Resources, Conservation & Recycling 136 (2018) 289–296

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Improving waste to energy rate by promoting an integrated municipal solid-waste management system

Lu Sun[a,b], Minoru Fujii[b], Tomohiro Tasaki[a,b], Huijuan Dong[c,*], Satoshi Ohnishi[d]

[a] Department of Environment Systems, Graduate School of Frontier Sciences, The University of Tokyo, Kashiwanoha, 277-8563, Japan
[b] National Institute for Environmental Studies, Tsukuba, 305-8506, Japan
[c] School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
[d] Department of Industrial Administration, Tokyo University of Science, Chiba, 278-8510, Japan

ARTICLE INFO

Keywords:
Energy recovery efficiency
Industrial-urban symbiosis
Waste management

ABSTRACT

As a means of converting waste to energy, improvement of energy recovery efficiency from municipal solid waste (MSW) has taken on great importance and necessity. Previous studies have focused on the waste-to-energy potential from the viewpoints of technology, such as waste power generation (WPG); however, there is large room for improvement in WPG efficiency. Moreover, with reduction in population in some developed countries, the potential for further improvement of energy recovery from waste needs to be investigated, considering both geographical characteristics and future trends. To fill this research gap, this study proposes four efficient MSW management options through integrating MSW management and an urban symbiosis network. The Tokyo Metropolis, Japan, was selected as a case study, and the costs and benefits, effects of greenhouse gas (GHG) emission reduction, and energy recovery efficiency of each option were quantitatively analyzed. The results showed that Option 4 (urban symbiosis without source separation) has the highest energy recovery efficiency (65.95%), followed by Option 3 (urban symbiosis with source separation) and Option 2 (MSW centralized treatment) in 2030. Compared with Option 1 (business as usual), Option 3 will slightly increase the total cost, while Option 4 is the most profitable option, and the benefit will rise to 1.81×10^{10} JPY in 2030. Reduction of greenhouse gas (GHG) emissions by 2030 will be greatest with Option 3, which will eliminate 9.44×10^5 tonnes of CO_{2e} emissions. Also by 2030, Option 4 and Option 2 will reduce the CO_{2e} emissions by 6.58×10^5 tonnes and 2.27×10^5 tonnes, respectively. To promote the transition to a low carbon city, Tokyo must improve the energy recovery efficiency of MSW and use more renewable and recycled energy resources to substitute for fossil fuels. This study provides a practical guide for establishing a more efficient MSW management system toward the goal of a low carbon society.

1. Introduction

Energy recovery from waste is an essential part of modern waste management (Astrup et al., 2015). The most common methods used for municipal solid waste (MSW) treatment are recycling, landfilling, mechanical biological treatment, and incineration (Psomopoulos et al., 2009). Incineration of waste is a widely applied treatment operation to recover the energy content from residual waste (Grosso et al., 2010).

During the past two decades, there have been numerous studies focusing on waste-to-energy technologies; the study areas include disposal technologies for incineration residues (Hjelmar, 1996; Sabbas et al., 2003), emissions' reduction (Buekens and Huang, 1998; McKay, 2002; Porteous, 2001), and technological applications (Chen and Christensen, 2010; Hartenstein and Horvay, 1996; Stehlik, 2009; Wang et al., 2016). Damgaard et al. (2010) pointed out that waste incineration plants with high energy recovery have turned waste incineration into an attractive source of renewable energy, as long as a significant fraction of the energy produced can be utilized. Bosmans et al. (2013) reviewed thermochemical technologies, including incineration, gasification, pyrolysis, plasma technologies, and their combinations, for energetic valorization of calorific waste streams in MSW. Their results showed that incinerators hold considerable waste to energy potential due to their heat recovery and potential for electricity generation using steam turbines.

Improving the efficiency of energy recovery is a key issue in MSW management. For instance, in Japan, although many incinerators have electric power generation facilities, their generation efficiencies are, on average, around 12%; this is much lower than the generation

* Corresponding author at: School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China.
E-mail address: donghj@sjtu.edu.cn (H. Dong).

https://doi.org/10.1016/j.resconrec.2018.05.005
Received 14 October 2017; Received in revised form 10 April 2018; Accepted 3 May 2018

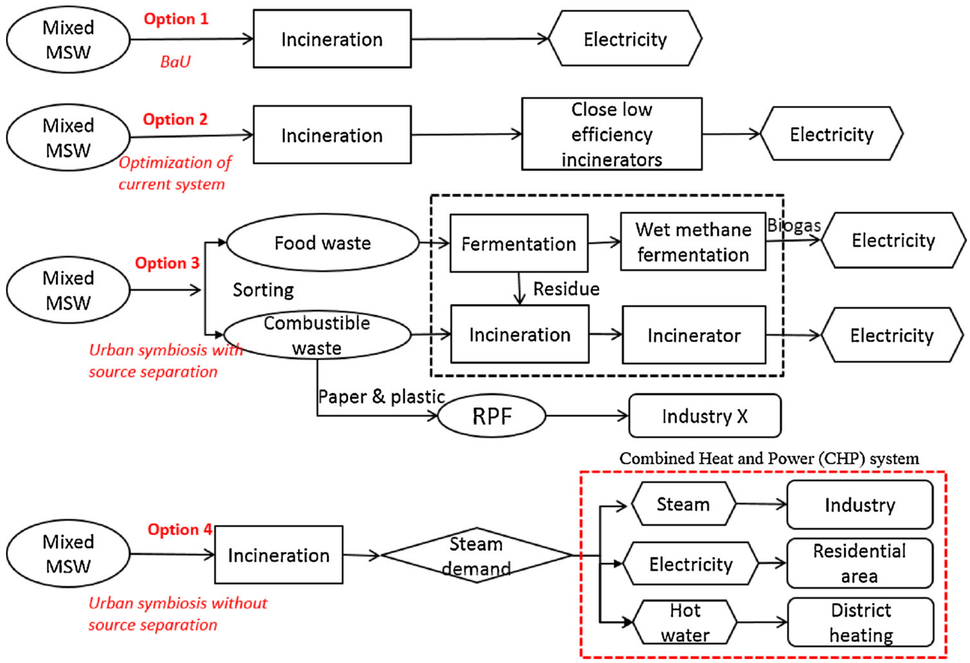

Fig. 1. Schematic diagram of four MSW treatment options.

efficiencies of electric thermal power plants, which are approximately 40% (Fujii et al., 2015). Thus, to increase the energy recovery efficiency of MSW treatment, Choy et al. (2004) developed a novel design for an integrated cement production process that incorporates MSW separation and combustion. Expanding on this idea, researchers have considered using MSW as an input to substitute for fossil fuels in industries by linking a MSW management system with local industries and transferring physical resources from urban refuse directly to industrial applications to improve the overall energy recovery efficiency of the city as a whole (Chen et al., 2012; Tsiliyannis, 2012; Dou et al., 2018; Kim et al., 2017). This is the concept of “industrial-urban symbiosis” (Berkel et al., 2009; Geng et al., 2010; Sun et al., 2017).

Previous studies have analyzed the waste-to-energy potential from the viewpoints of technology, economy, environment, and policy (Leme et al., 2014; Liu et al., 2017). The energy recovery from MSW still has much room for improvement. In mega-cities in Japan (such as the Tokyo Metropolis), WPG is the most common treatment method. Meanwhile, the potential for further improvement of energy recovery from waste through combining different kinds of technologies and treatment systems must be analyzed, taking geographical characteristics and future trends into consideration. Furthermore, the energy recovery performance and carbon emission reduction benefits of different methods also must be evaluated quantitatively.

Considering these facts, the objective of this study is to improve the efficiency of energy recovery from MSW by combining different kinds of technologies and treatment systems. To achieve this objective, this study will take the following steps: (1) Design circulation and urban symbiosis network systems that use MSW as the fuel resource for energy-intensive industries, either producing steam for industries or providing heat for district heating systems; and (2) evaluate both the efficiency of energy recovery and the carbon emission reduction effect of the urban symbiosis systems.

2. Method

2.1. Options for the design of MSW treatment

The Tokyo Metropolis is one of the most populous mega-cities in the world, and both the energy consumption and amount of MSW generation of the region are huge. As the local government pays great attention to improving energy recovery from waste, the city was selected for this case study. As of 2013, the population of Tokyo Metropolis was 13.2 million, the amount of MSW was 4.14 million tonnes, and the waste generation per capita was 949 g/person/day. There were 44 incinerators located in the city.

To determine highly efficient ways of treating MSW, four options were set. Option 1 is the business as usual (BAU) option, which assumes that the MSW treatment system is no different from the current system used. Option 2 is a solution from a new policy perspective, in which centralized treatment of MSW is carried out. Low efficiency incinerators are closed and consolidated with others. The operation of high efficiency incinerators is maintained. Option 3 proposes a solution from a technological perspective, wherein a source separation treatment policy is applied to MSW, with waste paper and plastic being separated and sent to make refuse of paper and plastic fuel (RPF), which is then used as a substitute for fossil fuels. Food waste is sent for fermentation treatment. Option 4 is urban symbiosis without source separation treatment; this option combines the waste management systems with other systems in the city. The steam production efficiency in the incinerators is much higher than waste power generation efficiency (WPG), and the fossil fuel reduction effect of steam production is two times higher than that of WPG. In Option 4, when the steam demand of industries near the incinerator is high enough, the incinerator will produce steam only and supply it to energy-intensive industries. When the steam demand of industries near the incinerator is too small, the incinerators will apply a combined heat and power generation (CHP) system. The electricity produced will be used in the city, and the hot water will be used for a district heating system. Fig. 1 illustrates the treatment process for the four different options.

The locations of existing incinerators, energy-intensive industries, and district heating systems are shown in Fig. 2. The steam supply and district heating radius were set as 3 km × 3 km, based on the study by Kawakami et al. (2008). The steam and heat demand amount was calculated by summarizing the demand of residential and commercial areas that nearby incinerators (within 3 km). Data on the amount of heat demand for district heating were provided by the Japan Heat Supply Business Association.