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Effective approaches to reduce greenhouse gas emissions from waste to energy process: A China study

Yuan Wang[a], Yuanyuan Yan[a], Guanyi Chen[a,*], Jian Zuo[b], Huibin Du[c]

[a] *School of Environmental Science and Engineering, Tianjin University, Tianjin, China*
[b] *School of Architecture & Built Environment, Entrepreneurship, Commercialisation and Innovation Centre (ECIC), The University of Adelaide, Adelaide, Australia*
[c] *College of Management and Economics, Tianjin University, Tianjin 300072, China*

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ABSTRACT

As a way of disposing municipal solid waste (MSW), waste-to-energy (WtE) not only generates energy but also reduces greenhouse gas (GHG) emissions. This paper analyzes two WtE options, i.e. incineration with energy recovery (electricity and heat) (Incineration E hereafter), and landfill with landfill gas (LFG) utilization (Landfill E hereafter). It is imperative to investigate which approach is more effective in terms of GHG emission reduction in different climatic conditions. Two typical northern and southern cities in China, i.e. Tianjin in North China and Xiamen in South China are selected in this study. GHG accounting was undertaken per ton of waste received at the waste plant while GHG contributions were categorized as indirect emissions, direct emissions, substituted fossil fuel emissions and avoided emissions. The results show that North China should adopt Incineration E, while Landfill E is the better choice for South China. This study also benchmarks the waste management practices in these two cities to international practices in Europe in terms of the avoided emissions from both Incineration E and Landfill E approaches. The findings indicate that the energy recovery efficiency in Europe is higher than that of China, especially for Incineration E. Therefore, more efforts are required in China to enhance the substituted fossil fuel emissions, e.g. improving the energy recovery efficiency.

1. Introduction

The waste management industry plays a crucial role in the climate change mitigation (Ragoßnig and Hilger, 2008). According to the statistics from official submissions of GHG emissions to United Nations Framework Convention on Climate Change (UNFCCC, 2011), the GHG emissions in the field of waste from the "waste" sector in EU-15 accounted for as low as 3% of total emissions in 2007. However, more than 30% of the total reductions of GHG emissions (from 1990 to 2007) in EU-15 were achieved by the "waste" sector (Wang et al., 2012). For example, in Germany, which has reached its GHG emission reduction goal ahead of schedule, the "waste" sector was the second largest reduction category after the "energy" sector, although the emissions from the "waste" sector only accounted for 3% of overall emissions in 1990 (UBA, 2009). Germany recycled more than 60% of MSW, energy from waste (EfW) was used to treat 30% of waste, while only 1% was landfilled (Mühle et al., 2010).

Waste management activities generate GHG emissions, primarily carbon dioxide (fossil and biogenic carbon), methane (CH_4) and nitrous oxide (N_2O) (Gentil et al., 2009). The GHG emissions vary significantly according to waste disposal approaches. Waste-to-energy (WtE) disposal approaches help to reduce GHG emissions when substitute fossil energy is accounted for (Manfredi et al., 2009; Astrup et al., 2009). WtE is widely considered as a crucial part of waste management strategy (Jamasb and Nepal, 2010). Moreover, if open dumping and landfill without gas capture are set as the baseline scenarios, WtE also reduces CH_4 emissions significantly (Barton et al., 2008). In the short term, Waste to energy (WtE) projects will materialize the benefits from the energy recovery and reducing the garbage pollution. Similarly, there are ancillary benefits associated with Waste to energy (WtE) by means of avoided GHG emissions so that the global warming can be mitigated in the long term.

Therefore, under the context of energy crisis and climate change challenges, WtE has become a crucial approach for disposing the municipal solid waste (MSW). Especially, for developing

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[*] Corresponding author at: School of Environmental Science and Engineering, Tianjin University, No. 92 Weijin Road, Tianjin, China.
E-mail address: Gychen_tju@163.com (G. Chen).

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countries such as China, there is massive potential for GHG emission reductions in waste management. In 2012, the MSW clean-up and transport volume was 170.81 Mt (million tons) in China, of which 144.90 Mt was treated in harmless ways. According to the Chinese Statistical Yearbook, there are three harmless ways for the waste disposal, i.e. Sanitary landfill, Incineration and Composting. The proportion of landfill and incineration were 73% and 25% respectively. Moreover, 86% of landfills are passive venting without gas capture for flaring or energy production (i.e. simple landfill) (National Bureau of Statistics of China).

Due to the substituted emissions from fossil energy, the greenhouse gas emissions from WtE projects in most European countries were negative, thus that WtE was considered as a GHG sink (Gohlke, 2009; Riber et al., 2008; Astrup et al., 2009). However, it is contradictory to studies focusing on the Chinese context (Zhao et al., 2009; Woon and Lo, 2013; Yang et al., 2012). In some Chinese cities, MSW incineration plants were demonstrated as a source of GHG emissions, especially those produce mainly electricity and heat is not recovered.

China is a vast country where the climatic condition, energy consumption modes, social conditions and economic conditions vary significantly among regions. However, most WtE projects are located in developed cities at coastal regions. These developed regions are located in northern, southern and eastern China. Main research objective of this paper is to investigate the effectiveness of WtE approaches in terms of GHG emission reduction in regions with different climatic conditions. Therefore, north and south China regions were chosen in this study as climatic conditions are significantly different in these two regions. Two typical cities were selected in this research, i.e. Tianjin as the representative of developed cities in north China, and Xiamen as representative of developed cities in south China. It is a limitation of this study that only two regions were considered. Future research opportunities exist to validate findings of this research in other regions. GHG emission reductions during the WtE process between Tianjin and Xiamen were compared in order to investigate effectiveness of two WtE approaches i.e. incineration with energy recovery (electricity and heat) (Incineration E hereafter), and landfill with landfill gas (LFG) utilization (Landfill E hereafter). These findings will provide useful inputs for the decision making for the selection of WtE approaches in different geographical regions.

2. Method of accounting the GHG emission reduction

The different scopes of accounting lead to various ways of quantifying emissions. Generally, the main types of GHG accounting methods in waste management include: methodology of Intergovernmental Panel on Climate Change (IPCC) at the national level, and life-cycle assessment (LCA) and clean development mechanism (CDM) methodology at the corporate level. It is worth noting that these GHG accounting methodologies are related. For example, the CDM methodology mainly relies on equations and default emissions factors provided by the IPCC to model GHG emissions and abatement. Mass balance method can be used to calculate the total CH_4 and CO_2 emissions from the degradable organic component (DOC). The first order decay (FOD) model can be used to describe the fraction of degradable material in waste which is degraded into CH_4 and CO_2 each year (IPCC, 2006). In this paper, the mass balance method and the first order decay (FOD) model are integrated to calculate the GHG emissions reductions. The mass balance method is used for Incineration E, while the FOD model is mainly utilized for Landfill E.

In order to evaluate GHG emission reductions from WtE, four kinds of emissions were calculated, i.e. direct emissions, indirect emissions, substituted fossil fuel emissions and avoided emissions.

2.1. Direct emissions

2.1.1. Landfill E

The direct GHG emissions relevant to waste Landfill E are CO_2 and CH_4. CH_4 emissions are converted to CO_2 by the treatment in the power plant and flares during lifetime of Landfill E project (assuming about 70% of landfill gas is collected). During post-closure time of the project, landfill gas collection may not be practiced, and dispersive CH_4 are the primary direct emissions.

$$DE_{landfill} = DE_{CO_2,total} + DE_{CH_4,post\text{-}closure} \qquad (1)$$

Where: $DE_{landfill}$ is direct GHG emissions from Landfill E project (t CO_2-eq./t MSW); As for $DE_{CO_2,total}$, CO_2 emissions are partly derived from degradable biogenic CO_2 (calculated by the mass balance method), and partly from the combustion of methane during lifetime of the project (calculated by FOD method); $DE_{CH_4,post\text{-}closure}$ is CH_4 emissions of post-closure time.

$$DE_{CO_2,total} = DE_{CO_2,L} + DE_{CO_2,T} \qquad (2)$$

$$DE_{CO_2,L} = C_{DOC} \times r \times F_{CO_2} \times 44/12 \times GWP_{CO_2,biogenic} \qquad (3)$$

$$DE_{CO_2,T} = C_{DOC} \times r \times MCF \times (1 - e^{-TK}) \times F_{CH_4} \times 44/12 \times (1 - OX) \times \varepsilon \times GWP_{CO_2,biogenic} \qquad (4)$$

where $DE_{CO_2,L}$ is the CO_2 emissions from LFG; $DE_{CO_2,T}$ is CO_2 emissions from CH_4 utilization; C_{DOC} is degradable organic component (DOC) (t CO_2-eq./t MSW); r is the fraction of DOC that can decompose; F_{CO_2} is the fraction of the DOC that is converted to CO_2, and F_{CH_4} is the fraction of the DOC becomes CH_4, and assuming that on a mass base about half of the DOC becomes CH_4 and the other half part of the DOC becomes CO_2; MCF is methane correction factor, for anaerobically managed solid waste disposal sites, $MCF = 1.0$; k is reaction constant (yr^{-1}), $k = \ln(2)\,(t_{1/2})^{-1}$; $t_{1/2}$ is half-life time (yr); T is the project lifetime; 44/12 is molecular weight ratio CO_2/C (ratio); OX is oxidation factor (fraction), $OX = 0.1$; ε is collected efficiency, about 70%; $GWP_{CO_2 biogenic}$ is GWP of biogenic origin CO_2 (t CO_2-eq. t^{-1} $CO_{2biogenic}$).

As for $DE_{CH_4,post\text{-}closure}$, it can be calculated by subtracting CH_4 emissions during the project lifetime (calculated by FOD method) from total CH_4 emissions (calculated by the mass balance method).

$$DE_{CH_4,post\text{-}closure} = DE_{CH_4,total} - DE_{CH_4,T} \qquad (5)$$

$$DE_{CH_4,total} = C_{DOC} \times r \times F_{CH_4} \times 16/12 \times GWP_{CH_4} \qquad (6)$$

$$DE_{CH_4,T} = C_{DOC} \times r \times MCF \times (1 - e^{-TK}) \times F_{CH_4} \times 16/12 \times (1 - OX) \times \varepsilon \times GWP_{CH_4} \qquad (7)$$

where $DE_{CH_4,total}$ is total CH_4 emissions; $DE_{CH_4,T}$ is CH_4 emissions of the project lifetime; GWP_{CH_4} is GWP of CH_4 (t CO_2-eq. t^{-1} $CO_{2biogenic}$); C_{DOC} is degradable organic component (DOC) (t CO_2-eq./t MSW); r is the fraction of DOC that can decompose; 16/12 is molecular weight ratio CH_4/C (ratio); k is reaction constant (yr^{-1}), $k = \ln(2)\,(t_{1/2})^{-1}$; $t_{1/2}$ is half-life time (yr); T is the project lifetime; OX is oxidation factor (fraction), $OX = 0.1$; ε is collected efficiency, which is about 70%.

Direct emissions are also derived from the combustion of the diesel fuel used on-site in dozers, compactors and other landfill vehicles. However, the CO_2 emissions per ton of waste from the use of diesel for on-site operations accounted for about 5% of the total direct CO_2 emissions (Manfredi et al., 2009). Thus we assumed this part of emissions also accounted for 5% of the total direct CO_2 emissions in this paper.

2.1.2. Incineration E

The direct GHG emissions relevant to waste Incineration E are CO_2 and N_2O. Methane and trace gases are not considered significant in case of modern installations (Astrup et al., 2009).