Science of the Total Environment 625 (2018) 819–827

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Selecting appropriate wastewater treatment technologies using a choosing-by-advantages approach

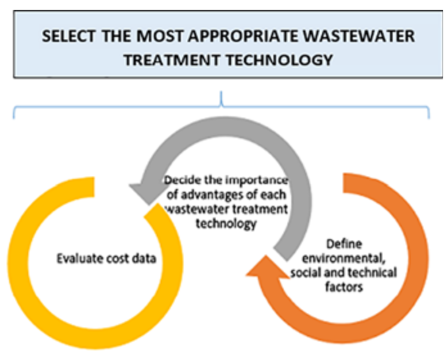
Paz Arroyo [a,b,1], María Molinos-Senante [c,d,e,*,1]

[a] Department of Construction Engineering and Management, Pontificia Universidad Católica de Chile, Santiago, Chile
[b] Senior Coach Lean Project Consulting, Berkeley, CA 94709, United States
[c] Department of Hydraulic and Environmental Engineering, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna, 4860, Santiago, Chile
[d] Institute of Urban and Territorial Studies, Pontificia Universidad Católica de Chile, El Comendador, 1916 Santiago, Chile
[e] Center for Sustainable Urban Development, CONICYT/FONDAP/15110020, Av. Vicuña Mackenna, 4860 Santiago, Chile

HIGHLIGHTS

- Choosing-by-advantages (CBA) was used to select wastewater treatment technologies.
- Energy requirement was identified as the most relevant advantage.
- CBA and AHP methods were compared for wastewater treatment technology selection.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 October 2017
Received in revised form 6 December 2017
Accepted 28 December 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Sustainability
Wastewater treatment plant
Choosing by advantages
Analytical hierarchy process
Multi-criteria decision making

ABSTRACT

Selecting the most sustainable wastewater treatment (WWT) technology among possible alternatives is a very complex task because the choice must integrate economic, environmental, and social criteria. Traditionally, several multi-criteria decision-making approaches have been applied, with the most often used being the analytical hierarchical process (AHP). However, AHP allows users to offset poor environmental and/or social performance with low cost. To overcome this limitation, our study examines a choosing-by-advantages (CBA) approach to rank seven WWT technologies for secondary WWT. CBA results were compared with results obtained by using the AHP approach. The rankings of WWT alternatives differed, depending on whether the CBA or AHP approach was used, which highlights the importance of the method used to support decision-making processes, particularly ones that rely on subjective interpretations by experts. This paper uses a holistic perspective to demonstrate the benefits of using the CBA approach to support a decision-making process when a group of experts must come to a consensus in selecting the most suitable WWT technology among several available.

1. Introduction

Sanitation and wastewater treatment (WWT) are essential for sustainable development and critical for maintaining healthy ecosystems and human health (UNESCO, 2015). The relevance of this issue was highlighted by the United Nations in its adoption of Sustainable

* Corresponding author.
E-mail address: mmolinos@uc.cl (M. Molinos-Senante).
[1] Both authors have contributed equally to this work.

https://doi.org/10.1016/j.scitotenv.2017.12.331
0048-9697/

Development Goals, which included ensuring "access to water and sanitation for all" (UN, 2017). In the framework of urban water systems, sustainability not only involves social, economic and environmental dimensions but "assets" and "governance" issues are also relevant (Marques et al., 2015). The "asset" dimension refers to physical infrastructure and involves aspects related to the performance and resilience of the system (Ashley et al., 2003). Governance is related to transparency, the public participation in decision-making process, the effectiveness and efficiency of the decisions among other issues (da Cruz and Marques, 2013).

In spite of significant efforts made over the last several decades to implement WWT systems worldwide, by 2015, 32% of the global population still lacked WWT facilities (UNICEF-WHO, 2015). Most of those people lived in developing countries where the construction and operation of wastewater treatment plants (WWTPs) had become a major challenge in need of addressing. Likewise, even developed countries require additional or updated WWTPs to meet newer, more stringent environmental regulations (Hadipour et al., 2016).

Traditionally, the selection of WWT technologies has been based on economic and technical factors (Popovic et al., 2013). However, environmental and social issues should also be integrated into the decision-making process to ensure long-term sustainability of WWTPs (Chhipi-Shrestha et al., 2017). Hence, selecting appropriate WWT alternatives, from an integrative perspective, is difficult and complex (Castillo et al., 2017), given the variety of linked objectives and conflicting criteria that must be considered (Molinos-Senante et al., 2012). To deal with this challenge, multi-criteria decision making (MCDM) has been shown to be an effective approach for supporting decision makers choosing the most-suitable WWT technology among a set of alternatives (Pinto et al., 2015; Dursun, 2016), because the approach is structured and logical (Delgado-Antequera et al., 2016). In fact, MCDM has been effectively used to find the most suitable solution for solving a variety environmental problems, including selecting various WWT alternatives (Aydiner et al., 2016).

A literature review (see Section 2) illustrates that analytical hierarchy process (AHP) and its derivatives have provided useful approaches for dealing with the complexities of selecting WWT alternatives by incorporated tangible and intangible elements into the assessment process. In all cases, decisions using the AHP approach have been based on both real data and the subjective decisions of experts. AHP allows users to integrate many qualitative criteria into assessments, including those related to societal and environmental mandates (Bottero et al., 2011). Notwithstanding the positive features of the AHP approach, the approach does have its limitations. AHP assumes linear trade-offs among criteria and there is no way to establish a threshold to express a level of satisfaction with the outcome, which is often necessary for obtaining a suitable outcome. In addition, AHP mixes values and costs, which often leads to cost being more heavily weighted than it should be, therefore substituting a poor, sustainable performance with a lower cost (Chen et al., 2009).

Choosing-by-advantages (CBA) is an alternative MCDM system that provides several advantages over AHP. CBA does not assume linear trade-offs among factors, and CBA does not mix value and cost (Arroyo, 2014). In addition, CBA links its decision-making process to examining differences between alternatives, thus avoiding conflicting abstract questions, such as what is more important energy required or water quality? Instead, CBA requests decision-makers to understand differences in energy usage between alternatives and differences in water quality between alternatives; then, the approach assesses the importance of those differences in any given situation. Moreover, CBA avoids rank order reversal, and AHP can produce this when irrelevant information is removed from the decision (Arroyo et al., 2015). CBA has been used in several decision-making scenarios, such as choosing a contract type for road maintenance (Haapasalo et al., 2015); fall-protection measures (Karakhan et al., 2016), or bidder selection (Schöttle and Arroyo, 2017), among others. Hence, the effectiveness of the CBA approach to select the most appropriate alternative has been proven in a wide variety of contexts. However, in spite of the fact that selecting the most suitable WWT technology is a complex and multi-faceted problem (Flores-Alsina et al., 2010), to the best of our knowledge, there have been no prior studies examining the application of the CBA method for selecting appropriate WWT technology.

In this study, the CBA method was applied to a hypothetical problem concerning the choice of the most sustainable WWT alternative from a set of seven secondary treatment technologies. The objectives of this paper are twofold. The first is to rank the seven WWT alternatives analyzed by using the CBA method. The second objective was to discuss the obtained ranking with a ranking obtained using the AHP approach, using the work by Molinos-Senante et al. (2014) as guide. To do this, we chose the details of the case study we used. The results of any WWT selection process depends on the details of the situation for which the decision is being made (i.e., the specific context should be kept in mind (Kalbar et al., 2013)).

Despite empirical studies using various MCDM methods to select WWT alternatives, none of them utilized the CBA approach. This paper contributes to current research by being the first to apply the CBA method to examine process of choosing alternative WWTs and evaluating the appropriateness of the alternatives. Moreover, we hope that by comparing the rankings provided by the CBA and AHP methods, we will contribute to current debates concerning the relevance of choosing suitable decision-making methods (Arroyo et al., 2015). The methods used and results of this study should be of great interest to urban water planners and policy makers who desire a decision-making process that will enable them to choose the most appropriate WWT technology from a set of alternatives.

The paper unfolds as follows. Section 2 presents a brief literature review of studies that applied MCDM approach to select the most-appropriate WWT technology alternative. The material and methods used are presented in Section 3 which describes CBA method, the problem and the experiment design. Section 4 presents the CBA results and also the comparison of CBA and AHP approaches. The final section concludes the study.

2. Literature review on wastewater treatment technology selection using multi-criteria decision making

Only a few papers have been published using MCDM methods to assess and select WWT alternatives. Some of these studies (e.g., Kalbar et al., 2012; Kalbar et al., 2013; Dursun, 2016) used a multi-criteria decision analysis approach called, a "technique for order of preference by similarity to ideal solution" (TOPSIS). This approach is based on the concept that the preferred alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution (Ruiz-Padillo et al., 2016). Recently, Ren and Liang (2017) evaluated the sustainability of four WWT technologies using an intuitionistic, fuzzy-set approach and a multi-attribute decision analysis method.

Nevertheless, in the framework of selecting WWT alternatives, the most-often used MCDM approach is the AHP and its derivatives. This approach was first proposed by Saaty (1977) to select the most suitable WWT alternative, based on a pairwise comparison of the alternatives that took into account their performances relative to a set of criteria defined by the decision maker. Some researchers have simply utilized conventional AHP methods to evaluate and select the most suitable WWT technologies under a variety of urban and industrial wastewater scenarios (Ellis and Tang, 1991; Tang and Ellis, 1994; Bottero et al., 2011; Srdjevic et al., 2012; Kalbar et al., 2013; Zorpas and Saranti, 2016; Aydiner et al., 2016; Hadipour et al., 2016), while others have expanded the conventional AHP approach by incorporating gray-relational analysis to it (Zeng et al., 2007; Pophali et al., 2011). In order to take into account uncertainty, Karimi et al. (2011) and Ouyang et al. (2015) applied fuzzy AHP to evaluate WWT alternatives. The AHP approach has also