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# ASTA — A method for multi-criteria evaluation of water supply technologies to Assess the most SusTainable Alternative for Copenhagen

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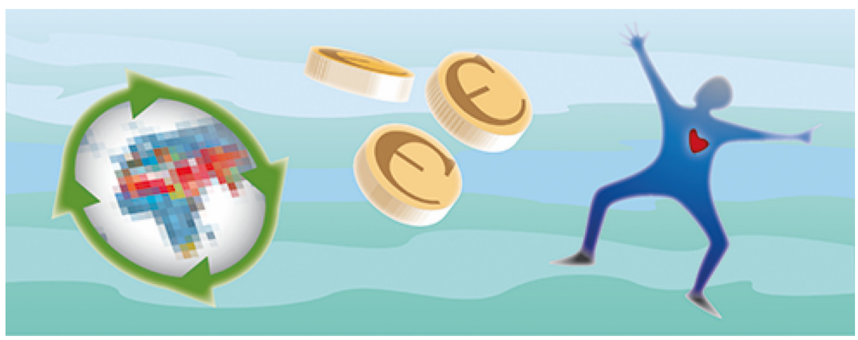
## HIGHLIGHTS

- Develop a method for combining sustainability dimensions in to one joint decision support system
- Emphasize the relevance of assessing various criteria when choosing your water supply source
- Develop and test a decision support system combining two multi-criteria assessments
- Demonstrate that freshwater is a limited resource
- Show water systems based on rain-& stormwater or groundwater are preferable in our case

## GRAPHICAL ABSTRACT



Graphical abstract of paper where sustainability is defined as the 3 dimensions – environment, economy and society. Environmental evaluation is built on LCA also covering the impacts of freshwater withdrawals which are presented by a recycling diagram around the globe where water scarce areas are highlighted in red. Economy is indicated by a Euro-coin and society by a person.

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## ABSTRACT

Utilities in larger cities have to make complex decisions planning future investments in urban water infrastructure. Changes are driven by physical water stress or political targets for environmental water flows e.g. through the implementation of the European water framework directive. To include these environmental, economic and social sustainability dimensions we introduce a novel multi-criteria assessment method for evaluation of water supply technologies. The method is presented and demonstrated for four alternatives for water supply based on groundwater, rain- & stormwater or seawater developed for augmenting Copenhagen's current groundwater based water supply. To identify the most sustainable technology, we applied rank order distribution weights to a multi-criteria decision analysis to combine the impact assessments of environment, economy and society. The three dimensions were assessed using 1) life-cycle assessment, 2) cost calculations taking operation and maintenance into account and 3) the multi-criteria decision analysis method Analytical hierarchy process. Specialists conducted the life-cycle assessment and cost calculations and the multi-criteria decision analyses were based on a stakeholder workshop gathering stakeholders relevant for the specific case. The workshop reached consensus on three sets of ranked criteria. Each set represented stakeholder perspectives with first priority given to one of the three sustainability dimensions or categories. The workshop reached consensus and when the highest weight was assigned to the environmental dimension of sustainability then the alternative of 'Rain- & stormwater harvesting' was the most sustainable water supply technology; when the highest weight was assigned to the economy or society dimensions then an alternative with 'Groundwater abstraction extended

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with compensating actions' was considered the most sustainable water supply technology. Across all three sets of ranked weights, the establishment of new well fields is considered the least sustainable alternative.



## 1. Introduction

The impact of withdrawing water is high on the agenda both regarding a worldwide focus on the limited freshwater availability (Alcamo and Gallopín, 2009; European Environment Agency, 2012), legislation (European Union, 2000) and the sustainable development goals (UN, 2015) emphasizing the importance of protecting freshwater environments and ecosystems. The European water framework directive (EU-WFD) is implemented in the EU-Member states by the national river basin management plans which among other parameters regulate the water flow requirements for water courses and the available amount of water in each freshwater compartment, including groundwater bodies. In Denmark the implementation of the EU-WFD has revealed that groundwater is not as abundant a resource as often assumed (European Environment Agency, 2007) since the river basin management plans for Denmark require that 65% of the renewable groundwater resource should be allocated to the freshwater environments (Danish Nature Agency, 2011).

In Europe on average 70% of the drinking water is produced from groundwater (Navarrete et al., 2008) and in Denmark groundwater is currently the only source used for centralized water supply and only very few local rainwater harvesting systems exist (Rygaard et al., 2009). Therefore, the implementation of the EU-WFD has forced the water utility in Copenhagen, HOFOR, to explore new approaches to maintain abstraction licenses or new water resources for water production in order to meet the water demand of the Capital City, Copenhagen. Since water production in Copenhagen today solely relies on groundwater, the impacts on the groundwater resources and natural environments such as water flow in watercourses has to be included in environmental evaluations of alternative water resources.

Besides groundwater resources, other criteria are important to include in the decision making process of how to identify the most suitable or, as in our case, the most sustainable water supply alternative for the City.

The term "sustainable development" is often quoted from the Brundtland Commission (WCED, 1987) as: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". In 1992 this definition of sustainable development was concretized a step further as a balance of three dimensions: environmental protection, economic growth, and social development (UNEP, 1992). Therefore, not only the impact on the water courses has to be considered but criteria representing these three dimensions – environment, economy and society – also have to be included in the development of decision support. This can be achieved by life-cycle assessment (LCA), cost-benefit analysis (CBA) and multi-criteria decision analysis (MCDA) with involvement of central stakeholders. The goal for our investigation was to develop a decision support system which incorporates criteria for all three sustainability dimensions and determines the trade-off between various criteria. Thus, providing the decision maker with a decision support material where weighting and tradeoffs are carried out and are not left for manual subjective judgment. The resulting decision support system "Assessing the most SusTainable Alternative" (ASTA) thus integrates LCA, CBA and MCDA into one joint decision support tool.

Multi-criteria decision analysis (MCDA) supports decision making in the choice between several options or cases based on evaluations involving several different criteria. MCDA has been applied in many cases within water management as documented by Hajkowicz and Collins (2007) who listed 113 studies on MCDA in water management published since 1973. The purpose of using MCDA in water management are various, e.g. policy evaluation, strategic planning, infrastructure selection. Within the water sector MCDA has thus been used to identify the optimal solution by a) elicit scores to criteria and b) determine the capacity for trade-offs between criteria: 1) Some MCDA methods are applicable for eliciting scores for alternative water management cases based upon pre-defined criteria, if other more quantitative evaluation methods such as LCA or CBA are not within hand (Jaber and Mohsen, 2001; Makropoulos et al., 2008). 2) Other MCDA methods are designed to assign weights to criteria based on their relative importance to central stakeholders (Goodwin and Wright, 2009; Lai et al., 2008; Rowley et al., 2012). For instance Sombekke et al., 1997) used MCDA to combine the results of an LCA with other criteria (water quality and public health, reliability, landscape, economy, etc.) when choosing between two types of water treatment for reducing water hardness at the waterworks (central softening). MCDA methods are also recommended for combining multiple criteria in the framework for decision support systems aimed at making a sustainable decision as described in the work of Lundie et al. (2006) and Halog and Manik (2011).

We developed a unique integration of quantitative evaluation tools (LCA, Freshwater Impact Assessment and Cost Assessment) and more qualitative assessment of societal impacts. At a stakeholder workshop we used the Analytical Hierarchy Process (AHP) (Saaty, 2006) to convert the assessment of the social dimension into quantitative scores. The combining of the sustainability dimensions, e.g. in a DSS is necessary to identify the optimal and most sustainable solution in a study. The same approach is found in studies planning sustainable community water systems when urbanization is increasing (Schoen et al., 2017; Rygaard et al., 2014) also aiming at combining various criteria or metrics. In our case, we used the above-mentioned evaluation tools and integrated the assessments in a multi-criteria workshop with representatives from a broad range of stakeholders with interest in urban water supply. To acknowledge different preferences, the assessment method was designed to assign individual stakeholder weights to qualitative criteria as well as the weighting between the three sustainability dimensions: environment, economy and societal impacts. Our method was demonstrated in a test case built on four suggested alternatives for water supply to Copenhagen, Denmark.

## 2. Material and methods

### 2.1. Study area and alternatives

Four water supply alternatives have been identified for Copenhagen that can, either alone or in combination with the existing groundwater abstraction (A0), constitute Copenhagen's future water supply fulfilling the EU-WFD requirements. The present water supply method and the alternatives are (Fig. 1): A0: 'Base alternative' (the current situation), A1: 'Rain- & stormwater harvesting', A2: 'Compensating actions', A3: 'New well fields', A4: 'Desalination'. A list of the alternatives' life-cycle inventory is found in Supplementary material.

#### 2.1.1. Alternative A0: base alternative (the current situation)

A groundwater volume of approximately 50 million $m^3$ is annually abstracted to supply the area of Greater Copenhagen (population of 1.28 million) with drinking water. The water is abstracted from groundwater sources mainly located outside the city and requires only treatment in terms of aeration and rapid sand filtration before distribution. The water abstraction, treatment and distribution consume as little as 0.27 kWh per $m^3$ drinking water. The groundwater originates from