pricing policy, profits for the company or the benefits of the users. This makes its determination relatively easy, because it does not require confidential data such as profits and non-quantifiable data such as benefits to the users.

Table 26 Economic performance results (all results are in € per year)

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Water Operator	18,112,091.91	33,406.08	54,043,452.73	35,964,766.90
Domestic Water Users	97,151,597.49	198,178,400.00	-48,636,896.23	52,389,906.28
Non Domestic Water Users	0.00	10,834,686.00	-5,406,556.50	5,428,129.50
Total Value Added				**93,782,802**

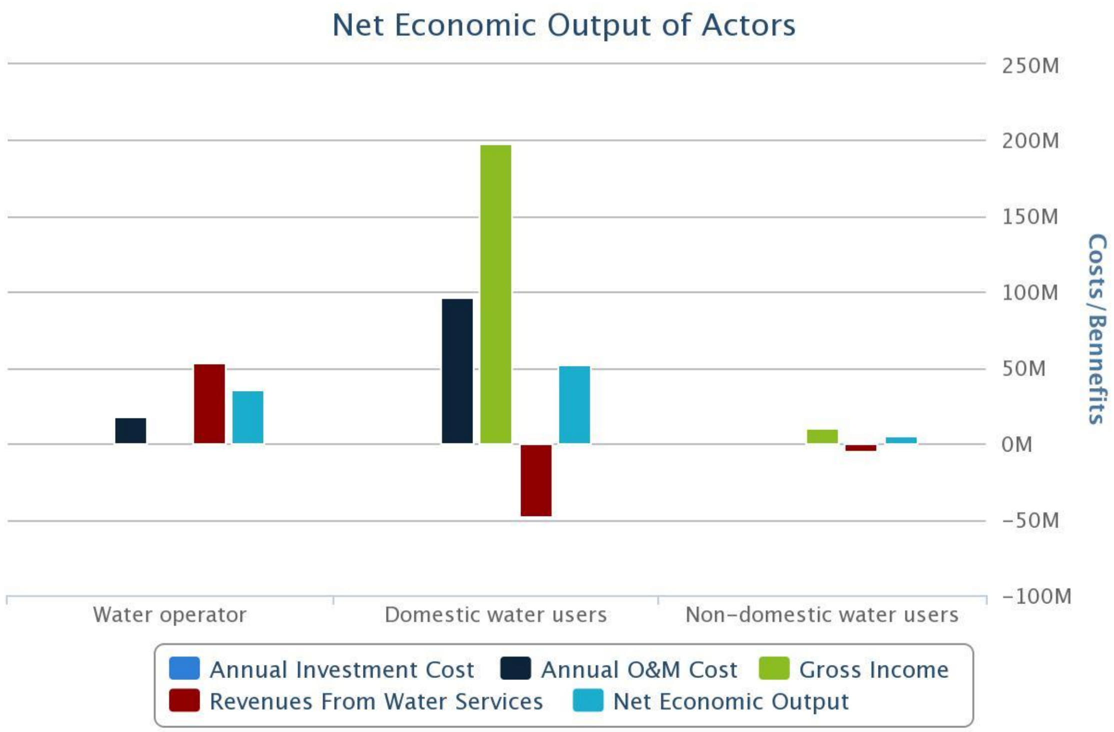


Figure 9 Economic Performance per Actor

The assessment of the economic performance through TVA has the advantage that the share of each actor could be easily revealed and this could be a good base in debating about new technology implementation and the burden of each actor (Figure 9). Table 26 summarizes the economic performance assessment of the studied system using TVA method. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 93,782,802 €.

2.6 Eco-efficiency indicators

The eco-efficiency indicators are determined using environmental and economic assessment presented above. Table 27 summarizes the values of the eco-efficiency indicators, corresponding to the 12 relevant environmental impact categories and TVA method for calculation of the economic performance.

Table 27 Eco-efficiency indicators using TVA

Environmental indicator	Unit	Value (€/unit)
Climate Change	t $CO_{2,eq}$	71.88
Fossil Fuels Depletion	MJ	0.02
Freshwater Resource Depletion	m^3	1.31
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	45.82
Human Toxicity	kg 1,4-$DCB_{,eq}$	2.24
Acidification	kg $SO_2^{-}{}_{,eq}$	5.07
Aquatic Ecotoxicity	kg 1,4-$DCB_{,eq}$	13.58
Stratospheric Ozone Depletion	kg CFC-$11_{,eq}$	407,455.41
Terrestrial Ecotoxicity	kg 1,4-$DCB_{,eq}$	589.51
Respiratory Inorganics	kgPM10,eq	26,52
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	122.98
Mineral depletion	kg Fe-eq	26.83

Table 28 summarizes the values of the eco-efficiency indicators, corresponding to the 12 relevant environmental impact categories and 1/cost method for calculation of the economic performance.

Table 28 Eco-efficiency indicators using 1/cost

Environmental indicator	Unit	Value ($€^{-1}$/unit $*10^{16}$)
Climate Change	t $CO_{2,eq}$	66.50
Fossil Fuels Depletion	MJ	0.01
Freshwater Resource Depletion	m^3	1.21
Eutrophication	kg $PO_4^{-3}{}_{,eq}$	42.39
Human Toxicity	kg 1,4-$DCB_{,eq}$	2.07
Acidification	kg $SO_2^{-}{}_{,eq}$	4.69
Aquatic Ecotoxicity	kg 1,4-$DCB_{,eq}$	12.57
Stratospheric Ozone Depletion	kg CFC-$11_{,eq}$	376,928.32
Terrestrial Ecotoxicity	kg 1,4-$DCB_{,eq}$	545.35
Respiratory Inorganics	kgPM10,eq	24.53
Photochemical Ozone Formation	kg $C_2H_{4,eq}$	113.76
Mineral depletion	kg Fe-eq	24.82

At this stage, when only the results for the baseline scenario assessment are available, comparison between the two methods for assessment of the economic performance of the system cannot be done. However, the results in the two tables show that the trends are similar.

2.7 Next steps

The baseline estimation showed that the stage with the highest negative environmental impact is the domestic use stage. The other two stages with high negative environmental impact are the distribution network and the WWTP. This analysis serves to the selection of the technologies, which will be used in the comparative scenarios (Table 29). Most attention is paid on the weakest stage – the domestic water use.

These technologies are described in details in Deliverable 3.3. In the next project phase the eco-efficiency of the urban water system will be assessed for different scenarios, based on single or combination of implementation of these technologies.

Table 29 Technologies, which will be used in the comparative scenarios

N	Technology name	Unit of implementation	Reason for selection
T1	Hydropower generator which functions as a pressure reduction valve	Distribution network	Will lower the water losses due to the high pressure, thus will lower the value of the indicator "freshwater resource depletion". In addition, it will improve the energy balance and it will reduce the relevant environmental impacts concerning energy production.
T2	Solar drying of the sludge	WWTP	Will lower the values of the transport and all relevant environmental impacts associated with it (Mainly the fossil fuel depletion and climate change)
T3	Water saving appliances (low flushing toilets, shower heads, dishwashers, washing machines)	Households	Will lower the amount of abstracted water and the value of indicator "freshwater ecosystem impact" respectively. Replacing the old water appliances with energy and water efficient ones will lower the energy demand and it will reduce all environmental indicators relevant to electricity production and heat production.
T4	Solar water heating	Households	Will lower the non-renewable energy consumption for water heating. The environmental impact indicators relevant to electricity and heat production will be reduced.
T5	Heat recovering from waste water	Households	The same as T4

3 Baseline eco-efficiency assessment for the municipality of Waedenswil, Canto of Zurich, Switzerland

3.1 Goal and scope definition

3.1.1 Objectives

The main goal of this study is the eco-efficiency assessment of the existing water value chain of the urban system of the municipality of Waedenswil as baseline for potential improvements. The analysis is targeted on a meso-level that encompasses every stage of the urban water cycle and entails the consideration of the interrelations among the heterogeneous actors. An assessment is performed for the baseline scenario which represents the reference point for benchmarking enhancements resulting from the upgrade of the value chain through the introduction of innovative technologies.

3.1.2 System Boundaries

The studied system considers the entire life cycle of water from its origin as a natural resource until its release into the environment after being used in urban facilities, (Figure 10). The main stages in the system include:

- Freshwater abstraction from surface water bodies or groundwater resources (abstraction and intermediate pumping);
- Potable water treatment;
- Water distribution network;
- Water use (domestic and non-domestic users);
- Sewage network; and
- Wastewater treatment and discharge.

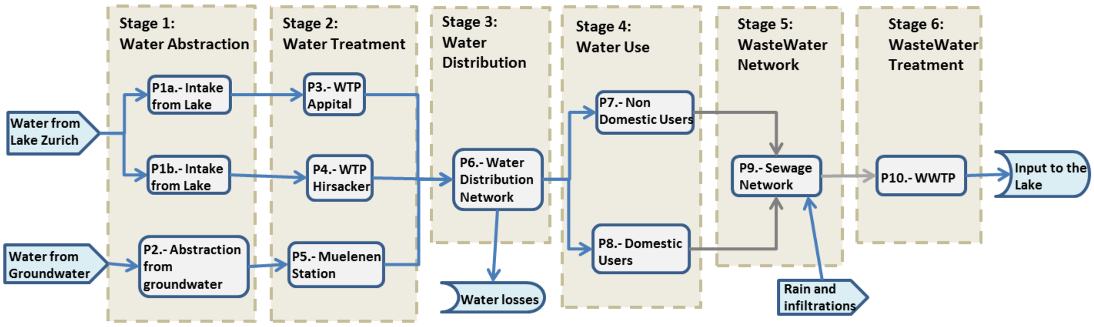


Figure 10 Stages and processes

Additionally, a value chain mapping including the relevant actors at the different stages, their roles and their interactions has been performed. These actors and the corresponding stages of the water value chain are presented in Figure 11.

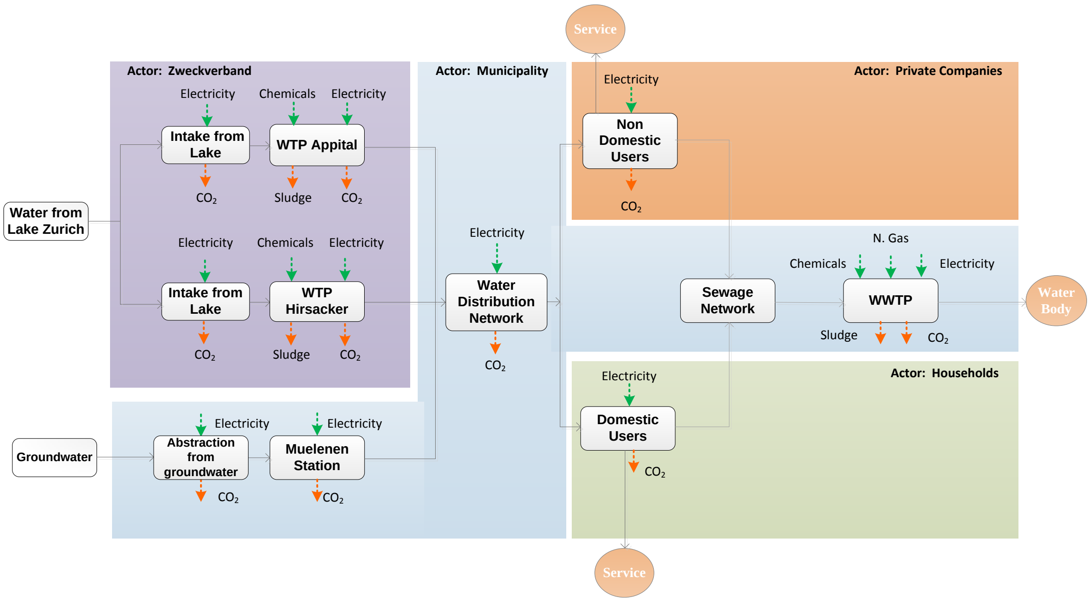


Figure 11 Processes and involved actors in the water value chain of the municipality of Waedenswil, Canton of Zurich

Each stage has been defined in such way that encloses the relevant actors involved in the system and the interactions among them. The actors involved in this case study are the following:

- The Association of municipalities for water treatment Hirsacker-Appital (Zweckverband Seewasserwerk Hirsacker-Appital)
- The Municipality Waedenswil which is responsible for sustainable and secure water supply (in means of quality and quantity) and Reliable water discharge
- Private persons/households
- Private companies using water and discharging waste water
- Office for waste, water, energy and air of Canto Zurich (AWEL) as indirect Actor for enforcement of legislation

For the life cycle assessment, the whole system is additionally divided into two sub-systems:

1. **The Foreground system** which is the system of direct interest and includes all the processes along the stages of the water value chain (the water abstraction and treatment stage, the distribution network, the water use in urban facilities and the wastewater treatment plant) where resources are used and emissions are released directly.
2. **The Background system**, which includes the production and transport processes of the various resources entering the system which are not included in the boundaries of the study system i.e. energy production, chemicals manufacturing, fuels production and distribution, etc.

The summary of system processes and their characterization as Foreground or Background are shown in Table 30.

Table 30 Foreground and Background processes of the municipality of Waedenswil, Canton of Zurich

Type of Process	Process Name
Foreground	1. Intake from Lake
	2. Groundwater Abstraction
	3. Water Treatment lake water
	4. Water Treatment groundwater
	5. Groundwater Pumping
	6. Water Distribution Network
	7. Non-Domestic Water Uses
	8. Domestic Water Uses
	9. Sewage network
	10. Wastewater Treatment
Background	1. Electricity Production
	2. Natural Gas Production and Distribution
	3. Ozone (O_3) Production
	4. Chlorine (Cl_2) Production
	5. Aluminium Sulphate ($Al_2(SO_4)_3$) Production
	6. Sodium Hypochlorite (NaOCl) Production
	7. Chlorine Dioxide (ClO_2) Production
	8. Aluminium Polychlorosulphate Production
	9. Chemicals (flocculant) Production
	10. Transport

The technologies applied in the foreground processes are presented in Table 31.

Table 31 Detailed analysis of the foreground system

Stages, processes and technologies
Stage 1: Water Abstraction
Process 1: Intake from Lake
Technology: Pumps and pipes
Process 2: Abstraction from Groundwater
Technology: Pumps and pipes
Stage 2: Water Treatment
Process 3: WTP Appital
Technology: Flocculation and filtration
Technology: Oxidation (Ozonation)
Technology: Activated carbon filtration
Process 4: WTP Hirsacker
Technology: Flocculation and filtration
Technology: Oxidation (Ozonation)
Technology: Activated carbon filtration
Process 5: Groundwater pumping
Stage 3: Water Distribution

Process 6: Water Distribution Network
Technology: Pumping station
Technology: Distribution Network and Reservoirs
Stage 4: Water Use (domestic and non-domestic users)
Process 7: Non-Domestic Water Uses
Technology: Production, service
Technology: Baths for electroplating
Technology: Washing/Cleaning
Technology: Cooling
Technology: Irrigation
Technology: Toilet flushing
Technology: Consumption through different technologies (e.g. washing machines)
Technology: Personal hygiene
Process 8: Domestic Water Uses
Technology: Irrigation
Technology: Toilet
Technology: Consumption
Technology: Personal hygiene
Stage 5: Sewerage network
Process 9: Sewage network and facilities
Technology: Sewage network and facilities
Stage 6: Wastewater Treatment
Process 10: Wastewater Treatment Plant
Technology: Mechanical Treatment (primary treatment: screening, sand tramp, primary sedimentation…)
Technology: Biological Treatment (MBR)
Technology: Chemical phosphate elimination
Technology: Anaerobic Sludge Treatment
Technology: Biogas usage with block heat and power plant

3.1.3 Cluster Analysis

This case study includes different water users and the environmental impacts can be expressed specifically using them as reference. As mentioned, for the entire study area two main types of urban water users are distinguished, i.e. Domestic and Non-Domestic water users. Users with the same consumptive patterns (e.g. technology, socio-economic characteristics) can be further grouped in clusters. The subdivision of the mass and energy flows of the whole system on a cluster scale will be performed on the basis of the water volumes at the point of consumption for water supply and discharged pollution load into the sewerage network for water discharge.

Domestic water users are subdivided in four clusters according to their source of energy for water heating: 1) domestic water users with electric water heating (25% of households), 2) with gas water heating (21%), 3) with oil water heating (40%) and 4) with alternative water heating (14%). For the fourth cluster it can be assumed, that water is heated with renewable energies, therefore this cluster is not considered in the environmental assessment. More conservative assumption would be to include some electricity consumption as heat pumps and solar heating consume some energy in their backup systems. The per cent data was derived from the national statistics on energy sources for domestic water heating (BFE 2012) and was assumed to be similar for Waedenswil.

At this stage of work, non-domestic water users have not been further clustered due to the fact that these are more heterogeneous water consumers with varieties of technologies. Data only for four SME could be gathered, as was presented in the previous Deliverable (3.1.), from which scaling up for the whole case study area was not possible. However, these non-domestic users can be analysed at a later step in specific scenarios.

3.1.4 Functional Unit

The functional unit to which all data are related should allow making different systems comparable. In this study two options have been examined:

1. When the unit of product/service delivered by the use of water is of interest, the functional unit is defined as 1 consumer being served, e.g. for water use for toilet flushing.
2. When the benefit derived is proportional to the quantity of water used then the functional unit is 1 m^3 of water used at consumer's level, e.g. for water use for drinking purposes.

3.2 Inventory Analysis

The Life Cycle Inventory flows for the Waedenswil case study were visualized in the SEAT program as presented in Figure 12.

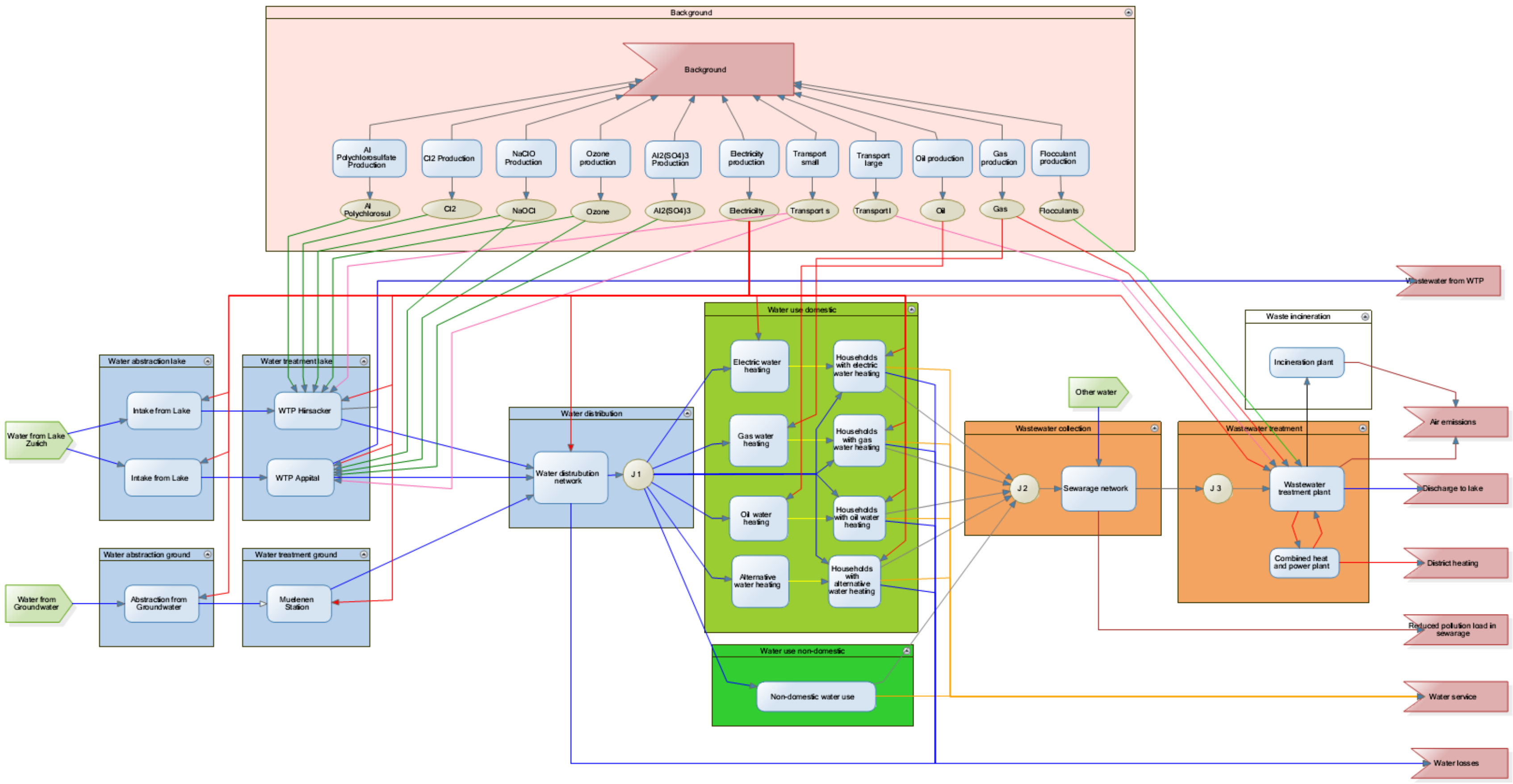


Figure 12: SEAT visualisation for Life Cycle Inventory flows of the Waedenswil case study

A list of the inputs and outputs taken into account for the system of CS4 and their categorization is presented in Table 32.

Table 32 Categorisation of the considered resources and emissions of the system

Category	Symbol	Resource
Water Service	w_1	Water from lake to WTP Appital
	w_2	Water from lake to WTP Hirsacker
	w_3	Water from groundwater (Muelenen station)
	w_4	Drinking water
	w_5	Water losses at distribution network
	w_6	Water from rainfall and infiltrations
	w_7	Wastewater
Supplementary resources	r_1	Electricity
	r_2	Natural Gas
	r_3	Biogas (burned)
	r_4	Oil
	r_5	Aluminia Polychlorosulphate
	r_6	Sodium Chlorite ($NaClO_2$)
	r_7	Chlorine (Cl_2)
	r_8	Aluminium sulphate ($Al_2(SO_4)_3$)
	r_9	Sodium hypochlorite (NaClO)
	r_{10}	Ozone (O_3)
	r_{11}	Flocculants
Emissions	e_1	Phosphorus (P)
	e_2	Nitrogen (N)
	e_3	Oxides of Nitrogen (NO_x)
	e_4	COD (Chemical Oxygen Demand)
	e_5	BOD (Biological Oxygen Demand)
	e_6	Sludge
Products	p_1	Satisfied customers
By-products	p_2	Heat from CHP

3.2.1 Elementary Flows

The values of the elementary flows in each stage are shown in the Table 33 to Table 39. Data from 2011 were used for water flows and data from 2010 were used for the chemicals at the WWTP. Some energy consumption values had to be estimated from the costs data. All data shown are exclusively for the Waedenswil region.

Stage 1: Water Abstraction

The water abstraction processes, from the lake and from groundwater, were modelled in this stage.

Table 33 Inventory of flows for the Water Abstraction Stage (Stage 1) (annual values)

Parameter	Unit	Abstraction Appital (from lake)	Abstraction Hirsacker (from lake)	Abstraction Muelenen (from ground)
Inputs				
Water in	m^3	484,664	613,320	657,782
Electricity	kWh	151,000	191,000	197,000
Outputs				
Water out	m^3	484,664	613,320	657,782

The water abstraction was separated into two different parts based on the different involved actors:

- Water abstraction from the lake, managed by Zweckverband Hirsacker-Appital, the responsible institution also for the Water Treatment Plants (WTP) and
- Water abstraction from groundwater, managed by the municipality Waedenswil.

The total electricity consumption by the Stages 1 and 2 is estimated based on the costs and the specific prices for electricity paid for both stages, and not individually per stage. An equal share of 50% was assumed for each stage. This means that the electricity related emissions will be the same for both stages. Water losses are not considered. Table 33 presents the inventory of flows from Stage 1, separated into inflows and outflows from the abstraction from lake and from groundwater.

Stage 2: Water Treatment

In Stage 2 the water from the lake is treated in two WTPs, i.e. Appital and Hirsacker. Water from groundwater is not treated, but directly pumped from Muelenen Station into the distribution network. Stage 2 is divided into two parts for the two involved actors. Table 34 shows the elementary flows involved at Stage 2, separated in inflows and outflows in both parts, i.e. the Water Treatment Plants and the Pumping Station.

As mentioned, the total electricity consumption by the Stages 1 and 2 is derived from costs for both stages together, but not per stage, so for simplicity a 50% share was assumed for each stage.

Stage 3: Water Distribution

In Stage 3, the water from the WTPs and from Muelenen Station is distributed to the different users. Table 35 presents the elementary flows involved at Stage 3, separated in inflows and outflows. Energy required for distribution throughout the network was estimated from the respective costs. The distribution network water losses are around 9.6% of the total of water that comes into the network (Stadt Waedenswil 2012).

Table 34 Inventory of flows for the Water Treatment Stage (Stage 2) (annual values)

Parameter	Unit	WTP Appital	WTP Hirsacker	Pumping station Muelenen
Inputs				
Water in	m^3	484,664	613,320	657,782
Electricity	kWh	151,000	191,000	197,000
Ozone	kg	384	490	0
NaOCl	kg	48	65	0
$Al_2(SO_4)_3$	kg	2,400	0	0
Aluminia Polychlorosulphate	kg	0	1,533	0
Cl_2	kg	0	26	0
Outputs				
Water out	m^3	479,817	607,187	657,782
Wastewater (10% assumed at WTP)	m^3	4,846	6,133	0

Table 35 Inventory of flows for the Water Distribution Stage (Stage 3) (annual values)

Parameter	Unit	From WTP Appital	From WTP Hirsacker	From Muelenen station
Inputs				
Water in	m^3	484,664	613,320	657,782
Electricity	kWh	151,000	191,000	197,000
Outputs				
Water out	m^3	484,664	613,320	657,782
Water out to domestic	m^3	1,168,000		
Water out to non-domestic	m^3	419,750		
Water losses	m^3	168,016		

Stage 4: Water Use

Use of water is allocated to two main types of users: domestic users and non-domestic users. For non-domestic users, some water remains in the products or is evaporated during the processes, so an estimated 90% of the water used was considered to be returned to the system as wastewater. Table 36 shows the inflows and outflows, resources and emissions for non-domestic water users.

Table 36 Inventory of flows for the Non-domestic Water Use Stage (Stage 4) (annual values)

Parameter	Unit	Value
Inputs		

Water in	m^3	419,750
Outputs		
Wastewater out	m^3	377,775
BOD out	kg	157,417
Person equivalents out	pe	7,188

The BOD load for non-domestic water users has been calculated from the assumed BOD concentration in industrial wastewater of 60 gram/capita/day which results in 21.9 kg/capita/year. This value has been multiplied by the person equivalents accounted to the non-domestic users of 7,188 to get the amount of BOD out of 157,417 kg/year.

Domestic water users are subdivided into four clusters based on the source of energy used for water heating like stated in chapter 3.1.3. The data was derived from the national statistics on energy sources for domestic water heating (BFE 2012). To calculate the number of households, the average number of 2.2 people per household was taken from statistical information. Accordingly, a number of households and the corresponding water-related energy demand for water heating can be estimated.

For electric and gas water heating an average energy demand of 61 kWh per m^3 of water was assumed, for oil water heating an energy demand of 59 kWh of oil per m^3 of water was assumed according to Dimitrov 2009 (Chapter 2.3.1).

Additionally electricity needed to operate washing machines and dishwashers was estimated. Likewise as in the Sofia Case Study, an electricity consumption for dishwashers class A of 253 kWh per year and for washing machines class A of 177 kWh per year was assumed (Chapter 2.3.1), i.e. a total electricity consumption for devices of 430 kWh per household. Furthermore, it was assumed that each household in Waedenswil case study area has a dishwasher and a washing machine.

Wastewater from domestic users is considered to be 90% of the water consumption due to some losses stemming from water of gardens, for example. Table 37 shows the inflows and outflows, resources and emissions for domestic water use.

Table 37 Inventory of flows for the Domestic Water Use Stage (annual values)

Parameter	Unit	HH with electric water heating	HH with gas water heating	HH with oil water heating	HH with alternative water heating
Share of total households (HH)	%	25	21	40	14
Number of households	amount	2,273	1,909	3,636	1,273
Person equivalents	pe	5,000	4,200	8,000	2,800
Inputs					
Cold water consumption (70%)	m^3	204,424	171,687	327,007	114,488
Hot water consumption (30%)	m^3	87,610	73,580	140,145	49,066
Electricity for devices	kWh	977,390	820,870	1,563,480	547,390
Electricity for water heating	kWh	5,344,241	0	0	0[1]
Gas for water heating	kWh	0	4,488,410	0	0
Oil for water heating	kg	0	0	686,715	0
Outputs					
Wastewater out	m^3	262,831	420,741	240,437	147,199
Water losses	m^3	29,203	24,526	46,715	16,355
BOD out	kg	109,513	91,975	175,182	61,333
Phosphorus out	kg	3,300	2,771	5,279	1,848
Nitrogen out	kg	20,102	16,883	32,156	11,258

Stage 5: Sewerage Network

In the sewerage network the wastewater from domestic users and from non-domestic users is jointly collected. Water from rainfall is also entering the sewerage network as it is a combined sewer system in most of the area and additionally infiltration from groundwater has to be expected. Rainfall and infiltrated groundwater represent on a yearly average more than 50% of the total wastewater that arrives to the WWTP. The wastewater is transported to the Waste Water Treatment Plant WWTP (Stage 6). Losses have not been accounted for in this stage as only the net fluxes in and out of the network are considered. Further it has been assumed, that BOD, Phosphorus and Nitrogen are reduced already in the network due to certain biological processes to a certain percentage. Table 38 presents the elementary flows for Stage 5.

[1] A more conservative assumption would be about 30% of households with electric water heating as some electricity is still consumed by the background system of heat pumps and solar heating.

Table 38 Inventory of flows for the Sewerage Network Stage (Stage 5) (annual values)

Parameter	Unit	Value
Inputs		
Waste Water in	m^3	1,428,985
Water in (rain and infiltrations)	m^3	1,671,014
Person equivalents in	pe	27,188
BOD in	kg	595,421
Phosphorus in	kg	13,200
Nitrogen in	kg	80,400
Outputs		
Wastewater out	m^3	3,152,775
Person equivalents out	pe	27,188
BOD out	kg	446,283
BOD reduced in network	kg	149,139
Phosphorus out	kg	12,390
Phosphorus reduces in netw.	kg	810
Nitrogen out	kg	39,879
Nitrogen reduced in network	kg	40,522

Stage 6: Waste Water Treatment

Wastewater from users and rainfall/infiltration water arrive at the WWTP. In the WWTP, electricity and natural gas are used as supplementary resources. Furthermore, electricity and heat are produced from the biogas derived from the surplus sludge. This electricity is used for own consumption and the heat is sold to a neighbourhood district heating system.

When the rainfalls in the region are strong, some amount of untreated water is discharged directly to the lake. According to the data from 2011, around 10% of the wastewater was discharged into the lake without biological treatment. Input and output data are shown in Table 39.

Table 39 Inventory of flows for the Wastewater Treatment Stage (annual values)

Parameter	Unit	Value
Inputs		
Waste Water	m^3	1,428,985
Water in (rain and infiltrations)	m^3	1,671,014
Person equivalents	pe	27,188
Electricity	kWh	1,794,408
Electricity from CHP	kWh	516,676
Gas	kWh	543,760
BOD	kg	446,283
Phosphorus	kg	12,390
Nitrogen	kg	39,879
Flocculants	kg	448,602
Outputs		
Wastewater	m^3	2,853,700
Wastewater untreated		246,300
Electricity from CHP	kWh	516,676
Heat to district heating	kWh	1,046,738
BOD	kg	6,253
Phosphorus	kg	135
Nitrogen	kg	10,875
Sludge	kg	1,903,160
N_2O	kg	6,083
CH_4	m^3	1,903

3.2.2 Economic Data

The economic performance indicator used to assess an EcoWater meso-level water use system is the **Total Value Added** (TVA) to the product/service due to water. It includes both the water supply and the production chains and is expressed in monetary units (Euros) per year. It is estimated as:

$$TVA = EVU - TFC_{WS} - TFC_{WW} + VP_{BP}$$

Where on an annual basis:

- EVU is the total economic value created from water use,
- $\mathrm{TFC_{WS}}$ is the total financial cost related to water supply provision for rendering the water suitable for the specific use purpose,
- $\mathrm{TFC_{WW}}$ is the total financial cost related to wastewater treatment and
- $\mathrm{VP_{BP}}$ is the income generated from any by-products of the system.

Table 40: Unit costs of raw materials and supplementary resources[2]

Cost/Benefits	Item	Amount
Cost	Electricity	0.14 €/kWh
	Natural Gas	0.046 €/kWh
	Ozone (O_3)	1.00 €/kg
	Chlorine (Cl_2)	1.00 €/kg
	Aluminium Sulphate ($Al_2(SO_4)_3$)	1.00 €/kg
	Sodium Hypochlorite (NaOCl)	1.00 €/kg
	Chlorine Dioxide (ClO_2)	1.00 €/kg
	Aluminium Polychlorosulphate	1.00 €/kg
	Chemicals	0.70 €/kg
Benefit	Drinking Water	6.50 €/m^3
	Heat from District Heating	0.05 €/kWh

A specific methodological challenge in the Urban Case studies is the estimation of Economic Value from Water Use (EVU) for domestic and non-domestic users. The Economic Value from Water Use refers to the total benefits from direct use of water, which cannot directly be derived for domestic water users, as domestic water users do not gain any monetary benefits from water use like companies, but are profiting from the different services provided. Therefore, the estimation of the economic value from water used is based on the customers' willingness to pay for these services.

Table 40 presents the data required to calculate the financial costs of the system. The Economic Value from Water Use (EVU) is estimated by:

$$EVU = EVU^{bl} = WTP \times f_{w,2-3}^{bl}$$

Where:

- WTP is the customers' willingness to pay for the services in €/m^3 provided by a certain quantity of water in the baseline scenario (defined as the maximum amount a person would be willing to pay for a certain amount of water from a reliable and adequate water supply);
- $f_{w,2-3}^{bl}$ is the total quantity of water supplied to the processes of domestic and non-domestic water use stages [m^3/y]. The superscript *bl* indicates the baseline scenario.

Willingness to pay for water services was derived from the maximum prices for drinking water and wastewater services in Switzerland as shown in Figure 13 and Figure 14, respectively. Based on the average 3 person household, representative for Waedenswil, and on the 2.2 persons per household assumed above the maximum prices are about 4.3 and 3.8 CHF/m^3 for drinking water and wastewater, respectively. Accordingly, the total price for water service amounts to about 6.5 €/m^3, assuming an exchange rate of 1.2 CHF/€.

[2] Costs for chemicals shown here are average values due to lack of better cost data. Nevertheless, multiplied with the respective amount of chemicals used, they represent well the variable costs for productive inputs.

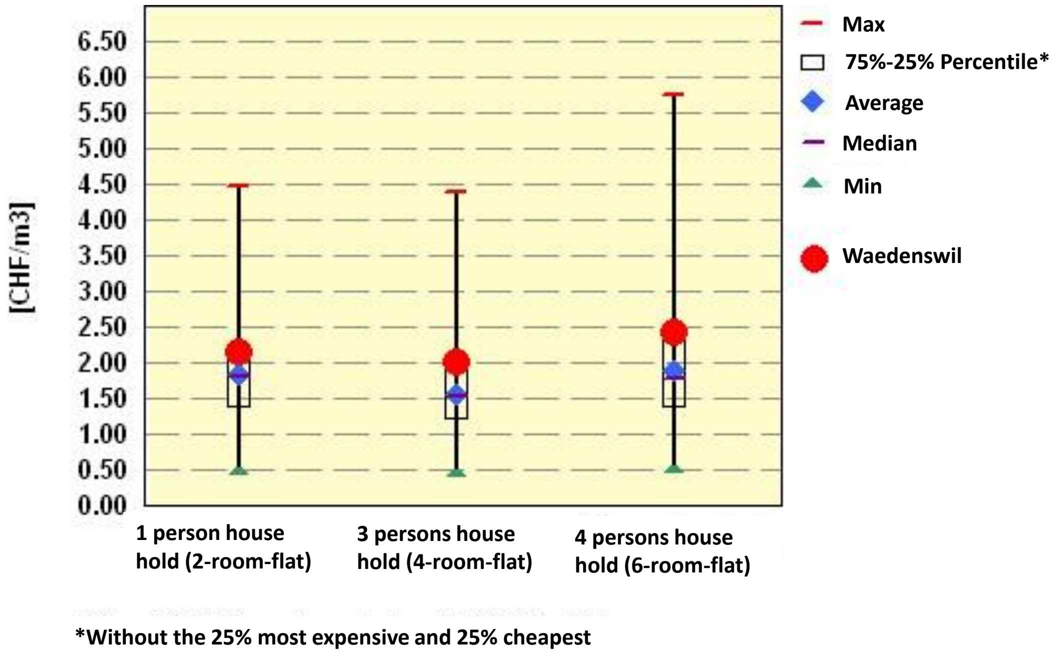


Figure 13: Drinking water prices in Waedenswil in comparison to Swiss average

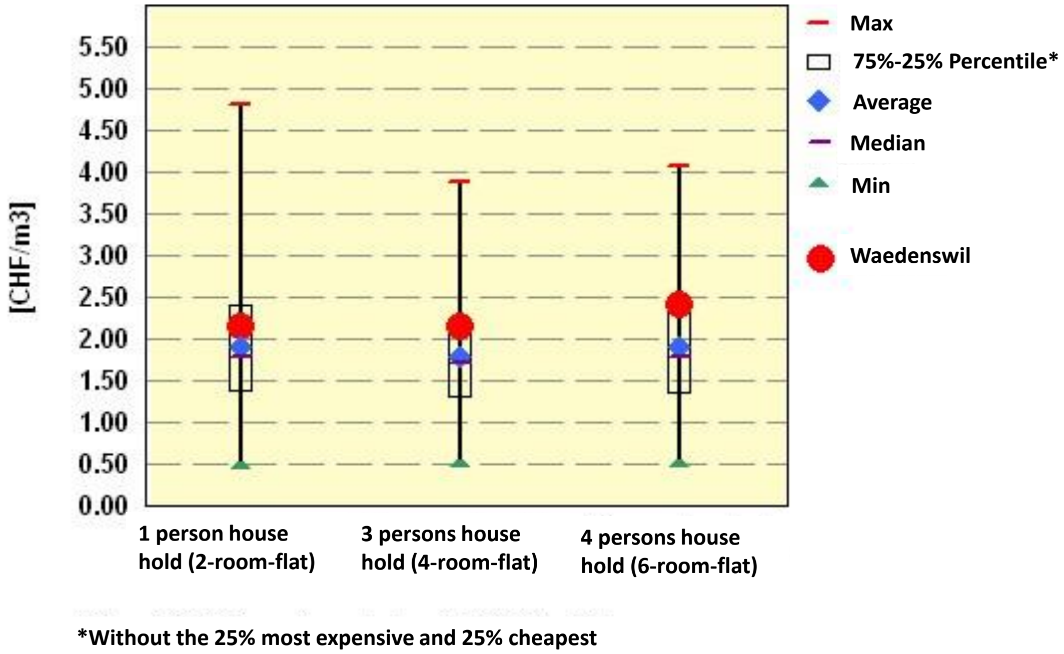


Figure 14: Waste water prices in Waedenswil in comparison to Swiss average

Table 41 and Table 42 present the economic value added and the expenditures for the non-domestic water users.

Table 41: Economic value added from water use of non-domestic water users

Parameter	Amount	Unit
Total water consumption	419,750	m^3/year
Willingness to pay per m^3 (assumed as **for** domestic)	6.50	€/m^3
Total EVU per year	2,728,375	€/year

Table 42: Expenditures for water services of non-domestic water users

	Amount (m^3/y)	Fixed fee (EUR/y)	Price per (EUR/m^3)	Total (EUR/y)
Water Services	419,750	300,000	1.22	812,095
Wastewater	377,775	400,000	1.46	951,551
Total Expenditures				**1'763'646**

Table 43 and Table 44 present the economic value added and the expenditures for the domestic water users.

Table 43: Economic value added from water use of domestic water users, i.e. for 9,901 households (hh)

Parameter	Value	Unit
EVU for water supply, waste water sewerage and treatment		
Average water consumption per household in baseline scenario[3]	128	m^3/hh/year
Water tariff (water supply, waste water sewerage and treatment)	3.25	€/m^3
Willingness to pay per m^3 (derived from max. price paid in CH)	6.50	€/m^3
EVU for water per household	**835**	**€/hh/year**
EVU for water per year	**7,592,000**	**€/year**
EVU for water heating		
Hot water consumed in average household	38.54	m^3/hh/year
Maximum costs for heating 1m^3 of water	6.10	€/m^3
Willingness to pay for water heating (assumed, the maximum costs for heating the water is increased with 20%)	7.32	€/m^3
EVU for water heating per household	**282**	**€/hh/year**
EVU for water heating per year	**2,564,928**	**€/year**
Total EVU		
Total EVU per household	1,117	€/hh/year
Total EVU per year	**10,156,928**	**€/year**

[3] Based on the following calculation: Average consumption of 58.4 m^3 per person per year times 2.2 persons living in a household.

Table 44: Expenditures for water services of domestic water users

	Amount (m^3/y)	Fixed fee (EUR/y)	Price per (EUR/m^3)	Total (EUR/y)
Water services	1,168,000	600,000	1.22	2,024,960
Wastewater charged for	1,051,200	700,000	1.46	2,234,752
Total Expenditures				**4,259,712**

3.3 Environmental performance

Based on the list of the midpoint impact indicators proposed in the approach followed by the EcoWater Project (Van Vliet et al 2012), 13 impact categories have been selected as the most representative for the environmental assessment of the water use systems. The characterization factors which were used for the estimation of the impact of the foreground systems and the background process are presented in Table 45 respectively. Similarly to the Sofia Case Study, the environmental impact factors are obtained from open access database ELCD and from the Ecoinvent 2.2 databank. The method applied is CML 2001, from which 9 Impact Categories are chosen. For the impact categories “fossil depletion” and “respiratory effects” TRACI method is used. The characterization factors were derived with the help of SimaPro 7 software.

The freshwater resource depletion impact indicator was calculated as the product of the total water abstracted for the system multiplied by the total withdrawal to availability ratio.

A 0.05 factor for the withdrawal to availability ratio is used, which is the value for whole of Switzerland (EEA, 2012), resulting in a value for the freshwater resource depletion impact indicator of 87,239 m^3/y.

Table 45: Environmental Impact Factors for Background Processes (ELCD for electricity mix and Ecoinvent 2.2 for other processes)

Indicators for background processes	Unit	Electricity mix, AC, consumption mix, at consumer, < 1kV CH (per kWh)	Natural gas, high pressure, at consumer/CH (per kWh)	Light fuel oil, at regional storage/CH (per kg)	Transport (small), lorry 7.5-16t, EURO4/RER (per tkm)	Transport (large), lorry 16-32t, EURO4/RER (per tkm)	(CL2) Chlorine, liquid, production mix, at plant/RER (per kg)	Ozone, liquid, at plant/RER (per kg)	Al2(SO4)3 Aluminium sulphate, powder, at plant/RER (per kg)	NaClO Sodium chloride, powder, at plant/RER (per kg)	NaClO2 Sodium hypochlorite, 15% in H2O, at plant/RER (per kg)	Iron (III) chloride, 40% in H2O, at plant/CH (per kg)
Acidification	kg S02,eq	0.000164000	0.000168000	0.005070000	0.000830000	0.000635000	0.005290000	0.038400000	0.010100000	0.000897000	0.004150000	0.00423657
Eutrophication	kg PO4-3,eq	0.000014112	0.000015379	0.000823008	0.000216102	0.000167264	0.003557898	0.026687675	0.001408591	0.000667974	0.002595992	0.00291287
Freshwater aquatic ecotox. 100a	kg 1.4-DB,eq	0.000244138	0.001103145	0.073103156	0.017308751	0.014042314	0.612623681	4.362657697	0.638787702	0.131814036	0.469982383	0.58274349
Global warming 100a (Climate ch.)	kg CO2,eq	0.085292045	0.040415627	0.584562302	0.220936004	0.165091144	1.054946263	7.991561659	0.491834290	0.179735699	0.884411061	0.80061956
Human Toxicity 100a	kg 1,4-DB,eq	0.001049115	0.001159466	0.167914172	0.032677433	0.025875140	0.442448207	1.588029246	0.168812133	0.225997919	0.496740271	0.79793335
Ozone layer depletion 20a	kg CFC-11 eq	0.000000082	0.000000061	0.000000484	0.000000031	0.000000023	0.000002820	0.000000430	0.000000038	0.000000012	0.000000075	0.00000173
Photochemical Oxidation	kg C2H4,eq	0.000006465	0.000013011	0.000307268	0.000025825	0.000020167	0.000211724	0.001498828	0.000398556	0.000040906	0.000173071	0.00017938
Terrestrial Ecotoxicity 100a	kg 1.4-DB.eq	0.000003030	0.000004476	0.000202883	0.000035779	0.000029188	0.002080718	0.001653943	0.000117068	0.000060576	0.001234357	0.00189525
Metal Depletion	kg Fe eq	0.000238000	0.000725000	0.014000000	0.008980000	0.007850000	0.084800000	0.149000000	0.033300000	0.056400000	0.110000000	0.193000000
Fossil Depletion	kg oil eq	0.008930000	0.102000000	1.290000000	0.080700000	0.061100000	0.304000000	2.230000000	0.151000000	0.050400000	0.268000000	0.231000000
Respiratory effects	kg PM10,eq	0.000027139	0.000024583	0.000940000	0.000175000	0.000131000	0.001210000	0.008460000	0.002170000	0.000248000	0.000998000	0.001110000

The results of the environmental impacts of the entire system and of the contribution of the background and foreground processes into the system are presented in Table 46 and Figure 15.

Table 46: Environmental indicators results for CS4 baseline assessment

Indicator	Value (Unit)	Foreground Value (Unit)	Background Value (Unit)
Climate Change (tCO_2eq)	1,790.19	51.82	1,738.37
Fossil Fuels Depletion (MJ)	63,718,233.05	0	63,718,233.05
Freshwater Resource Depletion (m^3)	79,388.08	79,388.08	0
Eutrophication ($kgPO_4eq$)	6,122.50	5,258.70	863.80
Human Toxicity (kg1,4-DBeq)	138,190.77	0	138,190.77
Acidification ($kgSO_2eq$)	6,567.43	0	6,567.43
Aquatic Ecotoxicity (kg1,4-DBeq)	65,163.82	0	65,163.82
Stratospheric Ozone Depletion (kgCFC-11eq)	0.64	0	0.64
Terrestrial Ecotoxicity (kg1,4-DBeq)	204.95	0	204.95
Respiratory Inorganics ($kgPM_{10}$,eq)	1,144.53	0	1,144.53
Photochemical Ozone Formation (kgC_2H_4,eq)	364.50	0	364.50
Mineral Depletion (kgFe-eq)	17,042.98	0	17,042.98

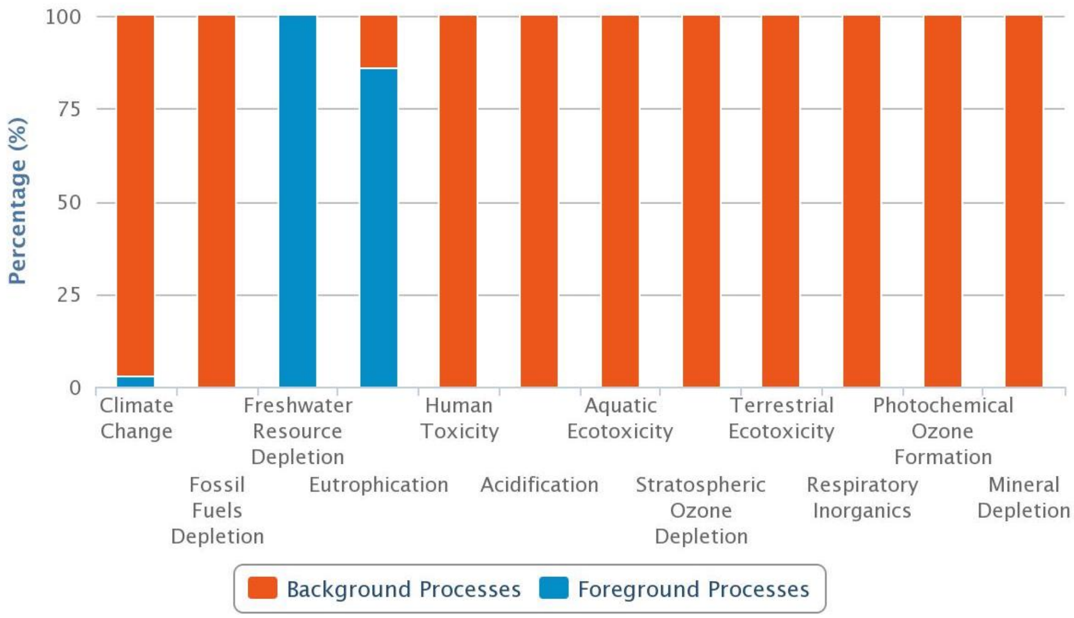


Figure 15: Contribution of Foreground and Background Systems in the environmental impact categories

The results on environmental indicators are presented as percentage per stage in Figure 16. Solid bars represent the foreground system and transparent bars the background system.

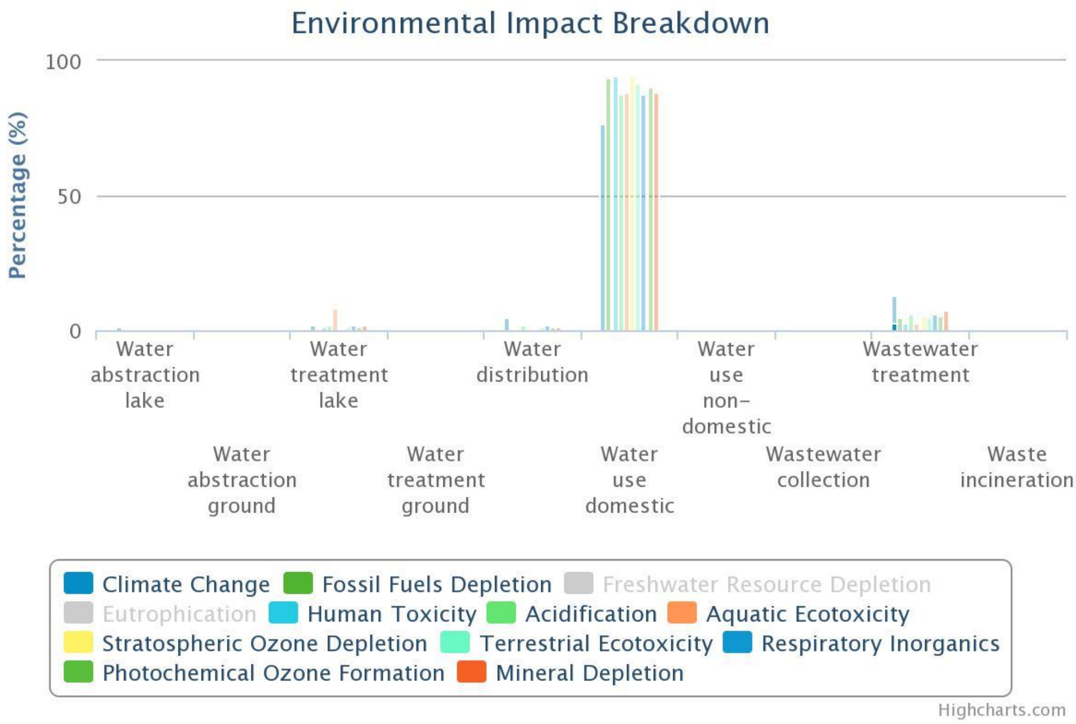


Figure 16: Environmental impact breakdown, percentage per stage of total except for freshwater resource depletion and eutrophication presented in the next figure

The Eutrophication and the Freshwater Resource Depletion indicator are presented separately (Figure 17) because the allocation of the environmental impacts per stage is not based on the point of exit of the elementary flows from the system (Stage 6. Wastewater Treatment), but is based on the processes which generate these flows in the first place (Stages 4a and 4b, Water Use).

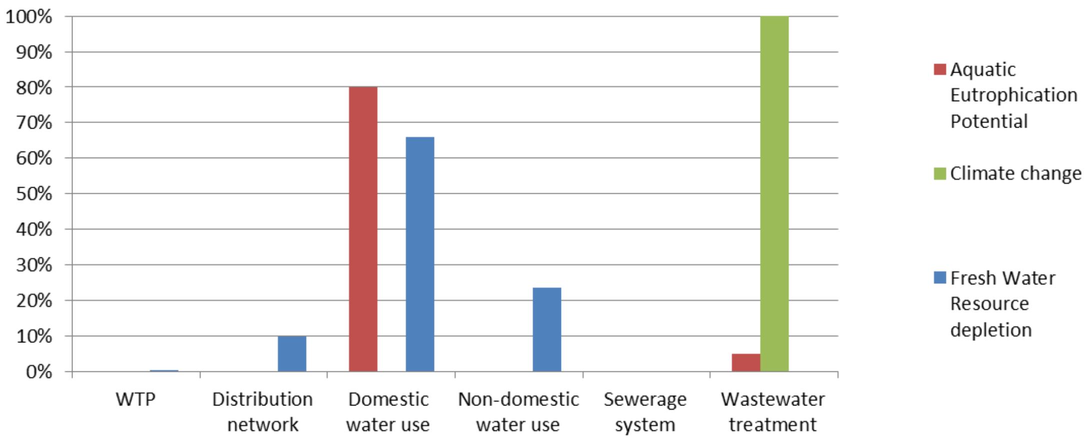


Figure 17 Environmental impact breakdown of foreground processes, percentage per stage's contribution (Eutrophication, Freshwater Resource Depletion and Climate Change)

3.4 Economic performance

Table 47 summarizes the economic performance assessment of the studied system. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 5,681,407 €.

Table 47 Economic performance results (in € per year)

Actor	Annual Equivalent Investment Cost	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Zweckverband	1,003,880	297,486	0	1,311,182	9,816
Municipality	2,894,520	1,796,475	53,384	4,712,206	74,595
Domestic Water Users	0	1,262,637	10,154,647	-4,259,742	4,632,268
Non-Domestic Water Users	0	0	2,728,375	-1,763,647	964,729
Total Value Added					**5,681,407**

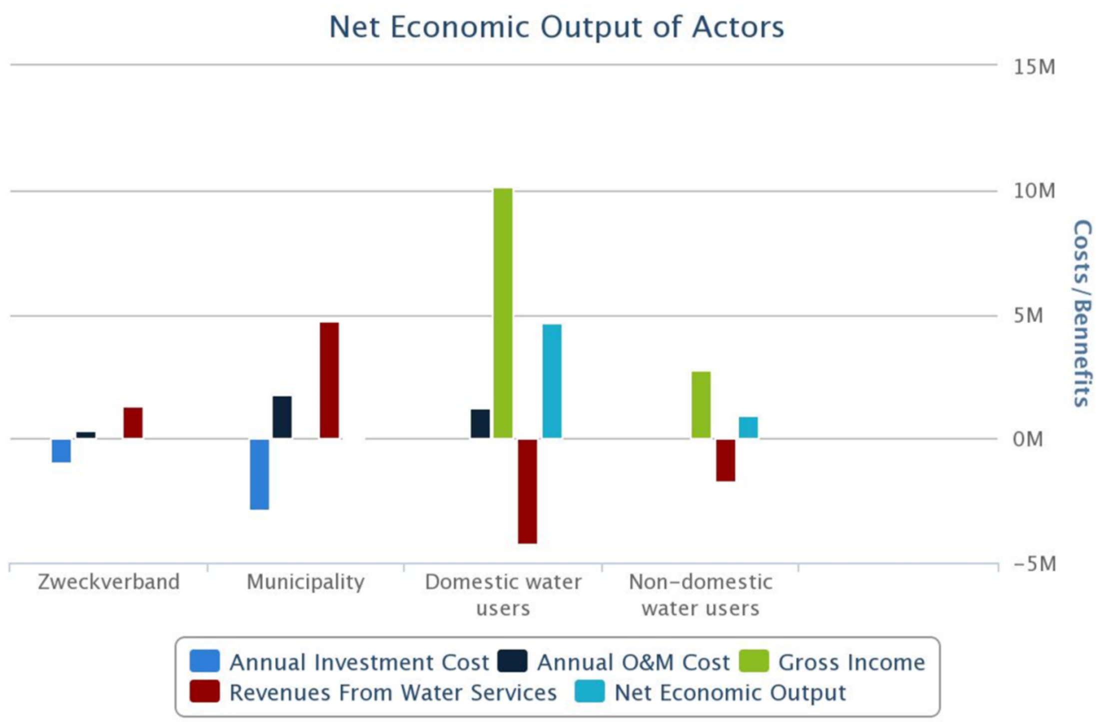


Figure 18 Economic Performance per Actor

3.5 Eco-efficiency indicators

The eco-efficiency indicators are evaluated from the results of environmental and value assessment presented above. Table 48 summarizes the values of the eco-efficiency indicators, corresponding to the 13 relevant environmental impact categories.

Table 48 Eco-efficiency indicators

Eco-efficiency indicator	Unit	Value
Global warming 100a (Climate ch.)	€/t CO_2,eq	3,174
Fossil Depletion	€/MJ	0.09
Freshwater Resource Depletion	€/m^3	72
Eutrophication	€/kg $PO4^{-3}$,eq	928
Human Toxicity 100a	€/kg 1,4-DB,eq	41
Acidification	€/kg SO_2,eq	865
Aquatic ecotoxicity 100a	€/kg 1.4-DB,eq	87
Ozone layer depletion 20a	€/kg CFC-11 eq	8,860,626
Terrestrial Ecotoxicity 100a	€/kg 1.4-DB.eq	27,720
Respiratory effects	€/kg PM10,eq	4,964
Photochemical Oxidation	€/kg C_2H_4,eq	15,587
Metal Depletion	€/kg Fe eq	333
Micropollutants	€/kg	137,500

3.6 Next steps

Based on this baseline eco-efficiency assessment the following types of technologies were preselected to be assessed in the scenario analysis whether they could improve the eco-efficiency in the future.

1. **Water-saving appliances for domestic and non-domestic water users** will not only save the amount of water and wastewater which hast to be paid by the users, but also the consumption of energy for the use of warm water. These measures will show in the indicator climate change.
2. **Micropollutants removal technology** will be probably applied by the WWPT in the next few years as the micropollutants discharge into Lake Zurich from a WWTP of such size is seen as a major environmental problem and will be regulated by law. Such technologies usually have removal rates of over 80% and will improve the eco-efficiency significantly.
3. **Pressure reducing valv**es will reduce water losses in the distribution system and therefore reduce the amount of water which has to be abstracted and increase the eco-efficiency with the indicator resource depletion freshwater.
4. **Smart pumping** will reduce the consumption of energy in the water distribution network and therefore improve the climate change indicator.
5. **Water reuse** will reduce the amount of water which has to be abstracted and therefore improve the freshwater resource depletion.
6. **Advanced phosphorus recovery** will show the improvement in the economic performance of the system if phosphorus will be recovered and sold. At the moment, this is rather a long-term option.

4 Conclusions for the urban case studies

The most important material flows in urban water systems are water and energy flows. There are also flows associated with transport of products to and from water and wastewater treatment plants. The concept for foreground and background system was adopted in order to consider the environmental impact caused by all flows: these, which are within the studied meso-level system itself, e.g. within the urban water system and these, which contribute to system’s functioning, but are outputs of other product systems. Twelve indicators from the list of the LCA mid-point indicators were selected and assessed.

The eco-efficiency assessment of the baseline scenario in urban water systems led to the following main conclusions:

Meso-level eco-efficiency: A methodology, which is in compliance with ISO standards on eco-efficiency and life cycle assessment, has been developed in the framework of the EcoWater project. The methodology has been tested for two quite different urban water systems - Sofia and Zurich. This will allow more profound conclusions about its strengths, weaknesses, limitations and future uses to be drawn. A comparison of the final results for the two case studies to derive generic and site specific conclusions and recommendations is envisaged.

Relevance of background systems for environmental impact: The results show that the main environmental impacts for most investigated indicators are due to the background systems, where production of energy, reagents and fuels is realised. The actual urban water system, i.e. the foreground system, has as currently modelled direct negative environmental impacts only to three out of twelve of the selected environmental impact indicators: fresh water depletion, aquatic eutrophication and climate change. These results confirm the importance to include background processes in the environmental assessment for a comprehensive analysis.

Limitations of modelling of domestic and non-domestic users: In the current model the main environmental impacts stem from the water heating of domestic users. The environmental impacts of the non-domestic users are not represented comprehensively as this would require more detailed information on company/sector level which is beyond the scope of this project and therefore only water consumption has been considered for non-domestic water users. For the technology assessments these limitations have to be considered.

Indicators for new challenges: For the Zurich Case Study beside eleven LCA midpoint indicators one regional indicator (Freshwater Resource Depletion) and one special, case-study relevant indicator to account for a recent evolving challenge, i.e. micropollutants, was considered. There are methods to assess the impact of micropollutants in the category Aquatic Ecotoxicity Chronic, but not for all the present micropollutants characterisation values are available. In this area the research is on-going. One possibility to account for the micropollutants release in the indicator Aquatic Ecotoxicity is focusing on some of the specific micropollutants for which characterisation factors are known.

Estimation of economic value generated by water users: The economic value added is generated only in the water use stages, as estimated in the present study. As the water operators in the system have to operate cost-covering they will pass on additional costs to the users in the system. Sofia case study will apply an additional method for the assessment of the value generated by the system different from the presented in this study. The strength and weaknesses of the two methods will be discussed after getting the final results, i.e. the assessment of scenarios with innovative technologies.

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