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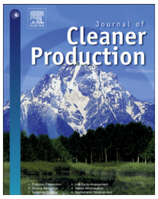

Effectiveness of waste-to-energy approaches in China: from the perspective of greenhouse gas emission reduction

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ABSTRACT

As a way of disposing municipal solid waste, waste-to-energy not only generates energy but also reduces greenhouse gas emissions. Indeed, waste-to-energy plays a crucial role in addressing various environmental issues such as climate change and security of energy supply. Two waste-to-energy approaches were compared with simple landfill in this study, i.e. incineration with energy recovery (electricity and heat), and landfill with landfill gas utilization. It is imperative to investigate which approach is more effective in terms of GHG emission reduction in the context of different climatic conditions. The effects on GHG emission reductions are examined in the Temperate Dry Zone and Tropical Moist Zone. An assumption is made that in 2020, the waste disposal approach will be switched from simple landfill to waste-to-energy approach in China. The contribution of different waste disposal approach to the GHG reduction (1 t municipal solid waste annually) during 2020–2060 is examined in this paper. Both landfill gas utilization and incineration with energy recovery approaches reduce GHG emissions in all cases compared to the simple landfill. However, this study revealed that landfill gas power generation system is more effective in the Tropical Moist Zone, whereas incineration with energy recovery is a better choice in the Temperate Dry Zone according to the comprehensive benefit. Similarly, the improvement of landfill gas collection rate and the heat recovery efficiency play a crucial role to reduce greenhouse gas emissions during the process of managing the municipal solid waste.

1. Introduction

Vast majority of carbon emission reduction related studies placed focuses on the energy sector. The waste sector, which plays a critical role in the climate change mitigation as well, was largely overlooked (Ragoβnig and Hilger, 2008). The wide range of mature technologies can mitigate GHG emissions from waste and provide public health, environmental protection, and sustainable development co-benefits. Therefore, existing waste management practices can provide effective mitigation of GHG emissions from this sector (Bogner et al., 2008).

A number of studies have reported the implementation of the life-cycle assessment (LCA) methodology, in which the life-cycle concept was described as direct emissions and indirect emissions (including upstream emissions and downstream emissions) (Consonni et al., 2005; Manfredi et al., 2009; Astrup et al., 2009, 2014; Luckow et al., 2010; Barton et al., 2008; Riber et al., 2008; Yang et al., 2013; Woon and Lo, 2013).

There is no lack of studies on GHG emissions in terms of different approaches of waste management. Some studies investigated the contribution of different MSW disposal approaches to the GHG reduction. These studies have suggested that the environmental impact of MSW management can be reduced by WtE (e.g. lower GHG emissions, energy production). Psomopoulos et al. (2009) reviewed the status of and benefits associated with waste-to-energy in USA. In 2011, Psomopoulos studied GHG emission reduction potential in Greece by implementing WtE facilities (Psomopoulos et al., 2011). Monni (2012) calculated the amount of GHG emission reduction by shifting from landfilling to WtE in Finland. Chandel et al. (2012) investigated the potential GHG emissions reduction from landfill to WtE in USA, and estimated

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the cost of CO_2 capture of WtE. Tabata (2013) investigated the GHG reduction potential in Japan between incineration plants with and without energy recovery. Ryu (2010) evaluated the potential of municipal solid waste for renewable energy production and reduction of GHG emissions in South Korea.

Some studies have suggested that the waste incineration power generation (narrowly WtE) is a better option than landfill gas utilization from the perspective of GHG emission reduction (Woon and Lo, 2013; Han et al., 2010). However, existing studies mainly placed focuses on scenarios of technological innovations. By contrast, the impacts of natural environment (e.g. climate zones) on the contribution of WtE to GHG emission reduction are largely overlooked.

Due to the substituted emissions from fossil energy, the greenhouse gas emissions from WtE projects were negative in most European countries, thus that WtE was considered as a GHG sink (Gohlke, 2009; Riber et al., 2008; Astrup et al., 2009). However, it is contradictory to those studies focusing on the Chinese context (Zhao et al., 2009; Wang et al., 2009; Woon and Lo, 2013; Yang et al., 2012).

Unlike developed countries, China suffers from a considerable amount of waste been disposed to dumping sites and simple landfills that are not equipped with LFG extraction systems (Zhang et al., 2010). This led to a large amount of CH_4 emissions. There are massive potential for GHG emission reductions in WtE. The aim of this study is to investigate the contribution of WtE to GHG emission reduction. GHG emission reduction during the WtE process was compared between Temperate Dry Zone and Tropical Moist Zone. Consequently, the 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) was examined. Temperate Dry Zone and Tropical Moist Zone were selected in this study and the focus was placed on the impacts of climate condition on GHG emissions derived from waste where half-life value is one of most critical parameters. Half-life value ($t_{1/2}$) is the time taken for the DOC in waste to decay to half of its initial mass. Half-life value of waste degradation rate is largest and smallest in Temperate Dry Zone and Tropical Moist Zone respectively (IPCC, 2006).

The comparison is made from the perspective of waste management strategy of government, rather than from the perspective of waste company. These findings provide useful inputs for the decision making of WtE approaches in the context of different geographical regions.

2. Materials and methods

2.1. System boundary and inventory

It is paramount to set up system boundaries and assumptions when establishing a GHG emission inventory (Braschel and Posch 2013). Fig. 1 shows the system boundaries of this study. As there is great uncertainty beyond the WtE site, the system only included GHG emissions during waste-to-energy process on site. By contrast, GHG emissions from MSW collection and transportation process and final disposal of residues were excluded.

GHG emissions and avoided GHG emissions are defined as below.

(1) GHG emissions
- Part 1: direct emissions-DE (CH_4) for landfill E and DE (CO_2) for incineration E

Biogenic carbon is generally accounted with a GWP of 0 in incineration E. For incineration E, direct GHG emissions include CO_2 and N_2O by burning non-biogenic (i.e. fossil-fuel-derived) waste and auxiliary fuels whereas CH_4 and trace gases are not considered significant in modern installations (Astrup et al., 2009). As for landfill E, dispersive CH_4 are the prime direct emissions, inclusive of the post-closure lifetime of the landfill no matter the practice of LFG or not (Manfredi et al., 2009).

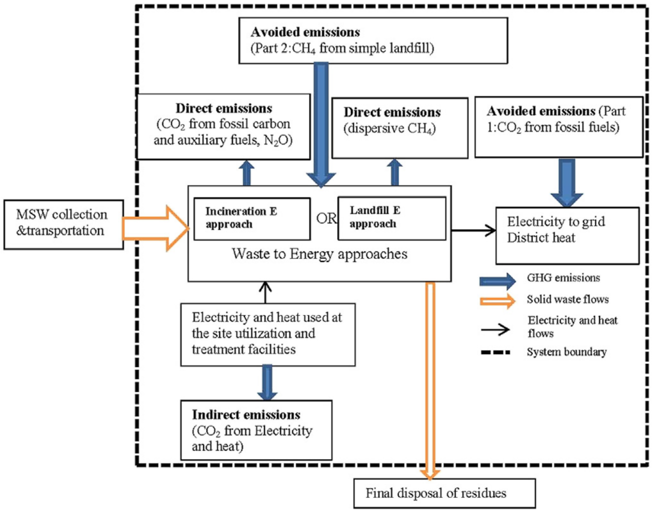

Fig. 1. System boundary of waste-to-energy projects.

- Part 2: indirect emissions-IE (CO_2)

If simple landfill is replaced by WtE approach, additional energy has to be acquired. Indirect GHG emissions in this paper are mainly from the additional electricity and heat required at the site and treatment facilities during the WtE process. It should be noted that GHG emissions from electricity consumption at the site account 70%–100% of indirect emissions in WtE projects (Manfredi et al., 2009; Astrup et al., 2009). Therefore, only the indirect emissions from electricity generation are considered in this paper. Other indirect emissions such as construction, materials (liner or auxiliary), vehicles and fuels were not taken into account.

(2) Avoided GHG emissions

There are two components of avoided GHG emissions, i.e. from the use of alternative energy sources; and from shifting simple landfill approach to WtE approach.

Part 1 CO_2 emission from fossil fuels for electricity and heat production-AE (CO_2)

The most attractive feature of WtE project is energy recovery, i.e. electricity and/or heat. The GHG emissions related to the substituted electricity and heat largely depends on what kind of energy is substituted.

Part 2 CH_4 emission from simple landfill-AE (CH_4)

CH_4 emissions produced from solid waste contribute approximately 3% to the annual anthropogenic GHG emissions globally as a result of degradation of organic material under anaerobic conditions (IPCC, 2006). This component of GHG emissions is influenced by a number of factors such as the composition of the waste, and climatic conditions of the location of the MSW site (Machado et al., 2009).

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