Journal of Environmental Management 93 (2012) 95–103

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

Performance measurement for incineration plants using multi-activity network data envelopment analysis: The case of Taiwan

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ARTICLE INFO

Article history:
Received 3 January 2011
Received in revised form
8 August 2011
Accepted 12 August 2011
Available online 18 September 2011

Keywords:
Incinerator
Russell multi-activity network data envelopment analysis
Undesirable outputs
Directional distance function

ABSTRACT

This study proposes the use of multi-activity network data envelopment analysis to appraise how incineration plants in Taiwan perform. Sample data from 2006 is used to examine the trade-offs between efficiency enhancement and pollution abatement. The respective efficiencies of the waste treatment and electricity generation are also assessed in a unified framework. The empirical results indicate that it is more important to improve the efficiency of waste treatment activity than of electricity generation activity in order to enhance the overall performance of Taiwan's incinerators. Since ownership, location and length of operations do not in general affect their performance, any improvement has to come from the careful monitoring of each process of the waste treatment operations. Furthermore, given that the policy in Taiwan has moved away from incineration to recycling, the problem of an over-supply of incinerators may become apparent in the near future. Our results indicate that the availability of capacity size may be an important factor when policy-makers consider whether to close down some existing incinerators.

1. Introduction

The management of solid waste is one of the major everyday issues that face policy-makers at both national and regional levels (Adamides et al., 2009) as the cities and populations grow, and the needs for waste disposal increase in households and industries. Although waste management practices differ between developed and developing nations, urban and rural areas, and residential and industrial zones (Kuo et al., 2008), incineration is one of the most important activities in an integrated waste management system due to its capacity to destroy hazardous waste, reduce the mass and volume of residues, and recover energy content from unrecyclable as well as recyclable materials having significant heat values (Morselli et al., 2007). Thus, many countries, such as France, Denmark, Sweden, Japan, Korea, Taiwan, and so on, have adopted incineration as one of the tools for treating waste.

On the other hand, incineration has the disadvantage of producing toxic ash and polluted air during the incineration process. In the Kyoto Protocol, the incineration process is regarded as one of the major sources of greenhouse gases. In addition, the disposal of the ash residues is another problem that has to be dealt with, because they may contain toxic chemicals such as dioxins which can be hazardous to the environment and human health. Modern cleaning and emission control technologies such as gas purification can be adopted to lower their hazardous impact significantly.

A number of studies have demonstrated that emissions of toxic pollutants from modern incinerators have a relatively low environmental impact in comparison with other waste disposal activities (McKay, 2002; Mari and Domingo, 2010). According to Chang et al. (2002), Taiwan has adopted the activated carbon injection (ACI) technology for reducing dioxin emissions since 1997. Right now 21 out of 22 plants use the ACI technology (Kuo et al., 2008). However, the removal efficiencies for dioxins pertaining to ACI technology are not always the same and thus should be carefully monitored to ensure its effectiveness.

Previous literature regarding incineration plants covers political, socio-economic, technical, environmental, public health and industrial issues because of its multi-faceted nature. Nevertheless, most studies mainly regard incinerators as typical waste-to-energy utilities, and therefore focus on discussing one of the following:

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0301-4797/$ – see front matter
doi:10.1016/j.jenvman.2011.08.011

how to improve their performance on energy recover or how to evaluate their performance on pollution control from an engineering or physical-chemical perspective (Autret et al., 2007; Yang et al., 2007; Morselli et al., 2007; Liamsanguan and Gheewala, 2007; Kuo et al., 2008; Pai et al., 2008; Sharifah et al., 2008; Tsai and Chou, 2006; Huang et al., 2006); how to identify the most appropriate locations and capacities for them since they are not-in-my-back-yard facilities (Alçada-Almeida et al., 2009); how to determine the distribution of the fair funds claimed by the residents for fair damages due to the installation of a new incinerator (Chang et al., 2009; Chiueh et al., 2008); how the risk perceptions of those living near an incinerator affect their psychological well being (Lima, 2004); to what extent the recycling volume would change following the introduction of an incineration tax (Sahlin et al., 2007), and so on. Most research, however, neglects the fact that, in addition to being waste treatment facilities, incineration plants are also production decision making units (DMUs) which provide the services of waste treatment and electricity to the public, with the undesirable pollutants of ash and dioxins being jointly produced. For example, if inefficiency exists during the process of providing waste treatment and electricity services through emitting toxic wastes and pollutants, these outputs should be treated as undesirable and reduced to improve the performance.

It is worth noting that, as undesirable outputs are jointly produced with desirable outputs, it makes sense for us to credit an incineration plant its provision of desirable outputs while making effort to control the toxic emissions from exceeding the environmental regulations. Therefore, whether the incinerators operate efficiently or not affects not only their own operating profitability, but also the cost of waste treatment and the quality of the environment they deliver to the public. Measuring and monitoring the production efficiency performance of incinerators are thus important steps for incinerator operators and policy-makers to detect management problems.

The major purpose of this study is to propose a multi-activity network data envelopment analysis (DEA) model to appraise the relative performance of incineration plants in Taiwan in which desirable and undesirable outputs are included simultaneously. DEA is a performance evaluation method that has the advantages of requiring neither price information nor a behavioral assumption in its construction. It is particularly useful when no objective standard is available to define efficient performance. The best-practice waste treatment profiles are developed which serve as standards for efficient plants that can be used as benchmarks for the less efficient ones to improve their performance while complying with the environmental requirements. By adopting this approach, the respective efficiencies from waste treatment to electricity generation and pollutant abatement are assessed in an integrated framework. In particular, the idea of the directional slacks-based inefficiency (SBI) measure developed by Fukuyama and Weber (2009) is incorporated into our model to allow inputs and outputs to change non-proportionally.

To our knowledge, very little research evaluates incineration performance, apart from an unpublished project implemented by COWI, a leading northern European consulting group. The DEA method was applied by COWI to assess the efficiencies of the incineration sector in Denmark, and also pointed out possible areas for improving future operations. Managing any organization requires the capability to effectively measure and analyze information that is generated by business processes (Sarkis and Weinrach, 2001). Thus, our study is intended to evaluate the management of the incineration sector and to provide policy-makers with information on how to upgrade the services of the incinerators.

The remainder of this paper is organized as follows. The next section will describe the efficiency evaluation framework and proposed methods. Then, the dataset is presented in Section three. Section four describes the empirical results. The final section concludes.

2. Methodology

2.1. The framework of incinerator performance evaluation

When developing an evaluation framework for an industry, it is important to organize the inputs, outputs, and production characteristics in a meaningful manner. A typical incinerator processes wastes that have been collected as input materials, and achieves its primary goal, i.e., the treatment (or destruction) of waste. As a secondary benefit, it recovers heat energy (i.e., cogeneration) from the combustion process (Yang et al., 2007). It thus consists of two production activities, namely, waste treatment and energy recovery (electricity generation). In the waste treatment activity, the plant operator employs labor, incineration equipment, and incurs other costs to sort and homogenize the feed waste before entering the incineration process. The hot air and gasses emerging from the incineration produces heat, which is then used by the energy recovery equipment (steam turbine-generator), labor and other operating costs to produce electric power as a secondary output to the public. In this study, we will provide efficiency measures on both activities. Note that our efficiency measure on energy recovery is based on the best-practice benchmark, and therefore focused on how each plant operates relative to its peers. In contrast, the conventional energy conversion efficiency is a ratio between outputs and inputs used and thus represents the engineering aspect of a conversion technology.

Fig. 1 provides a graphical representation of the operational activities and input/output relationships as mentioned. Specifically, these two activities are linked to each other via the disposed refuse as an intermediate product, since it is the output of the waste treatment activity, but is then utilized as an input in generating electric power. In the meantime, labor and other costs are shared in both activities. Ashes and dioxin emissions are jointly produced during incineration, causing environmental and health concerns, but they can be reduced by additional engineering or biological treatment as well as effective management on cleaning and proper removal of dust, slag, and other toxic materials. These additional treatment and technologies requires investment and may increase the operation cost of incineration plants.

Accordingly, the overall performance of an incinerator comprises several dimensions including the efficiencies of waste treatment, electricity production and pollutant abatement. Nevertheless, as Tone and Tsutsui (2009) pointed out, traditional DEA models deal with measures of the relative efficiency of DMUs regarding multiple inputs vs. multiple outputs, and neglect the intermediates and the relationships linking the different activities. Consequently, it is difficult to provide individual DMU managers with specific information regarding the sources of inefficiency within their DMUs (Lewis and Sexton, 2004).

In order to overcome this weakness, Färe and Grosskopf (2000) established the relationships among different production processes in their network DEA (NDEA) model, where more structure can be added to the model to better suit the application. Once this relationship is established, it provides insight regarding the sources of inefficiency and process-specific guidance to DMU managers in order to help them improve the DMU's efficiency (Yu, 2008). Tone and Tsutsui (2009) modified Färe and Grosskopf's model to incorporate the idea of a slack-based measure (SBM), and proposed the