D.32 Environmental, economic and socio-economic assessment of the case study of Berlin

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Abstract

This report presents the sustainability assessment of the application of the iBathwater solution to the case study of Berlin, in particular to the prospective inner-city bathing site of “Flussbad”. The sustainability assessment includes environmental assessment (LCA), economic assessment (LCC) and socio-economic assessment (HFIM). It compares a conventional approach of CSO management to reducing CSO volume and providing water quality information with the innovative solutions tested in iBATHWATER. These include the reduction of discharge volumes for major CSO events by activation of additional storage volume with the sewer system, advanced analytics of water quality at CSO outlets and within the bathing area, and predictive forecast of CSO events by simulation using real-time rain forecast.

The results illustrate that innovative solutions for bathing site management and CSO prevention can be more sustainable in environmental and economic terms than conventional solutions, i.e. the construction of large new infrastructure. The latter option is both costlier and comes with a higher environmental impact than using intelligent management of existing infrastructure (e.g. by activating storage volume in the sewer) and advanced solutions for water quality monitoring and prediction of CSO events. Combining iBATHWATER solutions at the Flussbad site will enable a more efficient and more environmentally friendly implementation of an inner-city bathing area than relying on traditional strategies of “more concrete”, i.e. heavy infrastructure with high cost and related environmental impact.

The contribution of the project towards improving the performance and the social aspects of the system have the highest socio-economic impacts, as shown with the application of HFIM. The reduction of the untreated wastewater discharged and related pollutants as well as the improvement in the governance and the awareness raising have the highest influence on the socio-economic impacts. The results have positively impacted all the socio-economic objectives of the project, especially improving the quality of bathing areas during and after rain events and ensuring bathing water safety and reducing human health risk.

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1 Introduction

In the iBATHWATER project, innovative solutions are tested and explored to allow a safe management of inner-city bathing areas. The focus is on a potentially negative effect of combined sewer overflow (CSO) events on hygienic water quality. During CSO events, rainwater mixed with raw municipal wastewater is discharged into receiving surface waters, so that pathogenic microorganisms originating from raw sewage are introduced in river, lake or ocean waters and thus generate risks for swimmer´s health.

For Berlin, different innovative options for CSO prevention and water quality assessment have been tested at the planned inner-city bathing area called “Flussbad”. This stretch of the Spree river is located directly in the city centre, and is potentially affected by CSO events upstream or directly within the future bathing area. Upstream pollution of the inflowing river should be cleaned with a large filter and is not in the focus of this study. This study explores different options for preventing CSO events from outlets located in the bathing area, i.e. which directly discharge into the bathing area and thus are not affected by the inflow filter. In addition, innovative options for monitoring of actual water quality and providing timely information of future or actual CSO events are explored and tested at the site: Aquabio online sensors for fast and automated analytics of hygienic water quality, online multiparameter sensors for fast detection of CSO events, and a forecast model to predict future CSO events in advance based on prediction of rain events.

This report presents the sustainability assessment of these applications based on their potential application at the prospective Flussbad bathing site. The assessment includes:

- environmental impacts analysed with Life Cycle Assessment (LCA)
- economic impacts analysed with Life Cycle Costing (LCC)
- socio-economic impacts analysed with Hybrid fulfilment-importance matrix (HFIM).

With these tools, iBATHWATER solutions are compared to a more conventional approach for the bathing site, which is based on existing planning studies from Flussbad. Through this comparative approach, benefits and potential drawbacks of iBATHWATER solutions can be explored for the different aspects of sustainability. Finally, the results of this analysis have to be reflected together with the technical aspects of the project to decide whether the solutions offered in iBATHWATER can be implemented at the Flussbad site in Berlin.

The report is structured as follows:

- Chapter 2: Background of the case study and methodology of LCA, LCC and HFIM
- Chapter 3: Input data for the assessment
- Chapter 4: Results of the assessment
- Chapter 5: Conclusions

2 Methodology

2.1 Background of the Berlin case study

2.1.1 Description of “Flussbad” bathing site and tested iBATHWATER solutions

The Flussbad case study focusses on a defined part of the inner-city river Spree. This part of the river is highly urbanized, and the riverside is fully intrenched with walls and concrete structures. Within this area, an official bathing site could be established to allow the use of the river for recreational activities (Figure 1).

Figure 1: Map of “Flussbad” case study with bathing area between red marks and upstream filter area (left) and visualisation of the potential bathing site (right) © Flussbad Berlin

The present study focuses on the water quality aspects in the bathing area, which are required to be met for an official bathing site. In particular, hygienic aspects are important, as the contamination of river water with microbial pathogens could lead to an unacceptable risk for swimmer’s health. Upstream pollution of the inflowing river will be cleaned by a large filter located just before the bathing area. However, a series of CSO outlets is located also within the bathing area. The proper management of hygienic risks originating from this CSO outlets can be handled with different approaches. The more conventional approach has been elaborated in previous studies of the Flussbad project group: it consists of a large pipe within the bathing area which is directly connected to all relevant CSO outlets. This pipe receives CSO from all outlets and discharges the entire volume downstream of the bathing area. This “bypass” approach ensures that the water quality in the bathing area is not negatively affected by CSO events discharging into the bathing water. However, first design studies indicate that this approach could be both costly and material-intensive, thus having a high economic cost and potentially a high environmental footprint.

In contrast, solutions tested in iBATHWATER could also be used to manage water quality aspects for this bating site. In particular, different tools can be combined to allow for a safe use of this river area for bathing:

- Reduction of discharge volumes for major CSO events by activation of additional storage volume with the sewer system in real time, i.e. during potential CSO events (“real-time control” measures)
- Advanced analytics of water quality at CSO outlets and within the bathing area to have real-time information of a) potential CSO events and b) actual microbial water quality within the area.

- Predictive forecast of CSO events by simulation, using real-time rain forecast and suitable model software to predict CSO events before they occur.

These iBATHWATER solutions can be combined to minimize CSO events within the bathing area and provide information for bathing site management in real time, i.e. when to prohibit bathing due to potential water quality issues from CSO events and when to safely lift the ban if water quality is acceptable again.

For the assessment of environmental and economic impacts and benefits of the different options, it is important that the systems to be compared deliver a comparable function. Therefore, the present study has been split in two parts in relation to the two different goals that can be achieved with iBATHWATER solutions:

1. Solutions to reduce CSO volume discharged into the bathing area
2. Solutions to provide water quality information for safe management of bathing area

Both goals can be reached with conventional measures or iBATHWATER solutions, which are separately compared below with LCA and LCC. Ultimately, the management of the bathing water site will require a combination of the two goals, i.e. minimizing the discharge of CSO into the bathing area and providing water quality information for protecting swimmer´s health. After the singular assessment of both goals separately, combined scenarios are also compared to have an overall assessment for the solutions needed to establish a bathing site in this area.

2.1.2 Definition of system functions, functional units, and scenarios

The first goal relates to the reduction of CSO volume discharged directly into the bathing area. The function of the systems compared is “reducing the volume of CSO discharged into the bathing site”. The functional unit is difficult to define, as different scenarios can reduce different amounts of CSO. In addition, the actual volume of CSO not discharged into the bathing area will differ depending on the rain fall pattern of the respective year. Therefore, it was decided to have as functional unit “operation of the systems for one year [per year]”, without a relation to the amount of reduced CSO volume. However, the reduced volume of CSO is reflected in the water quality indicators (e.g. N and P load to the river) based on representative data of two reference years for CSO volume. It was decided to analyse one year with mean rainfall and normal CSO events, and another year with heavy rainfall events and large CSO events.

For the first goal, three scenarios are compared (Figure 2):

1. **Baseline:** no measures, i.e. discharge of CSO in a reference year
2. **Bypass pipe:** all CSO outlets in the bathing area are directly connected to a large collector pipe. This pipe transports the CSO water along the bathing area and discharges it back into the river Spree downstream of the bathing site.
3. **Volume activation:** an underground weir is installed at the most important CSO outlet, which can be closed in case of potential CSO events to increase the storage volume in the CSO outlet sewer. This will significantly reduce the total CSO volume discharged, with many CSO events fully prevented at this outlet. Stored CSO water

will be pumped back into the combined sewer system and treated at the central WWTP.

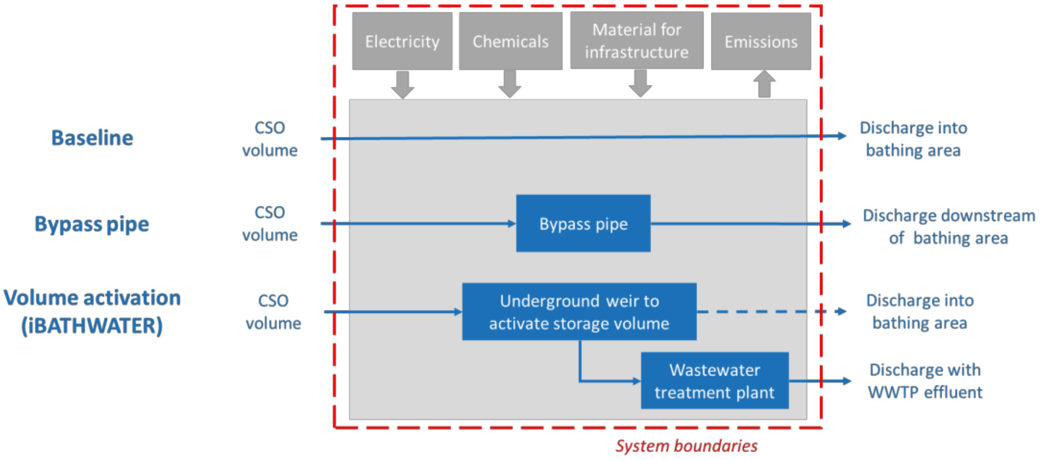

Figure 2 Scenarios for LCA and LCC at Flussbad Berlin for reducing negative impact of CSO events

The second goal relates to the collection of water quality information, which is required to manage the bathing site and prevent risks for swimmer´s health. The focus is on hygienic aspects, i.e. the risk of high concentrations of pathogenic microorganisms originating from CSO events with raw municipal wastewater. The system function is defined as “providing water quality information to the bathing site operator to reduce health risks from microbial contamination for swimmers”. Again, a suitable function unit is difficult to define, as the type and availability of information is quite different between the different possible solutions. Therefore, the functional unit is defined as “operation of systems for water quality information in one year [per year]”. Differences between the systems in terms of precision of information, time lag between water quality changes and availability of information, and other aspects also need to be considered when comparing the different options. However, these aspects are not reflected in the following analysis.

For the second goal, four options are compared (Figure 3):

1. **Regular sampling:** biweekly grab sampling of water quality at bathing water site according to requirements of EU bathing water directive (EU 2006) for *E.coli* and *Enterococci*.
2. **Aquabio sensors:** installation and operation of two Aquabio sensors for rapid detection of *E.coli* concentration. This scenario includes remote collection of sensor data and automatic processing in a laptop, which delivers the information to the bathing site operators.
3. **Multiparameter sensors:** installation and operation of 3 multiparameter sensors at major CSO outlets. These sensors can detect CSO events by rapid change in water quality parameters such as conductivity. This scenario includes remote collection of sensor data and automatic processing in a laptop, which delivers the information to the bathing site operators.

4. **Real-time forecast modelling:** setup, calibration and operation of a prediction model to predict CSO events based on real-time forecast data for rain events. This scenario includes setup of the model, calibration with rainfall data and water quality data for a defined period, and operation of the model during the bathing season to provide water quality information to the bathing site operator.

It is important to note that “annual operation” relates here to the provision of water quality information during the bathing season. This time span stretches over 18 weeks, usually from beginning of May to Mid-September. Operation of all devices or sampling intervals are only related to the time span of the bathing season, i.e. 18 weeks within one year.

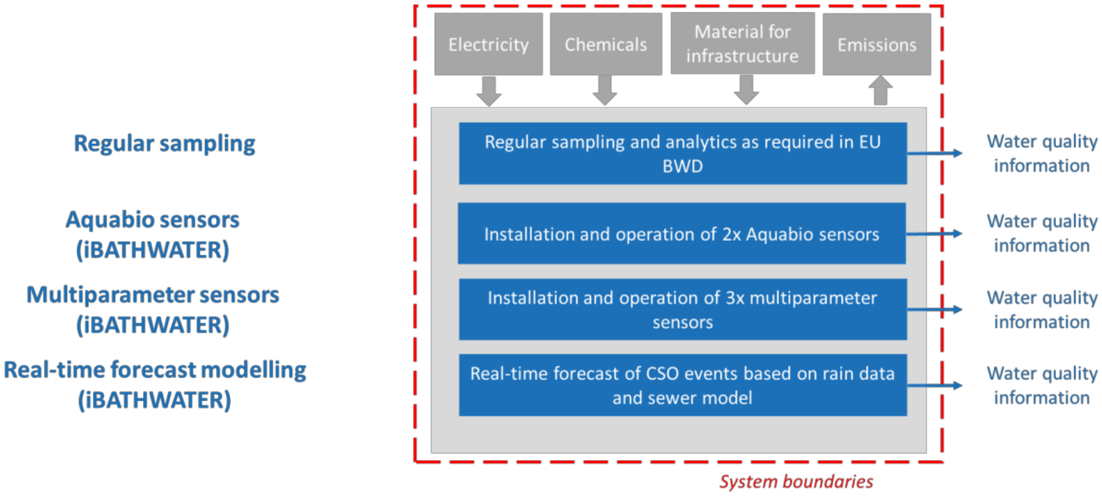

Figure 3 Scenarios for LCA and LCC at Flussbad Berlin for providing information of acceptable bathing water quality

Table 1 summarizes all scenarios analysed in this study in relation to the two goals. For combined functions, the baseline scenario includes bypass pipe and regular sampling of water quality, whereas the iBATHWATER scenario includes all solutions explored within the project: volume activation in the sewer, Aquabio and multiparameter sensors, and real-time forecast modelling based on predicted rainfall data.

Table 1 Summary of the scenarios analysed with LCA and LCC for the Berlin case study “Flussbad”

Scenario	**Relevant components**
Function: CSO reduction	
Baseline	Status quo (no additional components)
Bypass pipe	Pipe (800m) to collect CSO discharges at outlets and discharge downstream of bathing area
Volume activation	Underground weir at major outlet to increase storage volume, retaining CSO volume and treating it at central WWTP
Function: information on water quality	
Regular sampling	Regular sampling and lab analytics as external service

Aquabio sensors	2x Aquabio sensors, water intake, housing, power supply, remote data collection and processing
Multiparameter sensors	3x multiparameter sensors + installation, remote data collection and processing
Real-time forecast modelling	Setup and calibration of model, operation of model based on real-time rain prediction
Combined functions	
Conventional solution	Bypass pipe + regular sampling
iBATHWATER solution	Volume activation + Aquabio sensors + multiparameter sensors + real-time forecast modelling

2.2 Life Cycle Assessment

2.2.1 Goal of the study

The goal of this LCA is to compare different solutions for bathing site management at the Flussbad site in Berlin in their potential environmental impacts. Conventional options are compared with innovative solutions tested and explored in iBATHWATER. System functions, functional units and related scenarios are described in detail above.

2.2.2 System boundaries

For the first set of scenarios, system boundaries are defined in relation to the actual CSO volume occurring in a reference year and its potential discharge into the bathing area (Figure 2). The foreground system relates to the actual CSO volume and pollutant load at the bathing site in two reference years and its discharge or treatment. The LCA includes all background processes related to this function, i.e. electricity and chemicals for system operation, and materials for infrastructure. Direct emissions into the environment relate here to the discharge of pollutants into surface water. Treatment of stored CSO volume in a central WWTP is also included in the system boundaries.

For the second set of scenarios, system boundaries relate to the installation and operation of solutions to provide information on water quality (Figure 3). LCA includes operational efforts for sensors and data processing (electricity, chemicals), and materials for major infrastructure of sensors.

2.2.3 Data sources and data quality

Input data for the LCA originates from different sources (Table 2). Water quality data for CSO volume and composition and its reduction by volume activation has been calculated with a simulation of the sewer network and historic rain data of two reference years. Material demand for the bypass pipeline or underground weir has been estimated based on preliminary design planning in a feasibility study. For iBATHWATER sensor solutions, primary data for electricity, chemicals and material demand has been collected from pilot trials with high data quality. Forecast modelling has also been estimated based on work carried out in iBATHWATER.

Table 2 Data sources and quality of input data for LCA for the Berlin case study "Flussbad"

Data	Source	Quality	Remarks
CSO volume and composition	Sewer model and historic rain data	High	Detailed simulation of sewer network
Material for bypass pipe	Feasibility study	Medium	Design planning
Material for underground weir	Feasibility study	Medium	Design planning
CSO reduction	Sewer model and historic rain data	High	Detailed simulation of sewer network
Treatment in central WWTP	KWB study for Berlin WWTP	High	Data of Berlin WWTP
Aquabio sensors (operation and infrastructure)	ADASA/KWB	High	Results of pilot trials
Multiparameter sensors (operation and infrastructure)	KWB	High	Previous studies
Forecast model (electricity)	KWB	Medium	Estimates based on iBATHWATER work

LCA has been modelled with software UMBERTO LCA+ (v10) (IFU 2017), using the database ecoinvent v3.6 for background processes (Ecoinvent 2019).

2.2.4 Indicators for impact assessment

Indicators for impact assessment have been selected as follows: primary energy demand and global warming potential as indicators for efforts in material, electricity and chemicals, and freshwater and marine eutrophication for water quality aspects.

In detail, the following indicator models have been used:

- Cumulative energy demand for fossil and nuclear resources (= non-renewable) (VDI 2012)
- Global warming potential for 100a (IPCC 2014)
- Freshwater and marine eutrophication potential from ReCiPe v1.13 (Huijbregts et al. 2017)

2.3 Life Cycle Costing

2.3.1 General remarks

In this part, costs of the different scenarios are assessed based on a life cycle approach. This approach considers capital costs for investment, but also operational costs for consumables (electricity, chemicals), personnel, and maintenance. Annual costs are calculated by summing up depreciated capital costs and operational costs per year. Functional descriptions, functional unit and scenarios are fully aligned with LCA and described above (2.1.2).

2.3.2 Calculatory assumptions

All costs are calculated as net costs (= without VAT) for the reference year 2020. Capital costs are based on basic cost estimates plus an additional +20% for any additional costs (e.g. planning). Due to the early stage of design planning, a risk margin of +30% was added on top of the sum to have a conservative estimate of the actual capital costs for each scenario. Capital costs have been linearly depreciated with an interest rate of 3% per annum. Depreciation time was assumed to 15a for machinery and sensors and 50a for any other infrastructure (e.g. buildings, pipes) including also additional costs and risk margin.

For operational costs, price factors have been estimated for electricity, chemicals and spare parts for sensor operation. Personnel costs are calculated with mean working time and a daily rate. Maintenance costs are calculated in relation to capital costs with 0.5% per year for large infrastructure (i.e. buildings, pipes, tanks) and 2.5% per year for machinery and sensors if not stated otherwise.

2.3.3 Data sources and data quality

Input data for LCC is collected from a variety of sources (Table 3). Capital costs for bypass pipe and underground weir are collected from a detailed feasibility study for the site, but are still in the preliminary planning phase. Costs for regular sampling and sensor operation is based on real prices and experience collected during pilot trials. Costs for the setup, calibration and operation of the forecast model have been estimated based on KWB experience with tasks in iBATHWATER project.

Table 3 Data sources and quality of input data for LCC for the Berlin case study "Flussbad"

Data	Source	Quality	Remarks
Bypass pipe	Feasibility study	Medium	Design planning
Underground weir	Feasibility study	Medium	Design planning
Regular sampling	KWB	High	Lab prices
Aquabio sensors (operation and infrastructure)	ADASA + KWB	High	Results of pilot trials
Multiparameter sensors (operation and infrastructure)	KWB	High	Previous studies
Forecast model (setup, calibration and operation)	KWB	High	Estimates based on iBATHWATER tasks
Cost factors for electricity, personnel, maintenance	KWB	High	Data representative for Berlin

2.4 Socio-economic assessment: Hybrid-fulfilment importance matrix (HFIM)

The Hybrid-fulfilment importance matrix (HFIM) has been applied to assess the socio-economic dimension of the system. This assessment allows addressing these dimensions in a more holistic way.

2.4.1 General remarks

The HFIM includes a range of indicators organised in four categories:

- i) Technical indicators: Determine the degree of achievement of project activities and demonstrate the performance
- ii) Environmental indicators: Focus on the environmental impacts, including indicators from LCA
- iii) Economic indicators: Focus on the economic impacts, including indicators from LCC
- iv) Social indicators: Present a set of indicators that reflect the influence of the system from a social perspective.

Moreover, the socio-economic objectives of the system are also defined, based on the intended effects of the system under assessment. These objectives are represented in columns in the matrix, whereas the indicators are represented in rows. The resulting matrix is used to perform a semi-quantitative analysis determining the importance of the indicators (their relation) for the socio-economic effects defined.

It must be highlighted that this methodology is designed to be used at project level. An important component that also needs to be defined is the degree of improvement for each indicator, indicating the value at the beginning of the project and at the end of the project. These percentages of accomplishment are converted to a fulfilment factor to obtain a discrete number (0.5, 0.75, 1, 1.25 and 1.5), and afterwards the correlation matrix is applied to obtain the final values for the indicators.

2.4.2 Definition of the correlations

The correlations between the socio-economic objectives and the indicators defined have been defined by a panel of experts composed of the partners of the IBATHWATER project. Each partner has provided the matrix fulfilled with a semi-quantitative indicator: 0=no influence, 1=low importance, 2=medium importance, 3=high importance. The final matrix is an average of all the matrices defined by the partners.

2.4.3 Expected results

This method provides interesting results at various levels. Firstly, the degree of accomplishment of the different indicators (values at the beginning and the end of the project) can be analysed before and after applying the correlation matrix. Moreover, these results can be analysed at the indicator level (each individual value) and at the sphere level (performance, environmental, economic and social). Secondly, the correlation matrix itself shows the main hotspots of the matrix, which are the strongest correlations. Finally, the degree of accomplishment of each socio-economic objective is also of interest, as it shows the socio-economic performance of the system.

3 Input data for LCA and LCC

This section presents most important input data for both LCA and LCC for the Flussbad case study in Berlin.

3.1 Input data for LCA

Inventory data for the LCA is summarized below for materials for infrastructure, electricity and chemicals for operation (Table 4). In detail, the following assumptions have been made:

- Bypass pipe: steel pipe (DN 1800) with 850 m length including mounting on pillars and foundation, 6 connections to CSO outlets, culverts to cross river if required
- Underground weir: underground slider or weir, including surrounding infrastructure on a 15x15m area, electricity for weir operation (200 kWh/a), pumping of CSO volume to WWTP (0.175 kWh/m³) and treatment at WWTP (0.25 kWh/m³, incl. 4 g/m³ $FeCl_3$ (40%))
- Aquabio sensors (2 pc): sensor material data from supplier, incl. housing and influent buffer tank with pump, consumable data for electricity, chemicals, and nutrient solution for operation during the bathing season (18 weeks per year)
- Multiparameter sensors (3 pc): sensor material data estimated by weight, incl. steel for piping and mount
- Forecast modelling: electricity demand for model setup and update (50 kWh/a) and regular simulation (3 min/d calculation time in the bathing season)

Table 4 Input data for electricity, chemicals and material demand for each scenario for the Berlin case study

Input data	Unit	Bypass pipe	Under-ground weir	Aquabio sensors (2x)	Multi-parameter sensors (3x)	Forecast modelling
Concrete	m³	755	270	-	-	-
Reinforcing steel	t	136	49	-	-	-
Low-alloyed steel	t	440	-	2	-	-
Stainless steel	kg	-	1200	60	90	-
ABS plastic	kg	-	-	48	-	-
Electronics	kg	-	-	11	17	-
Cable	kg	-	-	21	1.5	-
Cast iron	kg	-	-	22	-	-
Electricity	kWh/a	-	1521 / 4332*	530	50	100
$FeCl_3$ (40%)	kg/a	-	23 / 39*	-	-	-
HCl (37%)	kg/a	-	-	2.4	-	-
H2SO4 (96%)	kg/a	-	-	3.7	-	-
Ethanol (100%)	kg/a	-	-	3.1	-	-
Nutrient solution	kg/a	-	-	32	-	-

** demand of WWTP for normal / wet year*

Infrastructure material has been scaled to lifetime to calculate annual material demand (lifetime: 50a for concrete + reinforcing steel, 30a for low-alloyed steel pipe, and 10a for sensors). Background datasets are taken from ecoinvent v3.6 and are reportd in annex (Table 9).

For CSO volume and quality, input data is calculated from a detailed sewer model and historic rain data for two reference years (Table 5). Rain data from 2016 represents a typical rainfall pattern of the region (“normal year”), whereas rain data from 2017 represents a rainfall pattern with intensive events during the bathing season (“wet year”). In baseline and bypass pipe scenario, the entire CSO volume and corresponding nutrient load is discharged into the river Spree. The bypass pipe discharges the entire CSO volume downstream of the bathing area, but still back into the river with the resulting ecological consequences (= potential eutrophication). In the scenario with underground weir, part of the CSO is held back in the sewer system and redirected to the central WWTP, where it is treated together with the municipal wastewater and finally discharged into receiving surface waters. Resulting effluent loads of nutrients are significantly reduced compared to the baseline scenario, as the central WWTP removes 95% of P and 90% of N loads from this fraction of the CSO.

Table 5 Water volume and quality for CSO and WWTP effluent in the different scenarios of the Berlin case study

Parameter	**Unit**	**Baseline**	**Bypass pipe**	**Underground weir**
Reference year 2016 (“normal)				
CSO volume	m^3/a	7,687	7,687	1,525
N load	kg/a	32.2	32.2	7.5
P load	kg/a	5.5	5.5	1.4
WWTP effluent	m^3/a	-	-	6,162
N load	kg/a	-	-	2.5
P load	kg/a	-	-	0.2
Reference year 2017 (“wet)				
CSO volume	m^3/a	56,030	56,030	38,083
N load	kg/a	132	132	88
P load	kg/a	20	20	13
WWTP effluent	m^3/a	-	-	17,947
N load	kg/a	-	-	4.7
P load	kg/a	-	-	0.4

In normal years with mean rainfall pattern, the underground weir is able to reduce 80% of the CSO volume in the bathing area (reference year 2016). In fact, CSO events at the specific outlet of the weir are completely prevented, so that remaining CSO originates from smaller CSO outlets in the bathing area. For wet years with extreme rainfall events (reference year 2017), total CSO volume is significantly higher in the baseline (factor 7x) and can only be reduced by 32% with the underground weir. In fact, high CSO volume in wet years is mainly caused by one or two singular events with massive CSO discharge, and the underground weir is not capable of fully preventing this type of CSO event.

3.2 Input data for LCC

Input data for LCC is related to investment costs and operational expenses (Table 6). For infrastructure of bypass pipe and underground weir, a feasibility study is available with detailed cost estimates for the different categories (Inros Lackner 2018). For sensors and modelling scenarios, investment costs have been collected from partner information (ADASA) and results of KWB work in iBATHWATER.

Operational costs are calculated based on electricity and chemicals demand as reported above (Table 4), assuming specific cost factors for each element. Personnel costs are estimated based on a fixed cost per day and an estimate of personnel demand for each scenario (d/a). Maintenance costs for large infrastructure are calculated as annual fraction of investment, with 0.5% per year for construction and 2.5% per year for machinery. For Aquabio sensors, maintenance costs are estimated to 12% of invest per year according to information from supplier (ADASA). Server costs for automatic data processing are estimated to 100 €/month for 4.5 months of bathing season.

Table 6 Cost data for investment and operation for each scenario of the Berlin case study

Input data	Unit	Bypass pipe	Under-ground weir	Aquabio sensors (2x)	Multi-parameter sensors (3x)	Forecast modelling
Investment						
Preparatory work	k€	2,515	-	-	-	49
Construction	k€	998	2,856	9.4	3.6	-
Machinery	k€	2,115	510	77.1	23.7	-
Auxiliary cost	k€	1,238	741	17.3	5.5	9.8
Risk margin	k€	2,015	1,232	31.1	9.8	17.6
Total investment	k€	8,881	5,338	135	42.6	76.4
Operation						
Electricity	€/kWh	0.2	0.2	0.2	0.2	0.2
$FeCl_3$ (40%)	€/t	-	210*	-	-	-
Chemicals	k€/a	-	-	2.4	0.05	-
Personnel cost	€/d	400	400	400	400	400
Personnel demand	d/a	30	60	18	4.5	10
Server cost	k€/a	-	-	0.45	0.45	0.45

** demand of WWTP*

For the baseline scenario, no infrastructure costs apply. Operational costs for regular water quality sampling according to EU BWD are calculated to 990 €/a, assuming 110 € per sample for sampling and analytics and 9 sampling events during the bathing season.

4 Results and discussion

This section presents and discusses all results from environmental assessment (LCA), economic assessment (LCC) and socio-economic assessment (HFIM).

4.1 Environmental assessment

Results from the environmental assessment are discussed per indicator category.

Regarding cumulative energy demand (CED), scenarios for CSO reduction are between 65 MJ/a for volume activation and 461 MJ/a for bypass pipe (Figure 4). Major impacts originate from civil works, i.e. material demand for construction of the pipe and underground weir. Civil works for bypass pipe is around 10x more energy intensive than civil works for underground weir, mostly due to higher material demand in concrete and steel (cf. Table 4). Apart from civil works, operation of the weir and treatment of retained CSO in the central WWTP also have some energy demand. For normal years, WWTP operation adds 14 GJ/a, while for wet years with high CSO volumes the WWTP contribution rises to 58 GJ/a, totalling 109 GJ/a for the scenario with underground weir.

For providing water quality information, scenarios have a CED of 8.7 GJ/a for the Aquabio sensors, 1.4 GJ/a for multiparameter sensors and 0.9 GJ/a for forecast modelling (Figure 4). Operation of Aquabio sensors has the highest share of its CED (> 65%), which is due to the electricity demand of the sensor. Civil works and sensor construction contribute less to the CED of the Aquabio sensors. For the multiparameter sensors, CED originates mainly from sensor construction, as energy demand for operation is low (batteries plus server operation). Forecase modelling has only electricity demand, because no additional infrastructure is required.

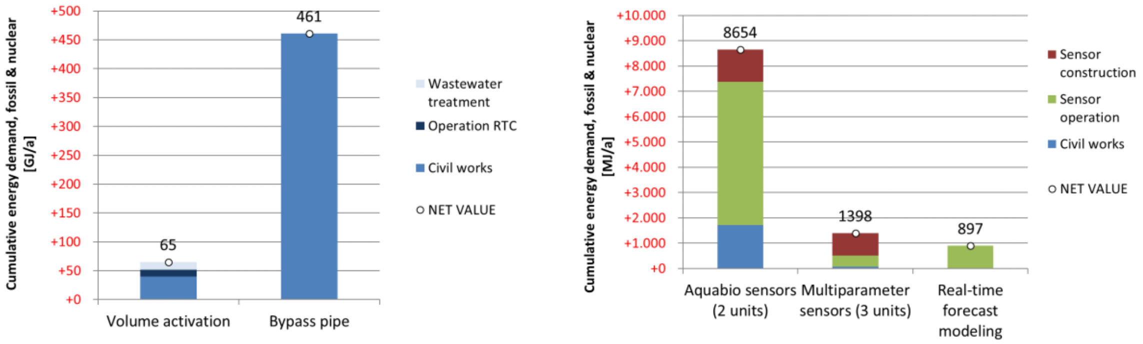

Figure 4 Cumulative energy demand of scenarios for reducing CSO discharge in bathing area (left) and providing water quality information (right) in the Berlin case study

For global warming potential (GWP), results are in strong analogy to the CED presented above (Figure 5). Again, construction of the bypass pipeline is dominating this scenario, with a total of 42 t CO_2e/a. Volume activation has a lower total GWP with 6 t CO_2e/a, mainly due to less impacts from construction. For normal years, WWTP operation adds another 1 t CO_2e/a, while the wet year causes a GWP of almost 3 t CO_2e/a due to higher CSO volume to treat. For scenarios providing water quality information, GWP of Aquabio sensors amounts to 604 kg CO_2e/a, again mainly due to impacts of sensor operation (electricity). Multiparameter sensors cause 100 kg CO2e/a, while forecast modelling has an impact of 62 kg CO2e/a (Figure 5).

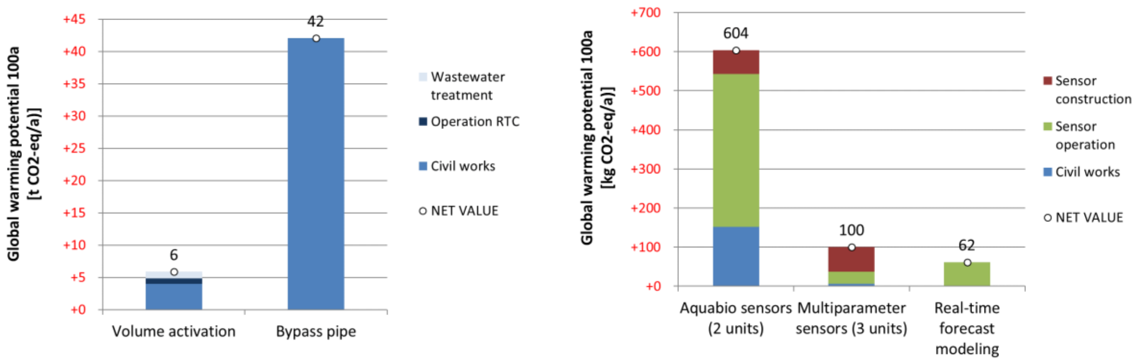

Figure 5 Global warming potential of scenarios for reducing CSO discharge in bathing area (left) and providing water quality information (right) in the Berlin case study

A split of the GWP contribution for the Aquabio sensors reveals that electricity demand is responsible for around 50% of its GWP impact (Figure 6). Inorganic nutrient solution contributes around 10%, while steel for cabin housing adds 18% to total GWP. The sensor infrastructure causes another 19% of the total GWP of this scenario.

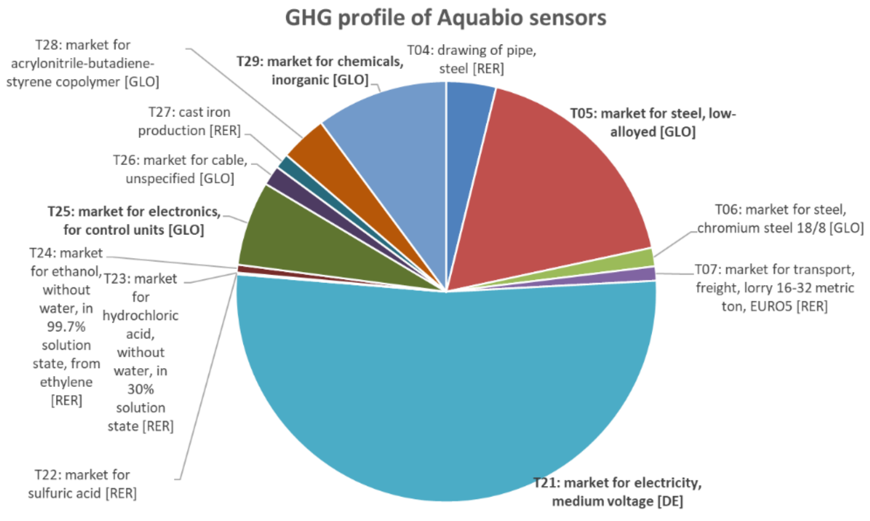

Figure 6 Contribution analysis of global warming potential of Aquabio sensors in the Berlin case study

Water quality is assessed with an indicator for P emissions as freshwater eutrophication potential (FEP) and N emissions as marine eutrophication potential (MEP). For FEP, the baseline situation shows an emission of 5.5 kg P/a in a normal year, and up to 20 kg P/a in a wet year (Figure 7). The scenario with bypass pipe does not at all reduce these emissions, as CSO volume is just bypassed around the bathing area and discharged back into the river downstream. In fact, FEP increases in this scenario due to P emissions originating from the life cycle of material production. The scenario with volume activation using the underground weir reduces total P emissions by redirecting potential CSO volume back into the sewer and to the central WWTP, where P is mostly removed before discharging into surface water. This leads to a reduction of 64% of P emissions in the normal year, and 29% in the wet year. For the wet year, higher emission loads from CSO originate from one or two major events with extremely high CSO volumes. These events cannot be completely prevented with the activation of additional storage volume, so that the positive effect of this strategy is less in years with extreme rain events.

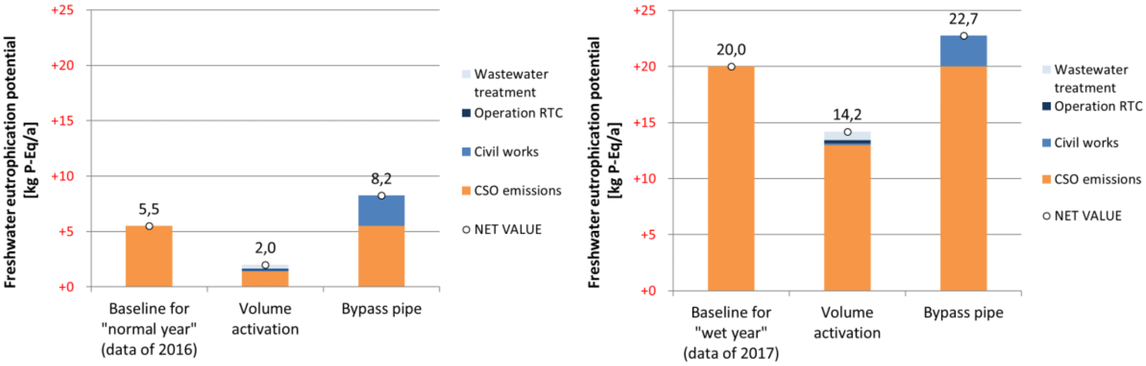

Figure 7 Freshwater eutrophication potential of scenarios for reducing CSO discharge in bathing area in normal year (left) and wet year (right) in the Berlin case study

In analogy to FEP, total nitrogen emissions and related MEP are also increased with the bypass pipe, again due to N emissions from the life cycle of material production. For the normal year, baseline MEP of 32 kg N/a is increased to 41 kg/a with bypass pipe, whereas baseline of the wet year with 135 kg N/a is increased to 144 kg N/a (Figure 8). Activation of additional storage volume with the underground weir reduces MEP by 67% in normal years and 31% in wet years with extreme CSO events.

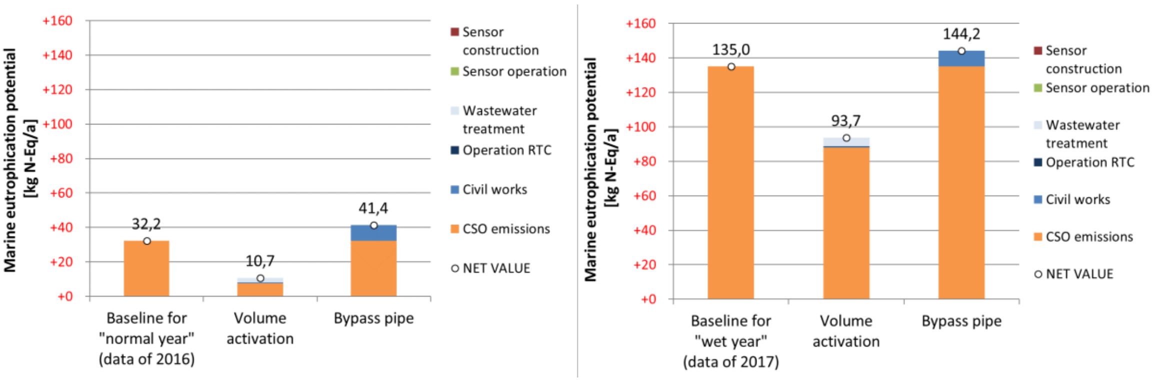

Figure 8 Marine eutrophication potential of scenarios for reducing CSO discharge in bathing area in normal year (left) and wet year (right) in the Berlin case study

Overall, the environmental assessment clearly indicates that iBATHWATER solutions to reduce CSO by activating additional storage volume in the sewer lead to less impacts from infrastructure in energy demand and GHG emissions than building a bypass pipe. On top, nutrient emissions into the river Spree are also reduced by 60-70% when CSO volume is stored and redirected to the WWTP. However, the latter effect is somewhat limited in extreme CSO events, which cannot be completely prevented even with higher storage volume and thus lead to pollution of the river and bathing area in these cases. Hence, a close monitoring of hygienic water quality in the bathing area and a reliable prediction and indication of CSO events are then required to allow for a safe management of the bathing site.

Considering the provision of this water quality information, additional impacts from monitoring devices such as Aquabio sensors or multiparameter sensors are relatively low compared to larger infrastructure. Indeed, it is still better for the overall GHG emission balance if all iBATHWATER solutions are implemented at the bathing site, compared to the conventional approach of building a large bypass pipeline (Figure 9). This illustrates that the savings in large infrastructure are significantly higher than additional impacts from water quality monitoring. Overall, implementing innovative iBATHWATER solutions enable a safe management of the bathing water site with lower environmental impact, both in terms of energy and related GHG emissions, but also related to water pollution by CSO events.

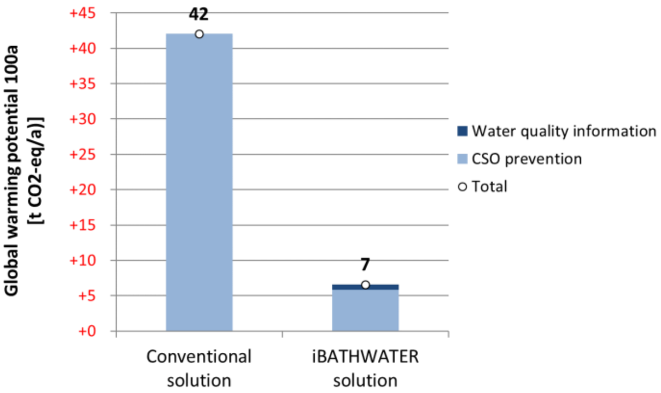

Figure 9 Global warming potential of conventional solution with bypass pipe and iBATHWATER solution with volume activation and monitoring of water quality with Aquabio sensors (2x), multiparameter sensors (3x) and real-time forecast modelling in the Berlin case study

4.2 Economic assessment

For the economic assessment, investment costs for all scenarios are compared below (Figure 10). The most expensive scenario is the bypass pipe, with investment costs of 8.9 Mio € for installing the pipeline. Building an underground weir at the major CSO outlet is less expensive, with 5.3 Mio € of required investment. Compared to these large infrastructure assets, investment for providing water quality information is significantly less expensive: two Aquabio sensors require an investment of 135 k€, while three multiparameter sensors will cost around 43 k€. Setting up a forecast model for CSO prediction comes at a cost of 76 k€, mainly related to personnel cost for model setup and calibration.

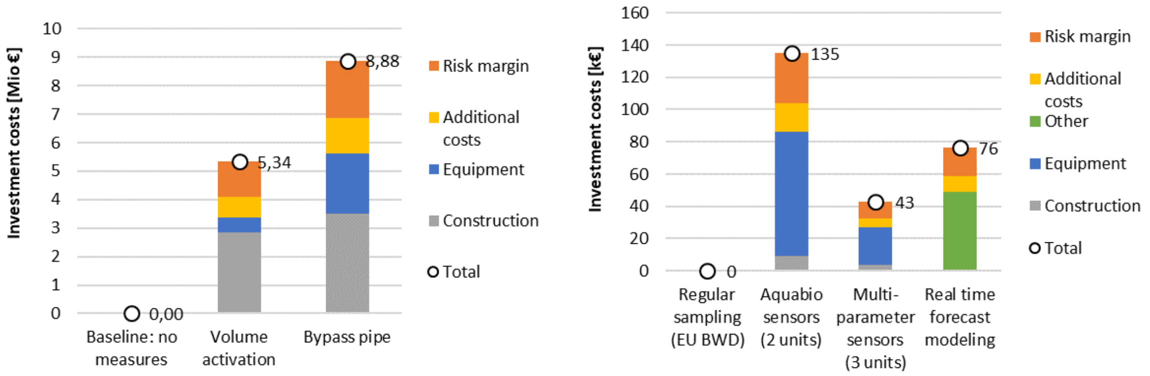

Figure 10 Investment costs of scenarios for reducing CSO discharge in bathing area (left) and providing water quality information (right) in the Berlin case study

For annual costs of each scenario, investment is depreciated and summed up with operational costs for energy, chemicals, personnel, and maintenance (Figure 11). Annual costs for larger infrastructure for CSO prevention are dominated by high capital costs, with operating costs adding a share of 14-18% of total annual costs. Again, the most expensive scenario in annual cost is the bypass pipeline with 510 k€/a, followed by the underground weir for volume activation with 282 k€/a. Compared to these numbers, the solutions for providing water quality information are between 28 k€/a for the Aquabio sensors, 5 k€/a for the multiparameter sensors, and 10 k€/a for the forecase modelling. Regular sampling according to EU BWD is still the cheapest solution for water quality monitoring with 1 k€/a, but it also delivers this information with a huge delay (usually 3-5 days between sampling and result) and may thus be not adequate for a timely and safe management of the bathing site. The latter fact also means that a combination of CSO prevention by volume activation and a “simple” biweekly sampling of bathing water quality is affected with either a high risk of water pollution and related hygienic risk for swimmers in case of heavy CSO events, or a more precautionary strategy with lead to long periods of bathing ban unless good water quality is approved again with lab analysis.

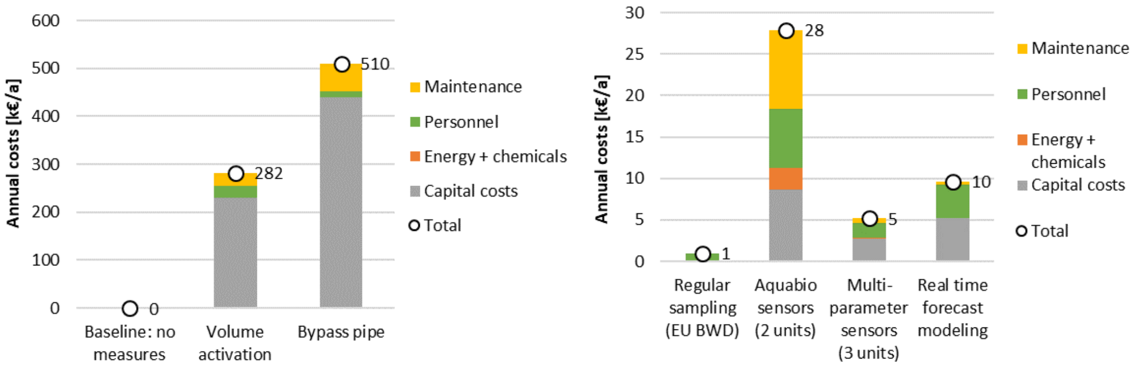

Figure 11 Annual costs of scenarios for reducing CSO discharge in bathing area (left) and providing water quality information (right) in the Berlin case study

Hence, possible combinations of CSO reduction scenarios with options for water quality monitoring only allow a more "conventional" approach of full protection of bathing area against CSO events with the bypass pipe combined with biweekly grab sampling to confirm good bathing water quality. With the IBATHWATER solution, a combination of volume activation and prevention of most of CSO events can then be combined with innovative options for real-time information on water quality, which enables a safe management of the bathing site based on reliable water quality data and timely forecast of potentially hazardous CSO events. In addition, lifting the bathing ban after CSO events can also be more timely, as actual information on hygienic water quality is available from Aquabio sensors in a period of few hours.

Overall, the conventional solution is still more costly with 511 k€/a than the innovative iBATHWATER solution with strategies for CSO prevention and close monitoring of the bathing water quality, which comes at 325 k€/a (Figure 12). For Flussbad Berlin, the iBATHWATER solution is thus not only more environmentally friendly, but also less costly than the conventional solution of the bypass pipeline. However, it has to be kept in mind that the monitoring strategy of iBATHWATER solution and the related integrated concept of bathing site management (when to allow or prohibit bathing in the area) has to be thoroughly validated to proof that the hygienic risks for swimmers can be minimized with this approach.

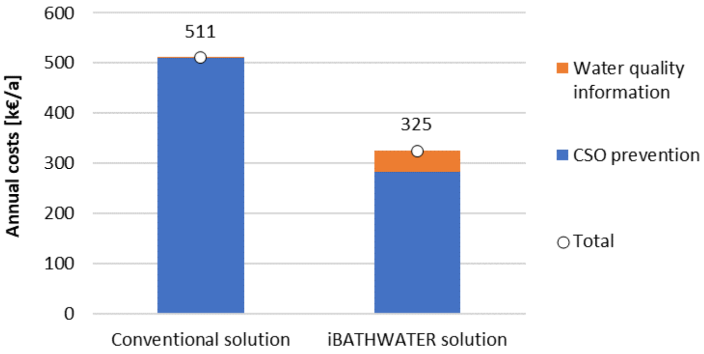

Figure 12 Annual costs of conventional and iBATHWATER solutions for reducing CSO discharge in bathing area and providing water quality information in the Berlin case study

4.3 Socio-economic assessment

The results of the application of the hybrid fulfilment-importance matrix for Berlin can be observed in Table 7. The results are based on both the scores obtained for the indicators of the project and the correlation matrix defined by the partners of the project. Moreover, the analysis can be done at different levels: degree of accomplishment of the indicators before and after applying the correlation matrix, hotspots of the matrix, performance per sphere and performance of the socio-economic objectives.

Table 7 Results of the Hybrid fulfilment-importance matrix for the case study of Berlin

SPHERE	INDICATORS	Units	GOAL*	RESULT	Sign	Accomplishment	Fulfilment factor	Improve quality of bathing waters during and after rain events	Ensure bathing water safety and reduce human health risk	Improve the management of the bathing areas	Increase citizen awareness of environmental and health impacts	Improve local economies	Indicator value	Sphere value	Sphere value/indicator
Performance indicators	Reduced untreated wastewater discharged	m^3/a	**5,000**	**6,162**	+	1.23	1.00	3.00	3.00	1.00	2.67	2.00	**11.7**	56.7	**11.3**
	Reduced annual COD load discharged	kg/a	**850**	**1,048**	+	1.23	1.00	2.00	2.67	1.00	2.33	2.00	**10.0**		
	Reduced annual *E. Coli* load discharged	log units	**0.30**	**0.45**	+	1.50	1.25	3.75	3.75	1.67	3.33	2.50	**15.0**		
	Reduced annual N load discharged	kg/a	**20**	**25**	+	1.25	1.00	2.00	2.33	1.00	2.33	1.67	**9.3**		
	Reduced annual plastic discharged	kg/a	**4**	**4**	+	1.00	1.00	2.67	2.33	1.33	2.67	1.67	**10.7**		
Environmental indicators	Reduction of greenhouse gas emissions (LCA)	kg CO_2e/a	**10,000**	**35,000**	+	3.50	1.50	1.50	1.50	1.00	3.00	2.00	**9.0**	29.7	**5.9**
	Ecotoxicity (LCA)	PAF·m^3·day	**61.6**	**61.6**	-	1.00	1.00	2.00	1.67	1.00	2.33	1.67	**8.7**		
	Reduction of dangerous substances - Pb	kg/year	**130.0**	**45.5**	+	0.35	0.50	0.83	0.83	0.33	1.17	0.83	**4.0**		
	Reduction of dangerous substances - Cu	kg/year	**547.0**	**191.5**	+	0.35	0.50	0.83	0.83	0.33	1.17	0.83	**4.0**		
	Reduction of dangerous substances - Ni and Cr	kg/year	**28.0**	**9.8**	+	0.35	0.50	0.83	0.83	0.33	1.17	0.83	**4.0**		
Economic indicators	Annual cost of iBATHWATER solution	k€	**500**	**325**	-	1.35	1.25	1.67	1.67	2.08	0.00	2.50	**7.9**	27.4	**5.5**
	Cost per m^3 of wastewater not spilled	€/m^3	**50**	**46**	-	1.08	1.00	0.67	0.67	1.67	0.00	1.33	**4.3**		
	Market uptake (number of customers)	N	**2,000**	**2,000**	+	1.00	1.00	1.33	1.33	2.00	0.00	2.00	**6.7**		
	Employment	N	**3**	**2.5**	+	0.83	1.00	0.00	0.00	0.00	0.00	2.00	**2.0**		
	Replication/transfer	N	**10**	**7**	+	0.70	0.75	1.50	1.50	1.50	0.50	1.50	**6.5**		
Social indicators	Better governance (number of pollution events without identified source)	Days/year	**40**	**35**	-	1.13	1.00	3.00	3.00	3.00	1.67	1.00	**11.7**	57.4	**11.5**
	Better governance (hours needed to predict concentrations in bathing areas)	h	**6**	**0.9**	-	1.85	1.50	4.50	4.50	4.50	2.50	3.00	**19.0**		
	Awareness raising (entities/people reached)	N	**500,000**	**2,911,100**	+	5.82	1.50	2.50	3.00	3.50	4.50	2.50	**16.0**		
	Environmental health (days with impaired quality without warning)	Days/year	**5**	**13**	-	-0.50	0.50	1.50	1.50	1.50	1.33	1.17	**7.0**		
	Visits to the website	N	**10,000**	**7,029**	+	0.70	0.75	0.50	0.50	0.50	2.00	0.25	**3.8**		
								36.6	**37.4**	**29.3**	**34.7**	**33.3**			

Coloured cells indicate the relative performance from green (best) to red (worst). COD=Chemical oxygen demand, LCA=Life cycle assessment, LCC=Life cycle costing

Regarding the accomplishment of the indicators, which links the results obtained for the different indicators with the goal established by the beginning of the project, 65% of the indicators considered have reached or exceeded the respective goals. The indicators with the higher accomplishments were better governance (hours to predict concentrations in bathing areas) and reduction of greenhouse gas emissions. In contrast, the indicators focused on the reduction of dangerous substances (Pb, Cu, Ni and Cr) were the ones with the lowest accomplishments.

The values of the indicators after applying the correlation matrix show that most performance and social indicators have a score above 10, being the highest reduction of *E. Coli* discharged, better governance (hours to predict concentrations in bathing areas) and awareness raising. The lowest values are again the reduction of dangerous substances, the employment, and the visits to the website. The disaggregation of the value in the matrix reveals that whereas in some cases the performance is poor due to a low accomplishment (reduction of dangerous substances) in other cases it is due to a low scoring in the importance matrix (employment or visits to the website). These later indicators are considered less relevant because they contribute less to the overall socio-economic objectives of the project.

If the results are considered at the sphere level, the performance and the social spheres are the ones that score the best, both around 57 against 27 and 30 from the environmental and economic spheres. Most indicators in the performance and the social sphere have fair accomplishment levels and had high correlations in the importance matrix, resulting in higher scores.

From the perspective of the socio-economic objectives considered, the last row of the table shows the summation of the whole column. This score indicates the relative importance of each objective considering the socio-economic impact of the project (the accomplishment and the importance matrix). To improve the quality of bathing waters during and after rain events and to ensure bathing water safety and reduce human health risk are the objectives with the highest scores (both around 37). These two objectives have a close link to the main outcome of the project and therefore it receives high punctuation from many of the indicators. In contrast, improving the management of the bathing areas is the one with the lowest score, as few indicators show high scores for this objective. However, it must be highlighted that the scoring of the five objectives does not show great differences, and all of them have a substantial contribution to different indicators (range between 29 and 37).

5 Conclusions

This report presents the sustainability assessment of the application of the iBathwater solution to the case study of Berlin. The sustainability assessment includes environmental assessment (LCA), economic assessment (LCC) and socio-economic assessment (HFIM). It compares a conventional approach to reducing CSO volume and providing water quality information with the innovative solutions tested in iBATHWATER.

From the environmental and economic analysis, the following conclusions can be summarized (Table 8):

- The iBATHWATER solution for CSO prevention by an underground weir at the major outlet has less environmental impacts and is less costly than the conventional solution of building a bypass pipe. This includes efforts for treating CSO volume at the central WWTP if it is stored and redirected to the sewer.
- In addition, redirecting CSO volume to the central WWTP for treatment also reduces nutrient loads in the Spree river by more than 60% for years with normal rainfall pattern. However, in case of heavy CSO events, the underground weir cannot fully prevent CSO discharge into the bathing area, so that additional solutions for real-time prediction and monitoring of CSO events and hygienic water quality are required.
- Additional environmental impacts and costs of these monitoring solutions are small in comparison to the large infrastructure required in the conventional solution with bypass pipe.
- Overall, an integrated iBATHWATER solution with volume activation for CSO prevention and advanced prediction and monitoring of CSO events and hygienic water quality can reduce annual costs by 34% and total GHG emissions by 83% compared to the bypass pipe.

Table 8 Results of LCA and LCC for conventional and iBATHWATER solutions for the Berlin case study

	Unit	Bypass pipe + regular sampling	Under-ground weir	Aquabio sensors (2x)	Multi-parameter sensors (3x)	Forecast modelling
Solution		*Conven-tional*	*iBATHWATER*			
Environmental impact						
Cumul. energy demand	GJ/a	461	65 / 109*	8.6	1.4	0.9
Global warming	t CO_2e/a	42	6 / 9*	0.6	0.1	0.06
Freshwater eutroph.	kg P/a	8 / 23*	2 / 14*	-	-	-
Marine eutrophication	kg N/a	41 /144*	11 / 94*	-	-	-
Economic impact						
Investment	k€	8,881	5,338	135	43	76
Annual costs	k€/a	511	282	28	5	10

** for normal / wet year*

This analysis illustrates that innovative solutions for bathing site management and CSO prevention can be more sustainable in environmental and economic terms than conventional solutions, which often lead to the construction of large new infrastructure. The latter option is both costlier and comes with a higher environmental impact than using intelligent management of existing infrastructure (e.g. by activating storage volume in the sewer) and advanced solutions for water quality monitoring and prediction of CSO events. Combining iBATHWATER solutions at the Flussbad site will enable a more efficient and more environmentally friendly implementation of an inner-city bathing area than relying on traditional strategies of “more concrete”, i.e. heavy infrastructure with high cost and related environmental impact.

In general, the contribution of the project in terms of improving the performance and the social aspects of the system have the highest socio-economic impacts, as shown with the application of the Hybrid fulfilment-importance matrix. The reduction of the untreated wastewater discharged and related pollutants (*E. Coli*, nitrogen, COD) as well as the improvement in the governance and the awareness raising have the highest influence on the socio-economic impacts. The results have impacted positively all the socio-economic objectives of the project, specially improving the quality of bathing areas during and after rain events and ensuring bathing water safety and reducing human health risk.

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7 Appendix

7.1 Background datasets for LCA

Table 9: LCA datasets from ecoinvent v3.6 for background processes (Ecoinvent 2019)

Process	Dataset from ecoinvent v3.6	Remarks
Electricity	market for electricity, medium voltage [DE]	Power mix 2014
Concrete	market for concrete, normal [RoW]	
Reinforcing steel	market for reinforcing steel [GLO]	
Steel for pipe	drawing of pipe, steel [RER]	For low-alloyed steel pipe in scenario “bypass pipeline”
Low-alloyed steel	market for steel, low-alloyed [GLO]	
Stainless steel	market for steel, chromium steel 18/8 [GLO]	
Cast iron	cast iron production [RER]	
$FeCl_3$ (40%)	market for iron (III) chloride, without water, in 40% solution state [GLO]	For WWTP operation
H2SO4 (96%)	market for sulfuric acid [RER]	For Aquabio sensor
HCl (37%)	market for hydrochloric acid, without water, in 30% solution state [RER]	For Aquabio sensor
Ethanol (100%)	market for ethanol, without water, in 99.7% solution state, from ethylene [RER]	For Aquabio sensor
Nutrient solution	market for chemicals, inorganic [GLO]	For Aquabio sensor
Electronics	market for electronics, for control units [GLO]	
Cable	market for cable, unspecified [GLO]	
ABS plastic	market for acrylonitrile-butadiene-styrene copolymer [GLO]	
Transport	market for transport, freight, lorry 16-32 metric ton, EURO5 [RER]	50 km for concrete, 600 km for other materials