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Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes

Jingzheng Ren[a,*], Hanwei Liang[b]

[a] Department of Industrial and Systems Engineering, The Hongkong Polytechnic University, Hong Kong Special Administrative Region
[b] Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disaster, School of Geography and Remote Sensing, Nanjing University of Information Science & Technology, Nanjing 210044, China

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ABSTRACT

There are various processes which can be used for wastewater treatment (WT), and the selection of the most sustainable one among different processes is a hard task. This study aims at helping the decision-makers (DM) to address this by developing an intuitionistic fuzzy set (IFS) theory based group multi-attribute decision analysis (MADA) method. Ten criteria in environment, economy, society-politic, and technology dimensions were employed to achieve sustainability measurement (SM) of WT processes. The multi-criteria sustainability assessment method developed in this study allow different experts to attend the SM, and enable the participants to employ the natural language/words to depict their intuitionistic opinions. Accordingly, the proposed method can achieve group SM under uncertainties. An illustrative case including four processes for wastewater treatment, namely Anaerobic-Anoxic-Oxic (AAO) process, Triple Oxidation Ditch (TOD) process, Anaerobic single-ditch oxidation (ASD) process, and Sequencing batch reactor activated sludge process (SBR), has been studied, and the results reveal that this method can determine sustainability sequence of different WT processes.

1. Introduction

The depletion, pollution and degradation of water resources become the severe problems worldwide (Wu et al., 2015). The pollution of water resources has become more and more severe recently because of population increase, and industrialization. As for this problem, scientists developed various processes for wastewater treatment, i.e. advanced oxidation process, membrane distillation bioreactor, emerging desalination processes, and physical and chemical method, etc. (Neoh et al., 2016; Ji et al., 2016; Subramani and Jacangelo, 2015). Wastewater treatment (WT) plants are usually highly energy-intensive and generate large amount of emissions (Chai et al., 2015). The selection of the most suitable technology for WT is usually difficult when facing multiple choices, because the accurate evaluation of these processes for WT has been a great challenge for the decision-makers (i.e. regulators and water companies) (Prasse et al., 2015).

Various studies have been carried to investigate and compare different processes for WT, and there are usually two most popular ways: one is environmental impact/economic feasibility assessment, and another is multi-criteria decision analysis. As for environmental impact/economic feasibility assessment, life cycle perspective analysis, referring to life cycle assessment, is one of the most popular way. For instance, Rodriguez-Garcia et al. (2012) developed a method for estimating the greenhouse gases emission of WT plants in life cycle perspective. Padilla-Rivera et al. (2016) used 25 indicators to evaluate the social concerns of WT facilities. There are also some other studies used life cycle assessment or economic analysis methods for investigating these processes (Meneses et al., 2015; Hendrickson et al., 2015; Mu et al., 2016). However, the decision-makers (DM) also feel difficult to make a decision, because they usually have to face multiple conflict indicators. Accordingly, the selection of technology for WT among several different processes is a multi-attribute decision analysis problem.

There are also various studies focusing on using multi-attribute decision analysis (MADA) methods for comparing different processes for WT. A composite sustainability index based on the sum weighted method for comparing WT processes was developed by Plakas et al. (2016). Hadipour et al. (2016) developed a MADA method to rank the processes for wastewater reuse by employing AHP. Zorpas and Saranti (2016) employed MADA to investigate the processes for wastewater treatment in the field of winery. Ouyang et al. (2015) developed the a multi-criteria aid tool by combining the fuzzy AHP and multidimensional scaling (MDS) for the selection of natural WT alternatives. Macuada et al. (2015) developed a multi-criteria analysis framework

* Corresponding author.
E-mail addresses: renjingzheng123321@163.com, jzhren@polyu.edu.hk (J. Ren).

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based on AHP for evaluating of the facilities of water treatment. Lorenzo-Toja et al. (2016) employed eco-efficiency criteria based on LCA and LCC to assess the WT plants. Castillo et al. (2016) developed a decision support tool by determining the weighted score for WT selection. All these studies are useful promoting wastewater treatment; however there are still some research gaps. Almost all the studies need to know the exact data when selecting the most suitable technology for WT; however, sometime it is impossible to get the accurate data due to various reasons, i.e. lack of information and data uncertainties. Accordingly, some methods employed AHP and various methods derived from AHP to score the WT processes regarding some criteria. For instance, Molinos-Senante et al. (2015) employed the ANP to assess different processes for the WT for small communities. Meanwhile, various MADA methods based on fuzzy set theory have been employed to address this, because fuzzy set theory has the advantages of dealing with problems such as vagueness and ambiguity existed in human judgements. For instance, An et al. (2016) employed fuzzy AHP to score the processes for groundwater contamination remediation. This kind of fuzzy MADA methods are based on the fuzzy theory Zadeh (1965, 1975) in which the membership function is used to characterize the fuzzy set. Atanassov (1986) developed a more powerful tool - IFS (intuitionistic fuzzy set). Accordingly, various MADA methods based on the IFS were developed for its advantages of dealing with more complex problems which need IFS format, i.e. voting process, a portion of rejection, and a portion of approval, etc. Therefore, this study developed a multi-criteria sustainability measurement method to select WT processes based on the IFST.

All in all, this study has two objectives:

(1) developing the hierarchal evaluation criteria system with multiple dimensions for sustainability measurement of wastewater treatment processes, the characteristic of this system is inclusive, and the decision-makers are allowed to choose parts of the criteria in each dimension or add more criteria in each dimension according to their preferences;
(2) developing a generic multi-attribute decision analysis method based on intuitionistic fuzzy set theory for helping the decision-makers to prioritize the alternative wastewater treatment processes.

Besides the introduction section, the remaining parts of this study has been structured as follows: the criteria system for sustainability measurement of wastewater treatment processes was developed in Section 2; the IFS theory based MADA method was developed (see Section 3); an illustrative case was investigated (see Section 4); finally, the discussions and conclusion were presented (see Section 5).

2. Criteria for sustainability measurement of WT processes

According to WCED (1987) and Othman et al. (2010), the criteria in the three dimensions of sustainability (namely, economy, environment, and society) are usually used for sustainability assessment. However, there is no unique criterion system for sustainability measurement as different decision-makers have different requirements. Besides the criteria in the three sustainability pillars, some other aspects are also widely used for sustainability including technological and political aspects as the criterion in both of the two aspects may have significant influences on the criteria that belong to the main sustainability pillars (Ren et al., 2013). Therefore, four aspects including environment, economy, society-politic, and technology dimensions are considered for sustainability measurement. According to the special characteristics of the processes for the treatment of wastewater derived from coal-fired power generation, ten criteria are used to measure the sustainability of the processes for WT based on literature reviews and focus group meeting, as presented in Table 1. These criteria are specified as follows:

Table 1
Criteria for SM of WT processes.

Aspect	Criteria	Abbreviation	Reference
Economic	Capital costs	EC_1	Sadr et al., 2015
	Operation and maintenance costs	EC_2	Sadr et al., 2015
Environmental;	Effect on water quality improvement	EN_1	Ling and Hang, 1998
	Occupied land	EN_2	Ling and Hang, 1998
Technological	Operability and simplicity	T_1	Meerholz and Brent, 2013
	Maturity	T_2	Ling and Hang, 1998
	Reliability	T_3	Eisenberg et al., 2001
Social-political	Public acceptability	SP_1	Ren et al., 2015a
	Added jobs	SP_2	Ren et al., 2015b
	Governmental support	SP_3	Ren et al., 2015a

2.1. Economic aspect (EC)

There are two economic criteria, namely, capital cost, and operation & maintenance cost.

2.1.1. Capital costs (EC_1)

The capital cost represents the initial investment of all the facilities for WT processes. Sadr et al. (2015) pointed out that the capital cost has significant influence on the implementation of the projects about the WT, because the initial investment cost can significantly influence the decision-makers.

2.1.2. Operation & maintenance costs (EC_2)

The operation & maintenance costs include all the costs related to operation and maintenance of the wastewater treatment processes, and this criterion consists of all the costs about human resources, energy use, waste management and various costs during the operations as well as the costs during maintenance (Sadr et al., 2015).

2.2. Environmental aspect (EN)

The criteria in environmental aspect aims at measuring the "environmental efficiency" of WT processes regarding consumed resources, emitted waste/harmful gases, and the effluent (Molinos-Senante et al., 2015). Two criteria including effect on water quality improvement and occupied land were used to measure the environmental efficiency of the processes for WT.

2.2.1. Effect on water quality improvement (EN_1)

This criterion is to measure the ability of different WT processes for removing the waste constituents (i.e. nitrogenous and phosphorous organic compounds) and hazardous materials existed in wastewater. As for the wastewater derived from coal-fired power generation, the effect on water quality improvement mainly refer to the ability of the processes for the removal of the suspended solid. It is worth pointing out that the users can define the meaning of effect on water quality improvement according to the actual conditions. In other words, the definitions are different for different wastewater systems.

2.2.2. Occupied land (EN_2)

This criterion refers to the sum of the occupied land due to the implementation of the processes for WT, i.e. the land for building the plant for WT, and the land for building the supplementary infrastructure.