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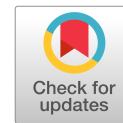
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# Cost-Benefit Analysis for Supporting Intermunicipal Decisions on Drinking Water Supply

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**Abstract:** Several countries promote a regionalization of the drinking water sector; however, few decision support tools are adapted to the intermunicipal level to aid in regional decisions. The aim of this paper is to describe and demonstrate a probabilistic cost-benefit analysis approach to assess the societal effects of regional water supply interventions to constitute support for decision makers. A special focus is given to the quantification of effects on consumers' health, water supply reliability, and operation and maintenance costs. The uncertainties of the quantified values are represented by probability distribution functions and analyzed by means of Monte Carlo simulations. The proposed approach was demonstrated in the Göteborg region in Sweden, for which five alternative interventions were evaluated. In conclusion, the proposed approach facilitates the identification and prioritization of societal effects so that costs and benefits normally overlooked in evaluation processes can be explicitly considered and addressed. The paper provides a transparent handling of uncertainties and enables a structured approach to improve decision makers' ability in making informed choices on regional water supply alternatives. DOI: 10.1061/(ASCE)JWR.1943-5452.0001121. This work is made available under the terms of the Creative Commons Attribution 4.0 International license, <http://creativecommons.org/licenses/by/4.0/>.

## Introduction

Water supply provision has traditionally been a municipal responsibility. However, with a growing focus on how to best finance and implement water supply improvements to address ever-increasing challenges, such as demographic and climate changes, an intermunicipal, regional governance level is emerging in the water sector (Kurki et al. 2016; Schmidt 2014). In Sweden, the responsibility of providing the water supply resides with the 290 municipalities. Currently, about 65 percent of them operate the water supply within their municipality. The remaining municipalities operate the supply in various forms of intermunicipal cooperations (SOU 2016).

In 2013, the Swedish government decided to investigate the public drinking water sector with the aim of identifying current and potential challenges to a safe drinking water supply, and, if necessary, to propose appropriate measures. The inquiry (SOU 2016) identifies a number of challenges for Swedish water providers, including an aging infrastructure; a continuous population growth in the larger cities; a depopulation of the countryside; and climate changes with higher average temperatures, increased and more extreme precipitation, changed patterns for drainage and evaporation, rising sea levels, altered land and water use, and a predicted increase in chemical and microbiological health hazards.

In addition, several municipalities are facing limited financial and personnel resources. To cope with present and future challenges and uphold a safe and reliable water supply, the inquiry recommends a further regionalization of the Swedish water sector, including extended regional planning and coordination as well as an increase in intermunicipal cooperations.

One of the major drivers of regionalization is to generate economies of scale, that is, the cost advantage that may arise from increased production. A number of studies have been investigating scale economies in the water sector, and there is generally a consensus that the water industry has important economies of scale up to a certain output level (Saal et al. 2013). Another driver for regionalization is to share unevenly spaced resources, for example, to secure access to sufficient water resources, treatment plants, and highly skilled personnel, and hence improve water supply reliability and safety. However, even though regional cooperation in the water sector takes place in several countries in Europe, the United States, the Middle East, and North Africa, research focusing on the associated societal effects is limited (Kurki et al. 2016).

Given that regionalization is promoted and argued to generate benefits, how do we assess those benefits to support decisions on regional alternatives? And how do we assess other, potentially negative effects that may arise as a result of regionalization? Considering the wide range of effects that may arise from regional interventions and the fact that detailed assessments can be difficult, time-consuming, and expensive at such an overarching level, a well-structured and clearly defined assessment method is needed to support complex decisions. Hence, the method needs to take into account which effects are reasonable and possible to assess at a regional level, and with what degree of certainty.

The aim of this paper is to describe and test a cost-benefit analysis (CBA) approach to assess the costs and benefits that may arise from regional water supply interventions. The specific objectives are to (1) present a generic CBA approach, with identified key effects, that is adapted to an overarching regional level; (2) show how some key effects can be valued economically; and (3) exemplify the CBA approach through application in the Göteborg region in Sweden. The paper is therefore organized to first present how the

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CBA approach was developed, followed by a detailed description of the relevant cost and benefit items and how these items can be monetized. The effects of interventions on operation and maintenance costs, water supply reliability, consumers' health, ecosystem services, and agricultural yields are given special attention. The presented CBA approach and economic valuation techniques are then used in a case study to illustrate its applicability.

## Method Development

In this chapter, the basis for the presented method is introduced, that is, the cost-benefit analysis, and an overview of the key steps for developing and applying the method is provided.

### Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a widely acknowledged method that has long been used to compare the effects of alternative projects and policies in a range of areas (Johansson and Kriström 2016). To conduct a proper CBA, certain methodical steps need to be followed. At first, the alternatives to be evaluated need to be determined along with the reference alternative to which they are compared. The initial part of the analysis also involves deciding who the stakeholders are, that is, whose costs and benefits to include, over which time horizon the alternatives should be evaluated, and which discount rate(s) to apply. The positive and negative consequences of the alternatives (i.e., their benefits and costs) are then identified and quantified in relation to the reference alternative. The theoretical foundation of CBA defines benefits as increases in human well-being and costs as reductions in human well-being (Pearce et al. 2006). Individuals' well-being depends on market goods and services as well as nonmarket goods and services, such as health and environmental quality. Various forms of economic valuation methods are also available for quantifying the benefits and costs of nonmarket goods and services in monetary units. The goal is to quantify the trade-offs that individuals are willing to make between income and a positive or negative change in the provision of a nonmarket good or services, that is, to quantify their willingness to pay/accept compensation (WTP/WTA) for a specific change (Freeman et al. 2014). A net present value (NPV) is calculated for each alternative as the discounted benefits minus the discounted costs. A distributional analysis of the costs and benefits as well as sensitivity analyses are important final steps in a CBA. An alternative is considered economically profitable when its total benefits are larger than its total costs, that is, when its NPV is positive. The emphasis in this paper is on the identification of costs and benefits, on the economic valuations of these consequences, and on handling the uncertainties of the quantified values.

### Literature Survey

To aid in the identification of possible consequences when evaluating regional water supply interventions, a generic list of private costs and benefits as well as externalities was compiled; see Table 1. First, a gross list was assembled based on a literature review (Sjöstrand 2017) on the effects of regionalization, the costs and benefits commonly assessed in the water sector, and the costs and benefits that are often missing in assessments of water supply alternatives (Rathnayaka et al. 2016).

### Stakeholder Workshop

The gross list of costs and benefits compiled from the literature survey was presented and discussed in a half-day stakeholder

**Table 1.** Potential cost and benefits items due to regional water supply interventions

Cost and benefit items	Description
Water utility costs and benefits	Investments Operational and maintenance costs Other costs and benefits
Water supply reliability effects	Lost value added in economic sectors Losses for residential consumers
Water-related health effects	Costs for health care Lost production Discomfort and loss of life
Effects on ecosystem services	Drinking water Irrigation Hydropower Industrial water use Recreational activities Flood and erosion risk reduction Retention of contaminants Other water services
Effects on agriculture, forestry, and industry due to water protection restrictions	Agricultural, forestry and other industrial production effects on agriculture, forestry, and industry due to water protection restrictions

workshop held in April 2016. The stakeholders were selected to represent decision makers, planners, authorities, and societal groups who were assumed to derive direct or indirect economic consequences from the implementation of regional water supply alternatives. The workshop participants were representatives of the following stakeholder sectors: water authorities, municipal community planners, environmental professionals, water utility managers, water resource organizations, fishing organizations, local politicians, and the agriculture, transport, and hydropower sectors, totaling 33 participants.

At the workshop, the stakeholders were divided into six groups with as much representation from the different stakeholder sectors as possible in each group. They were presented with the gross list, and each stakeholder group was asked to discuss the relevance of the proposed costs and benefits in assessments of regional water supply interventions and to reach an agreement on what costs and benefits to add and/or remove from the list. The list was modified based on the outcome of the workshop, and then further refined in the process of testing and evaluating the method.

### Case Study

A case study in the Göteborg region was used to test, evaluate, and illustrate the use of the proposed CBA approach in a real-world situation. The case study was set up to demonstrate decision situations regarding regionalization (de)centralization, source water quality, and redundancy, and to study the effects on society of such regional decisions.

### CBA Approach and Estimation of Costs and Benefits

A probabilistic cost-benefit model was constructed for the identification and quantification of the expected consequences of alternative interventions; see Fig. 1. Net present values (NPV) are calculated according to Fig. 1, in which  $a$  is the alternative intervention,  $C$  is the cost,  $B$  is the benefit,  $t$  is the time when the benefit or cost occurs,  $T$  is the time horizon, and  $r_t$  is the discount rate at

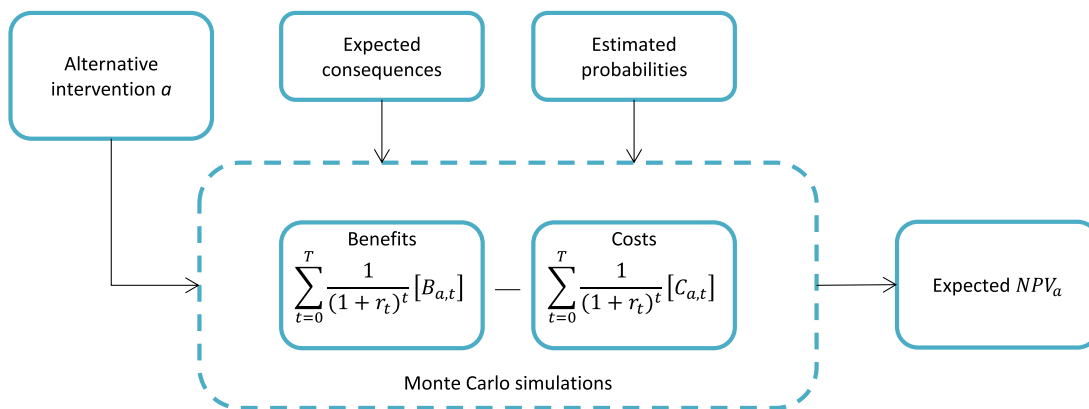


Fig. 1. Cost-benefit model for calculations of net present values of alternative interventions.

time  $t$ . The uncertainties of the quantified values are represented by probability distribution functions and handled by means of Monte Carlo simulations. All costs and benefits are calculated in relation to a reference alternative.

### Identification of Costs and Benefits

The first task is to identify the consequences of the suggested alternative interventions. This is preferably done through literature reviews and discussions with various experts, water utility managers, policy makers, stakeholders and members of the public. To aid in the identification process, the generic list of potential costs and benefits is provided in Table 1.

Given that economic valuations of costs and benefits can be both time-consuming and expensive on an overarching regional level, a first general assessment may be performed in collaboration between the decision-making team, experts, and key stakeholders to prioritize which costs and benefits to monetize and incorporate in the CBA. This first general assessment can include a simple estimation of the magnitude of the consequences of the alternative interventions (e.g., large, small, or nonexistent cost/benefit) as well as the likelihood that these consequences will occur (e.g., large, moderate, small, or nonexistent).

### Estimation of Costs and Benefits

When the relevant cost and benefit items have been identified, the next task is to quantify those items in monetary units. This section provides examples, from a Swedish perspective, of how some key types of costs and benefits can be monetized. The examples deal with how to estimate the effects of interventions on operation and maintenance (O&M) costs, water supply reliability, consumers' health, and agricultural yields. The selection of these costs and benefits is based on the outcome of the case study workshop in order to include consequences that can be expected to be important in regional interventions. In other studies, other cost and benefit items, and thus other valuation methods, may be relevant.

### Estimation of Operation and Management Costs

Cost and benefit items affecting the water utilities, such as investments and O&M costs, are generally estimated based on information from experts, benchmarking data, literature, and past and ongoing similar projects. In this subsection, a general model is developed to estimate the effects on O&M costs when small local utilities are replaced with larger regional ones. As economies of scale are one of the major drivers for regionalization, it is important

for the local water utilities to be able to determine how large that potential benefit could be. The model is based on benchmarking data from nine European countries and provides a way to handle a lack of data for the country in question, in this case Sweden.

The Swedish Water and Wastewater Association's Statistical System (VASS) collects yearly utility information from the Swedish municipalities. There is, however, no sufficiently large statistical basis for studying O&M costs in large water utilities in Sweden. However, the International Benchmarking Network for Water and Sanitation Utilities (IBNET) contains information from more than 4,000 utilities on, for example, O&M costs at IBNET 2016. To estimate a general relationship between a utility's size and its O&M costs, Swedish O&M costs from 213 municipalities reported to VASS between 2010 and 2015 were here combined with the O&M costs reported to IBNET between 2000 and 2015 from 550 utilities in eight European countries (IBNET 2016; VASS 2015). The selection of those eight countries was based on the availability and distribution of O&M cost data from small and large utilities. Other European countries, which may have conditions that are more similar to those of Sweden, are either not available in IBNET or do not provide sufficient variation in the data. The overall trend in the terms of costs versus the number of consumers in these countries was still considered reasonable to be used for generating estimates of Swedish O&M costs.

Costs in local currencies were converted to USD by the official exchange rate (LCU per USD, period average) (The World Bank 2017), and thereafter adjusted for inflation by the Consumer Price Index (CPI) to 2016 prices (US Inflation Calculator 2017). The data was first grouped by the number of consumers served by the water utilities, using the same group categories used within the IBNET database: <10,000; 10,000–49,999; 50,000–99,999; 100,000–499,999; 500,000–999,999 and  $\geq 1,000,000$ . Descriptive statistics are shown in Table 2, in which  $n$  is the number of data points, \$ is the US dollar, and  $std$  is the standard deviation.

Since we were only interested in trends, that is, the cost differences across water utilities of different sizes, the data was normalized to remove the effects of national general cost differences while preserving the relationship between utility size and cost. The data was, for this reason, not adjusted by the purchasing power parity (PPP). The data was normalized by scaling the costs for each country such that its average cost matched the grand average of all involved costs according to the following steps. Let  $p_i$  be the group population size for group index  $i \in (1, 6)$ , and  $c_{i,j,k}$  be the  $k$ th O&M cost per cubic meter for group  $i$  and country  $j$ . The mean cost per cubic meter for group  $i$  and country  $j$  is then

**Table 2.** Descriptive statistics of O&M costs (USD in 2016 prices) reported to IBNET between 2000 and 2015 and to VASS between 2010 and 2015

Country	Descriptive statistics	<10,000	10,000–49,999	50,000–99,999	100,000–499,999	500,000–999,999	≥1,000,000
Albania	n	139	291	93	67	11	0
	mean (\$/m <sup>3</sup> )	0.45	0.46	0.47	0.32	0.17	—
	std	0.28	0.37	0.26	0.26	0.04	—
Bulgaria	n	0	10	36	190	16	10
	mean (\$/m <sup>3</sup> )	—	0.47	0.42	0.42	0.38	0.26
	std	—	0.21	0.12	0.17	0.07	0.05
Croatia	n	10	44	20	15	5	0
	mean (\$/m <sup>3</sup> )	0.74	0.86	0.64	0.39	0.61	—
	std	0.33	0.39	0.38	0.29	0.11	—
Georgia	n	24	110	19	21	5	4
	mean (\$/m <sup>3</sup> )	0.17	0.12	0.10	0.12	0.08	0.04
	std	0.16	0.12	0.12	0.08	0.03	0.01
Lithuania	n	9	138	46	22	9	0
	mean (\$/m <sup>3</sup> )	3.40	1.62	1.48	1.19	0.98	—
	std	1.04	0.53	0.68	0.49	0.12	—
Poland	n	8	67	63	184	44	13
	mean (\$/m <sup>3</sup> )	1.41	1.55	1.40	1.39	1.38	1.29
	std	0.40	0.63	0.34	0.49	0.38	0.29
Russia	n	7	174	120	665	282	175
	mean (\$/m <sup>3</sup> )	1.69	1.30	1.13	0.50	0.38	0.36
	std	1.32	1.10	2.57	0.30	0.19	0.15
Serbia	n	20	175	60	63	0	2
	mean (\$/m <sup>3</sup> )	0.43	0.36	0.49	0.51	—	0.43
	std	0.34	0.28	0.20	0.20	—	0.00
Sweden	n	237	428	84	44	8	2
	mean (\$/m <sup>3</sup> )	1.56	1.45	0.33	2.18	0.20	0.12
	std	6.89	6.04	0.22	6.75	0.07	0.002

$$c_{i,j} = \frac{1}{n_{i,j}} \sum_{k=1}^{n_{i,j}} c_{i,j,k} \quad (1)$$

Given this, the mean cost per cubic meter for each country is

$$c_j = \frac{1}{n_j} \sum_{i=1}^{n_j} c_{i,j} \quad (2)$$

and the grand average cost per cubic meter over all countries is

$$C = \frac{1}{9} \sum_{j=1}^9 c_j \quad (3)$$

The costs per cubic meter for each country were then normalized by scaling according to

$$\hat{c}_{i,j} = \frac{C}{c_j} c_{i,j} \quad (4)$$

where  $\hat{c}_{i,j}$  is the normalized cost per cubic meter. We regress over normalized costs per cubic meter to find the rate of change for costs as a function of the common logarithm of the population size served by the water utility. The estimated model is

$$\hat{c}(p) = -0.215 \cdot \log_{10}(p) + 1.7 \quad (5)$$

where  $R^2 = 0.9061$  and the level of statistical significance  $<0.01$ . Given a utility of size  $p$  at current cost  $c$  per cubic meter, the projected cost  $\tilde{c}$  per cubic meter at size  $\tilde{p}$  can then be found by

$$\tilde{c}(c, p, \tilde{p}) = c \frac{\hat{c}(\tilde{p})}{\hat{c}(p)} \quad (6)$$

### Effects on Water Supply Reliability

Water supply disruptions have been shown to cause different economic consequences across businesses and economic sectors (Chang et al. 2002). For interventions affecting the risk of water supply disruptions, the economic consequences for both residential consumers and economic sectors should therefore be considered. Different approaches have been used in the literature to estimate consumers' WTP for avoiding water supply disruptions, for example, contingent valuation and the integration of estimated demand curves (Brozović et al. 2007; Griffin and Mjelde 2000). The valuation provided here follows the FEMA (2011) methodology applied to estimate the consequences of water supply disruptions for economic sectors and residential consumers. In order to use such measures in a CBA, however, they must be combined with risk estimations of the loss of water supply due to the evaluated alternatives.

The approach used to estimate consequences for different economic sectors was developed to assess the indirect economic losses of longtime water supply interruptions in the United States as the value-added loss in each economic sector (ATC 1991). It was here assumed that Swedish economic sectors have the same percentage reduction in the value added from a total water supply outage as US economic sectors. The percental reductions in each sector were combined with Swedish GDP data for 2016 (SCB 2017) and the population of Sweden in mid-2016 (SCB 2016b), generating a total economic impact of 351 SEK per capita per day of lost water

**Table 3.** Economic consequence per capita and day of lost water service per economic sector. 1 million Swedish Krona (MSEK) is approximately 125,000 USD

Economic sector	Percent reduction (%)	GDP 2016 (MSEK)	GDP 2016 per capita per day (SEK)	Cost per capita per day of lost water service (SEK)
Food and tobacco	70	41,509	11.5	8.0
Textile and leather	65	5,072	1.4	0.9
Pulp, paper, lumber, and wood	55	69,146	19.1	10.5
Chemicals, petroleum, and coal	65	93,093	25.7	16.7
Rubber and plastic	50	30,280	8.4	4.2
Primary and secondary metal products	85	83,880	23.2	19.7
Instruments	90	78,947	21.8	19.7
Electronic equipment	90	19,271	5.3	4.8
Machinery except electrical	60	70,565	19.5	11.7
Transport equipments	60	107,525	29.7	17.8
Furniture and miscellaneous manufacturing	55	37,248	10.3	5.7
Construction	50	237,607	65.7	32.9
Utilities	40	115,422	31.9	12.8
Wholesale and retail trade	20	421,682	116.6	23.3
Transportation and warehousing	20	163,618	45.3	9.1
Accommodations and food service	80	69,905	19.3	15.5
Information and communication	20	226,663	62.7	12.5
Finance, insurance, and real estate	20	881,218	243.7	48.7
Health, education, and social care	40	146,691	40.6	16.2
Arts, entertainment, and recreation	80	27,691	7.7	6.1
Public authorities	25	785,080	217.1	54.3
Total				351.1

service (see Table 3). Some original values of percental reductions were merged to correspond to the available GDP data. The agriculture and mining sectors were excluded as not being relevant to the public water supply, and the household sector was excluded to avoid double counting with the residential loss estimation.

The approach used to estimate the effects on residential consumers is based on an equation for consumer WTP to avoid water supply interruptions (Brozović et al. 2007), here adapted to Swedish water prices and quantity data:

$$W = \frac{\eta}{1 + \eta} P_{baseline} Q_{baseline} \left[ 1 - \left( \frac{BWR}{Q_{baseline}} \right)^{\frac{1+\eta}{\eta}} \right] \quad (7)$$

in which  $W$  is the daily loss of welfare per capita,  $P_{baseline}$  is the average water price when there are no interruptions,  $Q_{baseline}$  is the average amount of water consumed per capita per day when there are no interruptions,  $BWR$  is the basic water requirement, which is the minimum amount of water required for drinking and sanitation per capita day, and  $\eta$  is the price elasticity of water demand.

The average water price in Sweden in 2015 was about 0.035 SEK/L and the average amount of water consumed was 160 L per capita and day (SOU 2016). The basic water requirement ( $BWR$ ) was set to 25 L/day as the minimum required for drinking and basic sanitation (Gleick 1996; Howard and Bartram 2003), and the price elasticity was set to  $-0.378$ , following the mean price elasticity of water demand for developed countries as reported in the meta-analysis conducted by Sebrí (2013). The daily welfare loss then equates to 69 SEK per capita per day  $[-0.378/(1 - 0.378)] \cdot 0.035 \cdot 160 \cdot [1 - (25/160)^{(1-0.378)/-0.378}]$ . However, Eq. (7) assumes that the utility is able to provide the  $BWR$  during the entire water interruption period, but does not value how much the consumers would be willing to pay for that service. Following the FEMA methodology, the cost of bottled water was used to proxy that value. According to the Swedish Water and Wastewater Association (2017), bottled water costs about 250 times as much as tap water, exerting a total economic impact on residential consumers of 288 SEK per capita and

day (69 SEK + 250 · 0.035 SEK/L · 25 L), and a total for both economic sectors and residential users of 639 SEK per capita and day [288 SEK + 351 SEK (Table 3)].

### Health Effects

When assessing alternatives affecting drinking water safety, the economic effects of changed health risks should be considered. Two commonly used methods to assess the benefits of reduced health risks are the defensive behavior and the damage cost methods. In the valuation presented here, the damage cost method was used to estimate the economic costs for a case of water related infection in Sweden. These measures must then be combined with estimations of changed health risks due to the evaluated alternatives.

The economic cost of water-related infections was valued as the sum of health care costs, costs of lost production, and costs of discomfort (Hurley et al. 2005). The health care costs were based on the 2016 average health care cost of gastroenteritis caused by *Campylobacter*, rotavirus, and other unspecified causes according to the Swedish KPP (cost per patient) database, which was approximately 5,900 SEK per visit (SKL 2017). The cost of lost production due to work absence was calculated as the sum of direct and indirect costs. The direct cost was here based on the direct sick leave costs for Swedish employers (Swedish Social Insurance Agency 2017) for the average monthly salary in Sweden in 2016 (SCB 2016a), equating to 2,352 SEK per day. The indirect costs, which refer to the lower productivity of replacement workers, coworkers, and supervisors, was calculated as 8.9 percent (SHRM 2014) of the average monthly salary in Sweden 2016, providing an approximate indirect cost of 139 SEK per day (assuming 21 work-days per month). The cost of discomfort was based on a study by Ready et al. (2004), who found that individuals from five different European countries were willing to pay approximately 576 SEK in 2016 prices to avoid a day of symptoms that are common to gastrointestinal infections (i.e., nausea, headache, cramps, stomach-aches, and diarrhea). Based on an assumption that a case of infection may cause 13 days of symptoms, 2.5 days of work absence, and, on average, 0.1 hospital visits (Hunter et al. 2004;

Morgan and Owen 2008; Robertson et al. 2002), the total cost of health care, lost productivity, and discomfort hence add up to  $13 \cdot 576 + 2.5 \cdot 2,352 + 2.5 \cdot 139 + 0.1 \cdot 5,900 = 14,305$  SEK per case.

### Effects on Ecosystem Services

When evaluating interventions with environmental impacts, the resulting changes in ecosystem services should be considered. There are numerous economic valuation methods to assess changes in such services, ranging from direct market valuation approaches to revealed and stated preference approaches. Direct market approaches have the advantage of using relatively easily obtainable market data on goods and services, which are directly subject to trade. In revealed preference methods, individuals' demand for market goods or services are used to assess their WTP to related ecosystem services, whereas in stated preference methods, the individuals are asked about their WTP for hypothetical changes in the provision of ecosystem services (Hanley and Barbier 2009). Given the wide range of ecosystem services potentially affected by regional water supply interventions, a specific economic valuation is not provided here. We instead refer to the extensive literature on this subject; see, for example, Hanley and Barbier (2009) and Young and Loomis (2014).

### Effects on Agriculture, Industry, and Forestry due to Water Protection Regulations

When considering alternatives that include the establishment of new, or the dismantling of old, water protection areas, the costs and benefits arising as a result of those changes should be included in the evaluations. There are potentially many different consequences that need to be considered. In Swedish water protection areas, for example, the exploitation of certain raw materials, professional use of pesticides, handling of petroleum products, and establishment of environmentally hazardous activities are usually regulated. The valuation method provided here regards economic consequences for farmers due to pesticide regulations.

According to the Swedish Environmental Protection Agency's regulations (Swedish EPA 2015), permits are required for the professional use of pesticides in all Swedish water protection areas. The mobility of the pesticides, the permeability of the soil, and the amount and frequency of the pesticides needed are some parameters affecting whether a permit is granted or not. To estimate the economic consequences for farmers from not receiving permits for pesticide use for certain crops, the value difference of conventional and organic production yields is here used as a proxy, assuming that a potentially higher production cost for organic production is covered by a higher crop price. The annual yield difference  $Y$  of the crops in question can then be calculated as

$$Y = \sum N_{C,K} \cdot H_C \cdot P_{C,K} - \sum N_{C,O} \cdot H_C \cdot P_{C,O} \quad (8)$$

where  $C$  is the specific crop,  $K$  is conventional production,  $O$  is organic production,  $N$  is the norm harvest (kg/hectare),  $H$  is the area harvested within the water protection area (hectare), and  $P$  is the crop price (SEK/kg). Consideration should be given to the influence of subsidies, and whether the crop productions per hectare and/or crop prices are expected to change over the evaluated time horizon.

### Time Discounting

In order to adequately account for the life span of water supply infrastructure as well as effects that may occur well into the future, time horizons of 50–100 years may be considered for the assessments (Mitchell et al. 2007). Time horizons of this length require considerations of intergenerational equity, and how the discounting

of costs and benefits can be performed in an appropriate manner. Time-declining discount rates have, for example, been proposed for assessing interventions that propose to conserve or provide ecosystem services (Gollier et al. 2008). To account for different views and prioritizations in the decision-making team, the CBA is preferably conducted under different discount rates and time horizons to assess the sensitivity of the outcome.

### Uncertainty and Sensitivity Analyses

Given that cost and benefit values rarely are known with certainty, the uncertainties should also be taken into account in the analysis (Pearce et al. 2006). Uncertainties can derive from a lack of available data or knowledge to estimate certain effects, the bias and subjectivity of experts and stakeholders, and natural random variability. In economics and cost analysis, uncertainties about cost and benefit values are often represented by lognormal probability distribution functions (Garvey et al. 2016). The parameters defining the lognormal distribution are the mean value and standard deviation of the specific cost and benefit item assessed in the monetization process. Alternatively, the distribution can be defined by two percentiles, for example, the 5th and 95th percentiles, which may be very useful in practical applications.

Monte Carlo simulations can then be used to model the uncertainties in input values and outcome. Based on the Monte Carlo simulations, decision makers can determine, for example, the probability of an alternative being economically profitable and uncertainty estimates of the outcome. The Monte Carlo simulation facilitates sensitivity analyses by, for example, measuring the contribution of variance from each input variable to the total variance of the outcome. The variables can be ranked by order of impact on outcome uncertainty and thereby help decision makers prioritize which variables to be aware of and which require more data gathering to reduce uncertainties.

To study the impact of different discount rates, time horizons, and uncertainties of future conditions, such as demand and supply predictions, scenario analyses can be performed. This means that the model is run using different values on the relevant parameter, representing different possible future scenarios. In the application presented here, scenario analysis is performed for the discount rate and time horizon. Additional future scenarios could, for example, include the capacity of the relevant source waters due to the different extent of climate change effects.

## Method Application

### Water Supply Alternatives in the Göteborg Region

Five alternative water supply interventions were analyzed for the Göteborg region in Sweden. The alternatives were designed to meet regional sustainability targets and to illustrate decision situations regarding regionalization (de)centralization, source water quality, and redundancy; see the descriptions in the subsequent text. All alternatives were evaluated in relation to a reference alternative over the time horizons of 30 and 70 years, respectively, to study the sensitivity of choosing a shorter versus longer time horizon. The constant discount rates of 1.4% and 3.5% were selected. The rate of 1.4% reflects the average discount rate used in the Stern Review on Climate Change (Stern 2006), whereas the rate of 3.5% reflects the suggested best practice of the Swedish Transportation Administration Guidelines (Swedish Transportation Administration 2018).

The Göteborg region has 13 municipalities, within which Göteborg is the largest city. The region reached 1 million inhabitants in 2017 and according to municipal prognoses, there will be

1.3 million inhabitants in 2050 (GR 2014). For this evaluation, a linear population growth was assumed from 2017 (year 1 in the analysis) through 2050. Based on 2011 values, the drinking water production per capita and day in the region (250 L) was assumed to be constant over the evaluated time horizons (GR 2014). To handle expected population growths within the time horizons, treatment and distribution capacities were increased in all alternatives, including the reference alternative.

*Reference Alternative* The region's water supply system includes 30 water treatment plants, of which 12 are supplied from surface water, 15 from groundwater, and 3 from artificial groundwater. Four of the municipalities are fully or partly dependent on water produced in the City of Göteborg. The region's water production is highly dependent on source water from the river Göta älv, which has varying water quality and is considered to be particularly exposed to the effects of climate change. Major investments in capacity and treatment improvements in the region are carried out between the year 2045 and 2055.

*A1: Regionalized governance and centralized production from Lake Vänern* A single drinking water organization operates the production for the entire region. Costs associated with the regionalization of water utilities and an increased maintenance are expected initially. O&M costs are thereafter expected to decrease as a result of economies of scale. Sweden's largest lake, Vänern, is the main source water for the entire region. New source water facilities, including a 100-km source water tunnel, are constructed initially. The tunnel leads the source water from Vänern to two treatment plants located in the City of Göteborg, where the water is treated and then further distributed throughout the region. The capacity of the two treatment plants as well as of the region's distribution system is initially adapted to the production need of the time horizon. Old water treatment plants are shut down and water protection areas for prior source waters cease to exist.

*A2: Regionalized governance and centralized production from the river Göta älv* This example is similar to A1, with the exception that the river Göta älv is the main source water for the entire region. Hence, the source water tunnel and other new source water facilities in A1 are not included in A2.

*A3: Regionalized governance and maintained semi-decentralized production* A single drinking water organization operates the production within the different municipalities. Costs associated with the regionalization of the water utilities and increased maintenance are expected initially. O&M costs are thereafter expected to decrease as a result of a regionalized organization. Current water treatment plants, source waters, and water protection areas are maintained.

*A4: Maintained governance and decentralized groundwater dependent production* Current water treatment plants, water protection areas, and source waters, except Göta älv, are maintained. The source waters are supplemented with increased and new withdrawals from several groundwater resources as well as some lakes. Four new groundwater treatment plants and two new surface water treatment plants are constructed initially. The capacity increase in the region's distribution system is partly performed initially and partly at the same time as the reference alternative. New water protection areas and restrictions are established for the new source waters.

*A5: Maintained governance, with additional source waters and treatment plants* Current water treatment plants, source waters, and water protection areas are maintained. The current system is expanded with two new water treatment plants and an increased proportional use of the region's largest lakes. One new water protection area is established initially. The capacity increase in the

region's distribution system is partly performed initially and partly at the same time as the reference alternative.

### Identification of Costs and Benefits

The same stakeholder workshop that was used to compose the generic set of costs and benefits was also used to prioritize which costs and benefits to monetize and include in the cost-benefit analysis of the five alternatives. Each stakeholder group was asked to make a general assessment of the magnitude of the consequences of the alternative interventions from the generic list of possible consequences. They were also asked to assess the likelihood that the consequences would occur. The costs and benefit items that were assessed to have a low or nonexistent likelihood to occur and, at the same time, to have a small or nonexistent consequence were excluded from the CBA. The resulting costs and benefits items to be included in the CBA for the Göteborg region were: water utility items, that is, investments and O&M costs; water supply reliability effects; water-related health effects; effects on hydroelectric production; and effects on agricultural production due to pesticide regulations.

Water utility costs associated with implementing the alternatives, such as costs for new treatment plants, pipelines, pumping stations, water protection areas, tunnel constructions and so forth, were estimated based on information gathered from experts at water utilities, as well as from past and ongoing Swedish projects. The effects on O&M costs, water supply reliability, health, and agriculture were valued based on the methods explained in the preceding text. The estimations of risks for water supply delivery failures and negative health effects were based on prior risk analyses of the water supply systems in the Göteborg region (GR 2014; Lindhe et al. 2009, 2011), and effects on hydropower production in the river Göta älv over the time horizons were valued based on spot prices for the year 2016 and estimated prices of Long Term Power Outlook (Nord Pool 2016; SKM 2016). Input parameters and further details from the assessments of the five alternatives are reported in (Sjöstrand et al. 2018a).

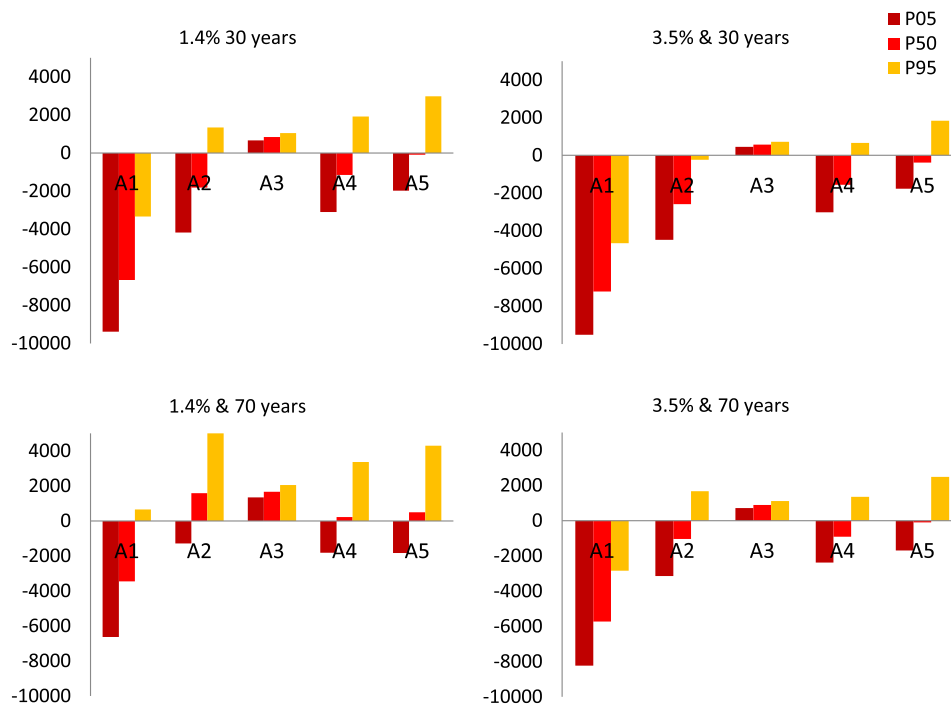
### Results from the Göteborg Region Application

The outcome of the CBA for the time horizons of 30 and 70 years and the discount rates of 1.4% and 3.5% is presented as net present values in Fig. 2. Since uncertainties are considered, the results are presented using the 5th, 50th (median), and 95th percentiles (P05, P50, and P95). The calculations of net present values and associated uncertainties were performed using Monte Carlo simulations, consisting of 10,000 iterations each, using Palisade's risk analysis software @RISK.

The alternative A1, comprising a centralized production with source water from outside the region, showed the most negative NPV values independent of analyzed time horizon and discount rate. The other centralized alternative, A2, with source water from Göta älv, also showed mostly negative NPV values. The major difference in costs between the two centralized alternatives is associated with new source water facilities in A1, including the construction of a 100-km source water tunnel.

The A3 alternative, with a regionalized governance and maintained semi-decentralized production, was the alternative that was most likely to be economically profitable independent of the applied time horizon and discount rate. It was also the alternative associated with the lowest degree of uncertainty in NPV estimation. One reason for the positive outcome for A3 was that the alternative did not comprise any major investments relative to the reference alternative. Further, the formation of a regional organization leads





**Fig. 2.** Net present values (P05, P50, and P95) of the five alternatives evaluated for the discount rates of 1.4% and 3.5%, and the time horizons of 30 years and 70 years (MSEK).

to assumed decreases of operation and maintenance costs. It is, however, likely that the model used to project new O&M costs overestimated the benefits of merging utilities for this alternative because the water utilities that the O&M model is built on are likely to have somewhat fewer treatment facilities than A3 for the same number of connected consumers.

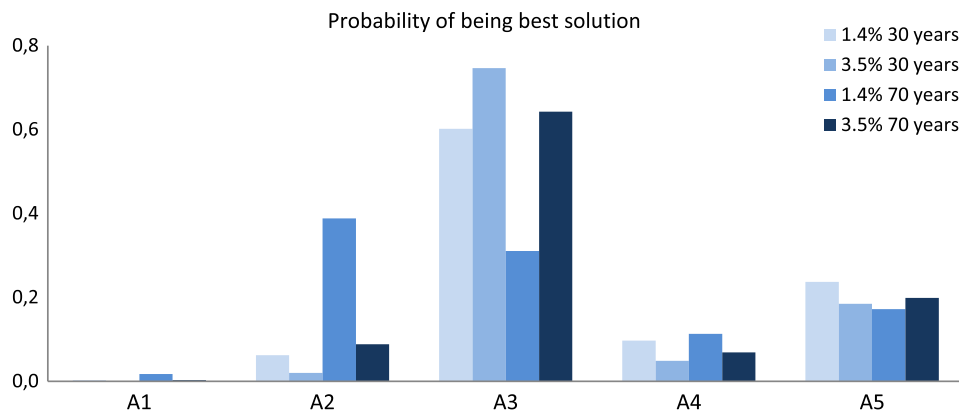
The A4 and A5 alternatives showed similar outcomes, with A5 being slightly more profitable than A4. Both alternatives maintained municipal governance but with the difference of a more decentralized groundwater-dependent production in A4 and an expansion of the current system with additional treatment plants and source waters in A5. Overall, all alternatives were assessed as more economically profitable the longer the time horizon was and the lower the discount rate was.

The probabilities of each alternative being the most economically profitable for each time horizon and discount rate can be seen

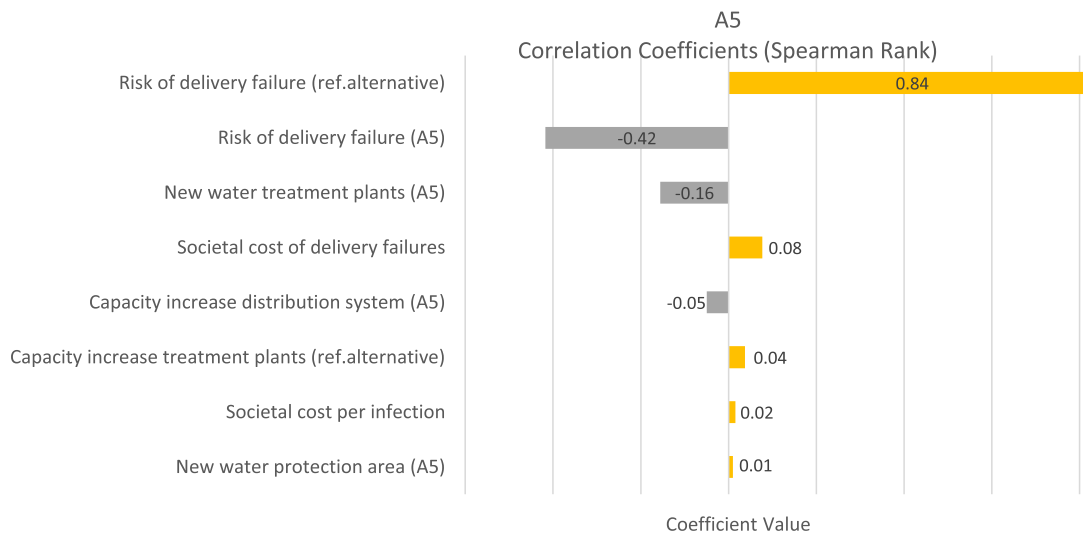
in Fig. 3. A3 showed the highest probability of being the best solution for all evaluated conditions except when analyzed over a 70-year time horizon with a 1.4% discount rate. The results indicate that a regional utility has the potential to generate great benefits. However, as previously mentioned, the benefits may be overestimated if the number of production facilities is not decreased alongside the number of utilities.

With a 1.4% discount rate and a 70-year time horizon, the aggregated long-term benefits of A2, that is, of increased water supply reliability and decreased O&M costs, outweighed the initial investment costs of A2 as well as the benefits of A3. Hence, in this case, A2 became the alternative with the highest probability of being the best solution. The probabilities of A1, A4, and A5 were fairly stable and not as affected by changed discount rates and time horizons.

A5 showed the second-highest probability of being the best solution. The alternative was assumed to benefit from a decreased risk



**Fig. 3.** Probabilities of each alternative being the best solution.



**Fig. 4.** Sensitivity analysis for A5, performed for a 3.5% discount rate and 70-year time horizon.

of delivery failure due to a more redundant supply system. A5 thus appears to be a rather advantageous alternative, considering that the risk of delivery failure contributes significantly to overall outcome uncertainties. Assuming that the risk of delivery failure in the reference alternative was underestimated, the A5 alternative might have appeared even more beneficial as an acceptable risk level may be hard to reach without the additional source waters and treatment plants of A5.

Based on the Monte Carlo simulations, an example sensitivity analysis performed for A5 is shown in Fig. 4. The figure shows the degree to which costs and benefits covariate with the NPV outcomes, expressed in the form of correlation coefficients between  $-1$  and  $1$ . Expected changes in risk for delivery failure contributed most to the outcome uncertainty in A5.

Overall, the externality that had the largest impact on NPV outcomes in the Göteborg region was changes in the risk of delivery failure. The reduced risks for negative health effects did not contribute to large differences in NPV and neither did the effects on agriculture or hydropower. However, future changes in health and delivery failure risk levels due to, for example, changed microbiological loads were not accounted for in this case study. Uncertainties regarding how changes in future risk levels may affect the alternatives differently should hence be considered when interpreting the results.

## Discussion

The main purpose of this paper was to present and test a CBA approach to assess effects that may arise from regional water supply interventions. Economic valuation methods of key effects were presented and applied. Five intervention alternatives, illustrating decision situations regarding regionalization (de)centralization, source water quality, and redundancy, were evaluated for the Göteborg region in Sweden.

Since economy of scale is a major driver for regionalization, a model to estimate changes in O&M costs when transforming from several small utilities to one large utility was developed. The model was based on water utility data from both IBNET (2016) and VASS (2015) to compensate for the lack of Swedish O&M cost data from large utilities, and provided a general relationship between the

number of connected consumers and O&M costs per cubic meter. There are, of course, several other parameters that also affect O&M costs. The purpose of this model, however, was to obtain a first estimate of the size of the economic benefit from merging utilities. This estimate may then constitute the basis for decisions on further detailed analyses. However, as mentioned in the preceding text, the model may provide overestimated benefits for regional utilities without centralized production systems and hence favor some alternatives over others in the analysis.

As water utilities' main duty is to provide their customers with a continuous supply of safe drinking water, and since regionalization is often argued to improve the fulfillment of this obligation, economic valuation methods to assess effects on water supply reliability and water safety were presented and applied. The damage cost method was used to assess the direct and indirect costs of negative health effects due to insufficient drinking water quality, resulting in a total cost of health care, lost production, and discomfort of about 14,000 SEK per case (mean value). The valuation of water supply reliability in this paper combined measures of the impact on economic activity in different economic sectors with the impact on residential consumers. The methodology employed to estimate the impact on economic sectors was developed to assess the indirect economic losses of longtime water supply interruptions in the United States as the value-added loss in each economic sector. There is, however, very limited empirical literature on the value of water reliability to study the impacts of shorter water supply disruptions at different levels of shortage and duration (Griffin and Mjelde 2000). The economic value of water supply reliability in Sweden for consumers and different economic sectors may therefore be further studied in order to address this omitted topic.

Uncertainties about cost and benefit estimations were modeled by probability distributions. Yet, the handling of uncertainties about future conditions and the modeling of interdependencies among cost and benefit items have not been addressed in full detail. Interdependencies may exist between several of the cost and benefit items, for example, between water supply disruptions and human health as well as between different ecosystem services. For example, during periods with low or no water pressure, the risk for intrusion of contaminants in the distribution systems increases, which in turn affects the water quality and hence human health (Lindhe et al. 2013). Interdependencies between benefit and/or cost

items might affect the results of a Monte Carlo simulation. These dependencies can be considered and included in Monte Carlo simulations through correlation analysis by the covariance matrix for the logarithmic variables; see, for example, Söderqvist et al. (2015). Correlation analysis is, however, limited to normal distributions and variations thereof. Assuming that not all distributions are log-normal, and the dependence in the tails of the distribution where the impacts are strong may be more important, interdependencies may instead be modeled by copulas (Kobus and Kurek 2018). The modeling of interdependent variables was, however, not included in the present study. Future research should be directed to examine interdependencies between cost and benefit items and their integration in the model. By applying existing methods to manage the uncertainties and dependencies that exist, the complexity of reality can be better taken into account. This would provide valuable information for planners and decision makers. Future research also needs to more formally integrate climate change, population growth, and regulatory restrictions; multiple futures; and the value of risk in terms that reflect preferences for risk aversion rather than expected net economic benefits alone.

Integrating those aspects involves information requirements that may seem daunting, and the collection of risk-averse estimates or the direct elicitation of the economic value of insurance against risk may appear beyond a realistic capacity to estimate with the resources that are commonly available. However, using suitable methods for expert elicitation and facilitating Bayesian methods for combining hard data and expert judgments may substantially simplify the work. The integration of all available information facilitates a comprehensive model and from a decision-maker perspective, it is important that the effect of the included scenarios and so forth can be traced and visually illustrated. Monte Carlo methods can facilitate this work and reduce the computational demand.

Economic valuations of assumed effects can be performed in several ways. It is, however, almost always impossible in practice or too expensive to value all consequences that may arise as a result of a proposed alternative (DCLG 2009). Hence, a prioritization is needed regarding which effects are reasonable and possible to assess, and to what degree of certainty. This can be particularly important at an overarching regional level. In this paper, the identification and prioritization of costs and benefits were completed with the use of stakeholder workshops, enabling viable and accepted decisions.

However, the focus in the paper is on effects that are feasible to assess by means of CBA. As CBA relies on the anthropocentric foundation of welfare economics, the analyses captures the human well-being aspects of the consequences of the evaluated alternatives (Pearce et al. 2006). For the inclusion and assessment of other aspects that may not be compatible with this ethical basis for a CBA, such as equity and final environmental values, the presented approach can be combined with multicriteria decision analysis for comprehensive sustainability assessments (Sjöstrand et al. 2018b; Söderqvist et al. 2015).

Several countries promote a regionalized water supply sector with intermunicipal cooperation in order to achieve more sustainable water services; see, for example, AWWA (2015) and SOU (2016). But due to vague understandings of the resulting effects, the regionalization of the water sector tends to be held back (Frone 2008). The CBA approach presented and tested here can support decision makers in making informed choices on regional alternatives, including intermunicipal cooperation, to maximize the benefits of water services at the lowest cost to society. The provision of generic costs and benefits along with valuation methods facilitates the inclusion and explicit economic assessments of, for example, delivery failure, health risks, and agricultural production, effects that are normally overlooked in such evaluation

processes. This inclusion is crucial for achieving an economically sustainable water supply provision since neglecting to assess the economic benefits of alternative interventions may lead to underinvestment in water supply improvements.

## Conclusions

The main conclusions of this paper are:

- The regionalization of the water sector is encouraged in several countries; however, few studies have focused on assessing the societal effects of intermunicipal cooperations or other large-scale intermunicipal policies and interventions that regional decision makers are faced with.
- A generic list of costs and benefits facilitates the identification and prioritization of potential consequences so that effects that are normally overlooked in evaluation processes can be explicitly considered and openly addressed.
- The probabilistic methodology allows for uncertainty and sensitivity analysis of quantified values. This enables calculations of the probabilities that alternatives will, for example, exceed certain cost limitations or be economically profitable. Aspects such as the uncertainties of future conditions and potential interdependencies across cost and benefit items are currently not included in the model, but these limitations are suggested to be relaxed by future research.
- The CBA approach presented here enables economic comparisons of regional water supply alternatives, including the formation of intermunicipal cooperations.
- The CBA approach should be combined with multicriteria decision analysis for comprehensive sustainability assessments of regional alternatives.

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