Journal of Environmental Management 189 (2017) 115–124

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Performance evaluation of restaurant food waste and biowaste to biogas pilot projects in China and implications for national policy

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ARTICLE INFO

Article history:
Received 26 July 2016
Received in revised form
6 December 2016
Accepted 12 December 2016

Keywords:
Food waste
Biogas
Anaerobic digestion
Performance evaluation
MCDA
China

ABSTRACT

The objective of this research was to conduct a performance evaluation of three food waste/biowaste-to-biogas pilot projects across 7 scenarios in China based on multi-criteria decision analysis (MCDA) methodology. The projects ranked included a food waste-biogas project in Beijing, a food waste-biogas project in Suzhou and a co-digestion project producing biomethane in Hainan. The projects were ranked from best to worst based on technical, economic and environmental criteria under the MCDA framework. The results demonstrated that some projects are encountering operational problems. Based on these findings, six national policy recommendations were provided: (1) shift away from capital investment subsidies to performance-based subsidies; (2) re-design feed in tariffs; (3) promote biomethane and project clustering; (4) improve collection efficiency by incentivizing FW producers to direct waste to biogas projects; (5) incentivize biogas projects to produce multiple outputs; (6) incentivize food waste-based projects to co-digest food waste with other substrates for higher gas output.

1. Introduction

In 2013, the total amount of MSW collected in China was 172 million tonnes, an increase of 11% compared to the 155 million tonnes of MSW in 2004. A large fraction of this MSW production – 55.86% – is kitchen food waste: so China produced 96 million tonnes of household kitchen food waste in 2013 (Zhou et al., 2014). On average, 98% of waste disposed in China is treated either via landfill or incineration. Recycling, composting, anaerobic digestion and other methods of resource recovery are minimal under China's current waste management strategy (China Statistical Yearbook, 2014). Food is putrescible, and when it is buried in a landfill, it decomposes to produce methane, a greenhouse gas with a global warming potential 25 times greater than CO_2 on a 100-year time scale (IPCC, 2007). China is not alone in facing this challenge: in the United States in 2010, food waste represented the single largest component of MSW reaching landfills; 97% of all food waste ended up in landfills. Landfills in the U.S. emitted 27.5 million tonnes of carbon equivalent in 2009, making landfill disposal the third-largest source of anthropogenic CH_4 emissions in the U.S., accounting for 16% of total CH_4 emissions (Levis et al., 2010). In China, according to Wang and Geng (2015), 1 kg of MSW can produce 1.16 kg of carbon emissions via sanitary landfill treatment, 0.79 kg under simple landfill treatment, 0.30 kg when composted, and 0.51 kg when incinerated. It is clear that food waste needs to be urgently redirected to less polluting treatment methods.

In response to mounting environmental issues surrounding food waste disposal, China has implemented a number of policies and laws promoting the comprehensive utilization of restaurant food waste in particular. Restaurant waste represents about 50% of total food waste in China - 40 million tonnes of restaurant waste were produced in 2014. For instance, in May 2010, the National Development and Reform Commission, the Ministry of Housing, the Ministry of Environmental Protection and the Ministry of Agriculture jointly issued the “Organized Development of Municipal Food Waste Resource Utilization and Safe Disposal Pilot Project” work notice. As a result, China's National Development and Reform commission has currently ratified 100 pilot cities to implement restaurant food waste treatment projects in 5 different batches. According to the 12th five-year plan, by the end of 2015 there will be 242 restaurant food waste treatment facilities in the country,

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http://dx.doi.org/10.1016/j.jenvman.2016.12.030
0301-4797/

and cities will achieve a 50% waste classification rate (will be able to treat 50% of generated waste). Due to dedicated government investment of 10.9 billion Chinese Yuan (RMB) – representing 4.1% of the total 12th FYP investment budgeted for total MSW treatment – the total restaurant food waste treatment capacity in China is expected to reach 30,000 tonnes per day. Crucially, 74% of the projects in the first 66 pilot cities implement some form of anaerobic digestion technology (Xu et al., 2015), which is the focus of this research.

In 2014, approximately 46 of these planned projects were operational, and 34 were under construction (80 in total), meaning that there are 162 projects remaining to be built to achieve the Chinese government's target. Unfortunately, initial surveys indicate that these projects are suffering from serious operational issues. In Beijing for instance, a recently constructed kitchen waste treatment facility was found to have numerous operational issues, such as weak process monitoring, low feedback control, biogas underutilization, excessive troubleshooting/downtime, under-capacity, and extremely low biogas output. The specific fermenter productivity, a crucial measure of fermenter tank biogas output productivity, was only 0.12 Nm^3/m^3 fermenter capacity/day. In comparison, the specific fermenter productivity of typical biogas plants in Germany is generally in the range of 1–5 Nm^3/m^3/day (Raninger and Dong, 2013). In addition to technical issues, the Beijing project also suffered from severe food waste collection issues, collecting only a small fraction of its total operational capacity. Lastly, economic and environmental problems were also persistent – the project struggles to break even under the current business model due to low marketization of outputs. Overall, these issues combined mean that the positive environmental impact of the project is much lower than expected.

Given such severe operational issues, it is crucial that best practices are implemented on a national scale across the 242 planned food waste treatment facilities in China, and that technical, economic and environmental risks are mitigated during the project planning stage. Therefore, a deeper analysis of the weaknesses of pilot projects in China is urgently needed to ensure that past problems will not be repeated. Based on multi-criteria decision analysis (MCDA), this research thus answers the following questions:

- How are recently built pilot projects performing from a technical, economic and environmental perspective?
- What are the implications of current project performance on national planning to improve future performance of restaurant waste treatment pilots?

MCDA methodology provides decision makers with a framework to evaluate the relative performance of projects based on multiple evaluation criteria. Reaching high levels of performance is important for the success of any sector or engineering project. As a consequence, appropriate management frameworks are important for analysing current performance, setting benchmarks to enhance process performance, and ascertaining why certain projects perform better than others (Madlener et al., 2009). MCDA does not necessarily provide decision makers (DM) with right answer or the most objective answer to decision making problems. However, the methodology does facilitate the decision making process in that it highlights trade-offs and subjectivity, increases the transparency of decision-making and reduces the difficulty in addressing complex issues (HTSR and Panaxea BV, 2014).

To the authors' knowledge, there have been no previous studies on the evaluation of operational restaurant food waste treatment projects based on integration of technical, economic and environmental factors. Both recent and older studies have focused on: LCA evaluation food waste to biogas case study projects (Xu et al., 2015); review LCA studies of food waste management systems (Bernstad and la Cour Jansen, 2012a); environmental impacts of a specific food waste-based biogas plant (Jin et al., 2015) and different food waste conversion options (Khoo et al., 2010; Vandermeersch et al., 2014); performance evaluation of food waste collection systems (Wen et al., 2015) and techniques/technologies (Bernstad and la Cour Jansen, 2012b); general management overviews of food waste (Thi et al., 2015); case-specific engineering frameworks/business models for food waste recycling for biogas fuel production (Woon and Lo, 2016); design and biogas potential of urban, small-scale food waste-based biogas systems (Curry and Pillay, 2012); biogas production potential of co-digested food waste in lab-scale studies (Liu et al., 2012a,b; Lin et al., 2011). The EU FP7-funded Valorgas project has also published publicly available research on food waste on topics such as pre-treatment, food waste energy potential in Europe, and energy balance in treatment plants. While there have been prior performance evaluations of biogas plants (Madlener et al., 2009), these have not focused on food waste in specific, and have not evaluated these projects to the level of detail found in this research, since it focuses on technical, economic and environmental factors combined. Analysis across these three dimensions provides policymakers with a more holistic view of biogas project problems and thus a better foundation to make informed decisions regarding sustainable policies.

The research output provides a benchmarking system that is tested on three restaurant waste treatment pilot project. This contributes to the existing literature, because we: a) focus specifically on restaurant food waste; b) provide comparative evaluation of three operational pilot projects based on a quantitative, integrated evaluation framework, which offers decision makers with national planning suggestions; c) take into account of broad range of projects that have differing food waste valorization technology options such as bio-methane production, fodder production, and electricity generation.

2. Methodology

2.1. MCDA framework and performance evaluation criteria

In this case, the decision maker's objective is to identify the best-performing biogas projects across *c* performance criteria and *a* project alternatives. This MCDA problem can be expressed in the following grouped decision matrix:

$$A = \begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_m \end{array} & \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{pmatrix} \end{array} \tag{1}$$

where (a_1, a_2, …, a_m) is a set of feasible alternatives (actions, stimuli, projects) and (c_1, c_2, …, c_n) is a set of decision-making criteria. The weight of the nth criterion (i.e. C_n) is called w_i. The performance of alternative *i* on C_n is denoted with $p_{i,k}$.

In the general form, if we assign the weight w_i ($w_i \geq 0, \sum w_i = 1$) to criterion *k*, then v_i can be derived from a simple additive weighted value function (Keeney and Raiffa, 1976):

$$V_i = \sum_{k=1}^{n} v_k(P_{i,k}) \times w_k \tag{2}$$

The above formula uses $v_k(p_{i,k})$ instead of $p_{i,k}$ because v_k is a the partial value function which translates the criterion-specific