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Urban sewage sludge, sustainability, and transition for Eco-City: Multi-criteria sustainability assessment of technologies based on best-worst method

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ABSTRACT

The treatment of urban sewage sludge is of vital importance for mitigating the risks of environmental contaminations, and the negative effects on human health. However, there are usually various different technologies for the treatment of urban sewage sludge; thus, it is difficult for decision-makers/stakeholders to select the most sustainable technology among multiple alternatives. This study aims at developing a generic multi-criteria decision support framework for sustainability assessment of the technologies for the treatment of urban sewage sludge. A generic criteria system including both hard and soft criteria in economic, environmental, social and technological aspects was developed for sustainability assessment. The improved analytic hierarchy process method, namely Best-Worst method, was employed to determine the weights of the criteria and the relative priorities of the technologies with respect to the soft criteria. Three MCDM methods including the sum weighted method, digraph model, and TOPSIS were used to determine sustainability sequence of the alternative technologies for the treatment of urban sewage sludge. Three technologies including landfilling, composting, and drying incineration have been studied using the proposed framework. The sustainability sequence of these three technologies determined by these three methods was obtained, and finally the priority sequence was determined as landing filling, drying incineration and composting in the descending order.

1. Introduction

The treatment of urban sewage sludge is one of the most severe challenges in wastewater management because sewage sludge is the residue produced when separating the liquids and solids in wastewater treatment (Fytili and Zabaniotou, 2008). The treatment of urban sewage sludge is of vital importance with objective of reducing the volume, improving the character and reducing the health problems and environmental problems (Appels et al., 2008). Accordingly, the treatment of urban sewage sludge has become an important concern all over the world (Singh and Agrawal, 2008) as inappropriate treatment will cause serious environmental pollutions and human health problems. Therefore, the development of the technologies for the treatment of urban sewage sludge has become a hot topic recently.

Similar to groundwater remediation and the treatment of e-waste, there are also various technologies for the treatment of urban sewage sludge, i.e., landfilling (Koenig et al., 1996), compositing (Fang and Wong, 1999), incineration (Li et al., 2014), and anaerobic digestion for energy recovery (Karagiannidis and Perkoulidis, 2009), etc. However, different technologies have different economic, environmental and social performances. For instance, one technology may perform better in regard to capital cost than another technology, but may cause more environmental impacts. Therefore, it is usually difficult for decision-makers to choose the most suitable technology for the treatment of urban sewage sludge when considering the multiple criteria in facing multiple options, because this is a typical multi-criteria decision making (MCDM) problem in which there are usually multiple conflict criteria. Many scholars employed MCDM methods for the analysis of the technologies for the treatment of urban sewage sludge. For instance, Pokoo-Aikins et al. (2010) used the multi-criteria approach for screening the alternatives (four solvents, toluene, hexane, methanol and ethanol in the extraction process were compared) for converting sewage sludge to biodiesel. Flores-Alsina et al. (2008) employed a multi-criteria analysis method for investigating the priorities of wastewater treatment plant control strategies under uncertainties. Karagiannidis and Perkoulidis (2009) used the multi-criteria decision support method ELECTRE III for analyzing different technologies in anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes. The applications of the methods presented in these studies can provide

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significant implications to the decision-makers to select the most suitable scenario for the treatment of urban sewage sludge among multiple alternatives. However there are also some problems to be solved:

(1) The lack of the incorporation of soft criteria for sustainability assessment: in most of the previous studies, only hard criteria that can be quantified with units were considered; however, they neglect to consider soft criteria that can only be depicted quantitatively, i.e. social acceptability, technology maturity, and technology generalizability, etc.
(2) The difficulty in the determinations of the weights of the criteria: Selecting the most suitable technology for the treatment of urban sewage sludge should consider the preferences and willingness of the decision-makers/stakeholders. Accordingly, the weights should reflect the preferences and willingness of the decision-makers/stakeholders. The analytic Hierarchy Process (AHP) is the most commonly used for weights determination as this method can reflect the preferences and willingness of the decision-makers/stakeholders, but it is usually difficult for the users of this method to establish a consistent comparison matrix by using numbers from 1 to 9 as human judgment usually involves vagueness, ambiguity, and subjectivity (Ren and Lützen, 2015; Ren et al., 2016).
(3) The lack of incorporation of the sustainability concept: pursuing sustainability aims at achieving sustainable development, and green operations initiatives have attracted more and more interest from industry for promoting sustainable development (Wang, 2015); however, there is a lack of a criteria system for sustainability assessment of the technologies for the treatment of urban sewage sludge.
(4) The reliability of MCDM methods: the priority sequences determined by different MCDM methods based on the same decision-making matrix are usually slightly different. Therefore, it is usually difficult for the decision-makers to make the correct decision.

With the objective of solving the above-mentioned four problems, this study aims at helping the decision-makers/stakeholders select the most sustainable technology for the treatment of urban sewage sludge for sustainability transition to an eco-city, and a generic criteria system for sustainability assessment of the technologies for the treatment of urban sewage sludge was developed. An improved AHP (Saaty, 1980) method, namely, the Best-Worst (BW) method (Rezaei, 2015; Rezaei, 2016), was employed to determine the weights of the criteria for sustainability assessment, and was also used to determine the relative performance of alternative technologies for the treatment of urban sewage sludge. Three MCDM methods, the sum weighted method, digraph model, and Technique for Order of Preference by Similarity to the Ideal Solution were employed to determine the sustainability sequence of these alternative technologies for the treatment of urban sewage sludge. The reminding parts of this paper have been organized as follows: the methods are presented in Section 2, three technologies for the treatment of urban sewage sludge are studied in Section 3, and the discussion and conclusions are given in Section 4.

2. Methods

In this section, the criteria system for sustainability assessment was firstly developed, then, the method for determining the weights of the criteria and the relative preferences of the alternative technologies for the treatment of urban sewage sludge with respect to soft criteria is presented, and finally the multi-criteria decision making (MCDM) methods including sum weighted method (SWM), digraph model, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for determining the sustainability indices of the alternative technologies for the treatment of urban sewage sludge is specified.

2.1. Criteria for sustainability assessment

Sustainable development emphasizes development with consideration of achieving economic profits, environmental cleanliness, and social effects, simultaneously (Ren et al., 2016). Accordingly, sustainability assessment is usually based on the simultaneous measure of economic performance, environmental impact, and social acceptability. Therefore, the criteria system for sustainability assessment usually consists of the criteria in economic, environmental, and social aspects which are the main three pillars of sustainability (Ren et al., 2015a). However, Manzardo et al. (2012) held the view that the criteria in some other aspects should also be incorporated in sustainability assessment, because these criteria may also have significant effects on the criteria belonging to the main three pillars of sustainability. For instance, technology development and progress will affect economic performance (i.e. reducing the cost and increasing the profit), environmental impact (i.e. mitigating CO_2 emission and decreasing occupied land), and also social acceptability (i.e. increasing vacancies and increasing social benefits) (Ren et al., 2015b). Therefore, a criteria system including four aspects, namely economic, environmental, social and technological aspects, has been developed for sustainability assessment of the technologies for the treatment of urban sewage sludge.

There have been many studies focusing on developing the criteria for sustainability assessment of the treatment of urban sewage or urban sewage sludge. For instance, Balkema et al. (2002) proposed a complete set of sustainability indicators for selecting sustainable wastewater treatment systems. Hiessl et al. (2001) established a criteria system including 44 criteria in economic, social, and ecological aspects for sustainability assessment of scenarios of urban water infrastructure systems. Muga and Mihelcic (2008) developed various criteria including economic indicators (including capital, operation and management, and user costs), environmental indicators (energy use, resource utilization, and performance of the technology in removing conventional wastewater constituents), and societal indicators (capture cultural acceptance of the technology, better education, or an improved local environment, etc.) for sustainability assessment of wastewater treatment technologies. An et al. (2016a) employed ten criteria including capital cost and running cost in economic aspects, occupied land, environmental risk, and resource utilization efficiency in environmental aspect, social acceptability in social aspect, such as operability, site selection, applicability, and management level requirement in the technological aspect to assess the sustainability of the technologies for the treatment of urban sludge. Meanwhile, An et al. (2016b) used a total of eight criteria for sustainability assessment of the technologies for groundwater remediation, capital cost, detection and analysis costs, and operation and maintenance costs in economic aspects, effect of secondary pollution in environmental aspect, effectiveness for water quality, improvement and time for remediation in technological aspect, the effect on public health in social aspect, and policy support in political aspect. Mels et al. (1999) developed five sustainability criteria based on the Life Cycle Assessment methodology, including energy balance, final sludge production, effluent quality, the use of chemicals and space requirement (footprint) to evaluate the sewage treatment scenarios. Based on the literature review, it is apparent that there are no uniform standards for selecting the criteria for sustainability assessment of the technologies for the treatment of urban sewage sludge. In this study, six criteria in regard to economic, environmental, social, and technological aspects have been used to measure the sustainability of the technologies for the treatment of urban sewage sludge based on a focus group meeting in which seven experts, including two professors, three Ph.D students, and two senior researchers were invited to participate. These six criteria are specified as follows.