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Sustainable development of sewage sludge-to-energy in China: Barriers identification and technologies prioritization

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ABSTRACT

In order to promote the sustainable development of sludge-to-energy industry and help the decision-makers/stakeholders to select the most sustainable technology for achieving the sludge-to-energy target, this study aims at using grey Decision Making Trial and Evaluation Laboratory (DEMATEL) to identify the critical barriers that hinder the sustainable development of sludge-to-energy industry in China and to investigate the cause-effect relationships among these barriers. Accordingly, some policy implications for promoting the sustainable development of sludge-to-energy industry in China were proposed. After the grey DEMATEL analysis, a grey Multi-Criteria Decision Making (MCDM) framework which allows multiple decision-makers/stakeholders to use linguistic terms to participate in the decision-making for prioritizing the alternative technologies for sludge-to-energy was developed, and the evaluation criterion system for sustainability assessment of sludge-to-energy technologies was determined based on the results of grey DEMATEL analysis. Three alternative technologies for sludge-to-electricity were studied by the proposed MCDM method, and the results show that the proposed grey MCDM method is feasible for group decision-making and sustainability assessment of the alternative technologies for sludge-to-energy.

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1. Introduction

The treatment of sewage sludge is of vital importance world widely though it is the secondary process after wastewater treatment, because the sewage sludge will lead to many environmental and health problems if inappropriate treatment, and the amount of sewage sludge increases significantly year by year in many countries [1,2]. Wang [3] pointed out that most of the sewage sludge in China has not been treated or disposed properly, and this leaded China to face severe environmental problems and health challenges. Therefore, it is necessary for China to promote the sustainable development of sewage sludge treatment. In order to address this issue, China also planned to take various alternative technologies/process for sewage sludge treatment, i.e. sludge incineration, sludge anaerobic digestion, compost, and ocean disposal, etc. [4]. Among these, the options that can transform sewage sludge into energy are very attractive to China's decision-makers/stakeholders as these options cannot only mitigate the environmental problems caused by sewage sludge, but also enhance China's energy security. Therefore, it is no doubt that the treatment of sewage sludge to energy in China will become emerging industry with the increase of the perceptions on environment protection of China's administrators and Chinese people. Therefore, the promotion of sustainable development of sludge-to-energy is of vital importance.

However, it is usually not easy for China's decision-makers/stakeholders to take the pertinent measures to promote as they are usually puzzled by two questions: (i) what are the most important barriers that hinder the sustainable development of sludge-to-energy? (ii) what are the cause-effect relationships among these barriers? The answers of these two questions are of vital importance for China's decision-makers/stakeholders to draft effective policies/regulations and take effective measures for promoting the sustainable development of the sludge-to-energy industry. Moreover, it is also difficult for the decisions-makers to select the most suitable one among multiple alternative solutions for achieving the sludge-to-energy target. And more and more studies focus on analyzing the environmental impacts of sewage sludge treatment options to compare their relative environmental impacts and economic performance. For instance, emergy theory was applied to analyze the sustainability of municipal wastewater treatment for electricity generation through digestion [5]. The environmental and economic consequences of four recycling and disposal options for municipal sewage sludge including agricultural application, co-incineration with waste, incineration combined with phosphorus recovery, and fractionation including phosphorus recovery were evaluated [6]. Life cycle approach was employed to analyze the environmental and economic impacts of the six alternative scenarios for sewage sludge treatment in Japan including dewatering, composting, drying, incineration, incinerated ash melting and dewatered sludge melting [7,8].

There are also many studies focusing on the technologies for treating the sewage sludge for environment protection, resources recovery and energy production. Müller [9] provided an overview of the applications of wet disintegration in wastewater and sludge treatment, and the applied disintegration techniques including mechanical, thermal, chemical and biological methods were discussed. Neyens and Baeyens [10] had a comprehensive overview of the optimum treatment conditions to obtain enhanced dewaterability and digestibility of sludge for sludge pre-treatment. Weemaes and Verstraete [11] reviewed the current state of the art and compared different wet sludge disintegration techniques, including mechanical, chemical, thermochemical, biological and oxidative treatments. Siegrist et al. [12] presented a mathematical model to depict the dynamic behavior of the anaerobic mesophilic digestion, and the acetate degradation kinetics were specified. Fytili and Zabaniotou [13] reviewed the methods for the utilization of sewage sludge including at thermal processes (e.g. pyrolysis, wet oxidation, gasification) and the utilization of sewage sludge in cement manufacture as a co-fuel. Werle and Wilk [14] reviewed the state of knowledge and technology in thermal methods for the utilization of municipal sewage sludge including pyrolysis, gasification, combustion, and co-combustion for energy production. Kelessidis and Stasinakis [15] analyzed the current situation and discussed future perspectives for sludge treatment and disposal in EU countries. Luostarinen et al. [16] investigated the feasibility of anaerobic co-digestion of sewage sludge and grease trap sludge from a meat-processing plant. Gao [17] investigated the development of legislation in waste disposal in German, the main subjects in sewage sludge ordinance of the European Community and that of Germany are compared. Wong et al. [18] focused on the efficacy of the microwave/hydrogen peroxide advanced oxidation process on the secondary sludge treatment; this novel technology is beneficial for both environment protection and energy security enhancement.

These studies are very useful for the decision-makers/stakeholders to understand the economic performances or environmental impacts of different technologies for sewage sludge treatment; however, it is also difficult for the decision-makers/stakeholders to make decisions directly as one alternative may perform better with respect to one criterion, but it may also be inferior with respect to another criterion. In addition, the selection of the most suitable or the most sustainable technology among multiple alternative scenarios is a multi-criteria decision-making problem. Besides the criteria in economic and environmental aspects, the criteria in some other aspects, i.e. technological, social and political aspects should also be incorporated in decision-making.

In order to address the above-mentioned issues, this study aims at achieving four objectives: (1) identifying the critical barriers that hinder the sustainable development of sludge-to-energy industry in China; (2) analyzing the cause-effect relationships among these barriers, propose some policy implications for promoting the sustainable development of sludge-to-energy industry in China; (3) establishing the evaluation criterion system for sustainability assessment of sludge-to-energy technologies; and (4) developing a multi-criteria decision-making framework for prioritizing the alternative technologies for sludge-to-energy. Grey Decision Making Trial and Evaluation Laboratory (GDEMATEL) method and grey Multi-Criteria Decision Making (MCDM) method were employed to address these four objectives. The reminder