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Research article

Sustainability assessments of regional water supply interventions – Combining cost-benefit and multi-criteria decision analyses

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ABSTRACT

To cope with present and future challenges, a growing number of water utilities in Sweden, Europe and elsewhere initiate various forms of inter-municipal cooperations creating a new regional level of drinking water governance. In order to reach viable decisions of alternative ways forward, there is an international consensus that sustainability needs to be addressed in water supply planning, design and decision-making. There are, however, few decision aids focusing on assessing the sustainability of inter-municipal cooperations and the inter-municipal policies and interventions that regional decision-makers are faced with. This paper presents a decision support model based on a combination of cost-benefit analysis and multi-criteria decision analysis for assessing the sustainability of regional water supply interventions, including formations of inter-municipal cooperations. The proposed decision support model integrates quantitative and semi-quantitative information on sustainability criteria. It provides a novel way of presenting monetized benefits and costs, capturing utilitarian aspects of alternative interventions, with non-monetized social and environmental effects, capturing aspects based in the deontological theories of moral ethics. The model is based on a probabilistic approach where uncertainties are defined by statistical probability distributions. A case study is used to exemplify and evaluate model application in decision situations regarding regionalization, (de)centralization, source water quality and redundancy. All evaluated alternatives were expected to contribute to a slightly improved social sustainability, whereas the results were more varying in the economic and environmental domains. A structured and transparent treatment of uncertainties facilitates a better understanding of the results as well as communication between decision-makers, stakeholders and the community.

1. Introduction

The main obligation of water utilities is to provide its customers with a continuous supply of safe drinking water. To fulfill this obligation, water utilities need to manage a variety of highly complex issues and future uncertainties. Climate variability, urbanization, ageing infrastructure and economic constraint add to other, ever present, challenges of water supply management. In Sweden, the responsibility for providing water supply to residents and society lies on each individual municipality. The 290 municipalities are characterized by a wide variety in land area and number of inhabitants. And as in many other countries, the Swedish municipalities' abilities to handle the above challenges vary significantly. To meet demands, a growing number of water utilities in Sweden, Europe and elsewhere initiate various forms of regional, inter-municipal, cooperations ranging from simple bilateral agreements to formations of regional alliances and companies (Frone, 2008; Kurki et al., 2016; Stenroos and Katko, 2011).

The motives for these cooperations can vary, but financial, human, and technological resource gains are often central arguments. Other motives include the possibilities of joint source water use, balancing of socio-economic and spatial differences as well as enhanced professional capacity (AWWA, 2015; Frone, 2008). However, there are also challenges associated with these cooperations that may pose new or increased risks, such as decreased transparency due to increased autonomy, loss of local knowledge and subsidiarity, and increased vulnerability due to dependency of fewer facilities and source waters (Kurki et al., 2016; Lieberherr, 2011, 2016; SOU, 2016). So, taking these strengths and drawbacks into account, how do we make sure that decisions on inter-municipal cooperations and regional interventions are well-informed and sustainable? And what aspects determine water

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supply sustainability on a regional level?

Due to the generally high complexity of regional systems, the main planning challenge is to understand *which* interventions to implement in order to improve and prepare the systems to future challenges (Arena et al., 2014). To be able to choose the most sustainable alternative, the interventions need to be properly evaluated regarding their economic, social and environmental effects. Evaluation methods such as multi-criteria decision analysis (MCDA) (Godskesen et al., 2017), cost-benefit analysis (CBA) (Hunter et al., 2009), life cycle assessments (Schulz et al., 2012) and optimization techniques (Lim et al., 2010) have all been proposed for assessments of water supply interventions.

However, the literature lacks generic decision-support frameworks, adapted to the inter-municipal level, that can assess economic profitability and environmental and social aspects of alternative interventions while allowing for a structured handling of uncertainties. This is needed to aid in complex regional decision situations to ensure a sound prioritization of society's limited resources.

Hence, this paper aims to present and apply a decision support model for assessing the sustainability of regional water supply interventions, including formations of inter-municipal cooperations, by combining CBA with MCDA. Specific objectives are to: (1) present a generic decision support model that incorporates uncertainties and that enables to combine fully monetized costs and benefits with criteria in the social and environmental sustainability domains; (2) identify key criteria as a basis for regional assessments; and (3) evaluate the applicability of the model to aid in complex regional decision situations.

2. Model development

In this chapter, the basis for the presented model is introduced in terms of sustainability, multi-criteria decision analysis and cost-benefit analysis, and an overview of the key steps for developing the model is provided.

2.1. Sustainability

There is a wide range of definitions of sustainable development. One of the most widely used is that of the Brundtland Report, in which it is defined as a *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (WCED, 1987). In the proposed decision support model, each alternative intervention is assessed relative to a reference alternative. The model thus provides information on whether a specific alternative *leads towards* sustainable development or not, taking a reference alternative as a point of departure. Sustainability is defined based on a set of criteria within the economic, social and environmental sustainability domains.

The model recognizes whether alternatives lead towards strong or weak sustainability, i.e. whether there is compensation between sustainability criteria or sustainability domains. According to the view of weak sustainability (Pearce and Atkinson, 1993), sustainability is attained as long as the sum of natural and human-made capital does not decline. There is no difference in the value provided by natural capital, such as water resources, and human-made capital, such as production plants and infrastructure, and hence they can be substituted for one another. According to the view of strong sustainability, certain environmental functions cannot be substituted by human-made capital. Human and natural capitals are regarded as complements rather than substitutes (Ang and Van Passel, 2012). To achieve strong sustainable development, neither natural nor human-made capital may hence decline.

Furthermore, the model distinguishes between the ethical theories of utilitarianism (a form of consequentialism) and deontology in terms of interpretation of sustainable development. In utilitarianism, the rightness of an action or decision is judged on the basis of its contribution to overall utility (well-being) (Sidgwick, 1981). The concept of sustainable development as put forward in the Brundtland Report has for example an anthropocentric utilitarian perspective which focuses on achieving and maintaining human well-being now and in the future (Farley and Smith, 2014). In deontological ethics, on the other hand, it is our duties to universal moral principles like justice and equity rather than fulfillment of well-being that guide our actions and decisions (Howarth, 1995). Hence, it is our duty, if not our preference, to leave an unharmed world to future generations (Laslett and Fishkin, 1993). The economic sustainability domain in the proposed model is assessed on the basis of welfare economics theory by means of CBA (Pearce et al., 2006), which means the evaluation is based on changes on human well-being. Thus, the economic domain of the model captures the anthropocentric utilitarian aspects of the alternative interventions. This is then balanced with the social and environmental domains which capture effects based in the deontological theories of moral ethics, such as final values of the environment, and local effects on equity and health (Söderqvist et al., 2015).

2.2. Multi-criteria decision analysis

The decision support model is based on the widely used decision support approach MCDA (Figueira et al., 2005) to support decisions of operational and strategic character. MCDA is often used for solving complex decision problems with large amounts of information and where several, possibly contradicting, criteria need to be considered in a structured and coherent way. Criteria are assessable objectives serving as performance measures in MCDA. Criteria can be quantitative, e.g. net present values based on monetized costs and benefits; semi-quantitative, e.g. scorings of social equity; or qualitative, e.g. value statements from public participation (Lindhe et al., 2013; Rosén et al., 2015). In the proposed model, we have used quantitative and semi-quantitative sustainability criteria.

The model makes use of the most common MCDA method to evaluate alternative interventions, i.e. the linear additive model (DCLG, 2009). Each sustainability criterion is assigned a weight reflecting its relative importance to the other criteria. Each alternative is scored, by e.g. expert judgement or data measure, based on how well that alternative performs in relation to a specific criterion on a predetermined performance scale. In the linear additive model, the total importance of an alternative is calculated as the weighted sum of scores on all criteria, allowing for compensation between criteria.

Several previous studies have proposed MCDA for evaluating sustainability of alternative water supply interventions, see for example Lai et al. (2008) and Scholten et al. (2015). There is however a lack of inclusion of cost externalities in existing evaluation criteria (Rathnayaka et al., 2016). To account for a more comprehensive economic analysis, the economic criterion in the proposed MCDA model is based on economic profitability including the impact of externalities and is evaluated by means of CBA.

2.3. Cost-benefit analysis

CBA is a systematic approach for estimating and comparing positive and negative economic consequences, i.e. benefits and costs, of alternative interventions and policies in relation to a reference alternative (Johansson and Kriström, 2016). The results can be used to determine whether an alternative is economically profitable, i.e. if its benefits for society are larger than its costs for society, and hence provide decision support. Benefits and costs are as far as possible expressed in monetary units, in which benefits are defined as increases in human well-being and costs are defined as reductions in human well-being. (Pearce et al., 2006). Individuals' well-being depends on market goods and services as well as non-market ones, such as health and environmental quality (Freeman et al., 2014). By using CBA to assess the economic domain, evaluation of effects on well-being at society level is made possible in addition to assessment on overall sustainability.