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Evaluation of greenhouse gas emissions for several municipal solid waste management strategies

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ABSTRACT

Burgeoning of municipal solid waste treatment issues and concerns on climate change have drawn massive attention. The Taiwanese Government is taking a concerted effort to voluntarily reduce greenhouse gas emissions to meet global warming protocols. This study evaluated the greenhouse gas emissions from five municipal solid waste treatment scenarios, including landfilling, waste to energy, and material recovery. The findings from this study indicate that a material recovery facility (8.08×10^3 to 1.52×10^4 kg CO_2-eq/day) or a landfill site (4.45×10^3 to 4.45×10^4 kg CO_2-eq/day) emits less greenhouse gases than a waste to energy plant (1.10×10^6 to 4.39×10^6 kg CO_2-eq/day) for handling 20,000 tonne/day of municipal solid waste. The greenhouse gas emissions from a waste to energy plant are mainly carbon dioxide and nitrous oxide, but can be offset by electricity generation and energy recovery. Furthermore, potential of greenhouse gas mitigation from waste recycling in a material recovery facility can be more effective than electricity generation in a waste to energy plant. This study provides valuable insights into the applicability of a policy framework for municipal solid waste management practices with regards to reduction of greenhouse gas emissions.

1. Introduction

Rapid urbanization, population growth, and socio-economic development have led to increases of waste generation around the world. Two billion tons of municipal solid waste (MSW) has been generated worldwide in 2011 (Amoo and Faglenle, 2013) and is expected to reach 9.5 billion by 2050 (FAO, 2009). Due to a great effort on implementation of waste management policies in Taiwan, MSW generation is being reduced from 2.0 in 1990 to approximately 0.8 kg/day/capita recently (Taiwan EPA, 2015), which is less than those of Korea (1 kg/day/capita) and EU countries (1.4 kg/day/capita) (Ryu, 2010; Skovgaard et al., 2008). MSW in Taiwan is predominantly from household with a small fraction from industries. Waste incineration can be considered as “recovery” rather than “disposal” if the energy recovery efficiency exceeds a certain threshold (Monni, 2012). MSW in Taiwan has been considered as a valuable resource and mostly treated by nearby waste-to-energy (WTE) plants for reduction of its volume and for generation of electricity and/or energy.

The waste treatment strategies in Taiwan have been shifted from landfilling to incineration within the past two decades. In 1991 the Taiwanese government implemented projects to build WTE plants to reduce the landfilled waste volume to minimize the need for land space. Percentage of MSW treated by landfill sites was reduced from 59% in 1991 to 1% in 2014; on the other hand, 99% MSW was treated by incineration nowadays (Taiwan EPA, 2015). However, waste incineration may produce toxic substances, such as heavy metals and dioxins which have negative impacts on the environment. Waste minimization at the source and recycling are challenges for waste management (Tudor et al., 2005). Many researches have been conducted on effects of recycling behavior and on minimizing environmental impacts (Harder et al., 2006; Robinson and Read, 2005; Vicente and Reis, 2007; Wilson and Williams, 2007). In 1997 the Taiwanese government uses recycle, clean, and disposal fees collected from waste generators to generate revenues for managing wastes (Chen and Wu, 2015). In addition, Taiwanese government started to collect fees from the designated trash bags. That follows the principle that polluters pay, as the fees are directly related to the amount of generated waste. General public is

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required to dispose of waste in pre-paid trash bags. Recyclable items are disposed in separate containers to reduce paying fees. This system fosters the growth of recycling industries in Taiwan, but also changes the lifestyle of general public.

It is known that human activities have led to accumulation of greenhouse gases (GHGs) in the environment. GHG emissions are accounted during production and usage of a product, but also related to its end-of-life phase, i.e., waste treatment processes (Braschel and Posch, 2013). Globally, total waste disposal is responsible for about 3–4% of anthropogenic GHG emissions (IPCC, 2006). The waste management operation consists of several sequential steps, including collection, transportation, and treatment (Chen and Wu, 2015; Weitz et al., 2002). Correspondingly, waste treatment has been gaining importance in the global emissions scene (Gomes et al., 2008). Separation of recyclables in the material recovery facility (MRF) has great benefit for reduction of GHG emissions (Mohareb et al., 2008). Several studies have been conducted to evaluate the GHG emissions from waste incineration and demonstrated that waste incineration can be a GHG sink (Astrup et al., 2009; Gohlke, 2009; Riber et al., 2008; Yang et al., 2012). In other words, energy recovery via production of heat or electricity could mitigate GHG emissions (Damgaard et al., 2010; Tchanche et al., 2011). An integrated WTE system could also bring a significant decrease in GHG emissions, and increase its revenue from electricity sales (Zsigraiova et al., 2009). At least 75% of Taiwan's MSW is made up of biomass materials and low moisture content of 50% make MSW in Taiwan is favorable for direct incineration with less GHG emissions (Chen and Lo, 2015). Cities and municipalities in Taiwan have committed to mitigate GHG emissions from MSW management through city networks and programs.

This study conducted a comprehensive evaluation of GHG emissions for several MSW management scenarios in Taiwan, including combining a WTE plant, a landfill site and an MRF. Proper MSW management can contribute to efficient resource uses including waste prevention as well as reuse and recycling of products and materials. The results of this study could serve as an additional view for development of practical guidelines in the MSW management system, as well as for evaluation of policy framework for MSW management practices with regards to GHG mitigation.

2. Material and methods

2.1. System boundary of this study

Taiwanese averagely generate 20,000 tonne/day of MSW. Five proposed scenarios in this study are presented in Table 1. Scenario 1 represents the strategy used before 1991, when most of the MSW was landfilled. Scenario 2 represents the current practice in Taiwan. Half of the MSW generated is being directed to nearby WTE plants. Process residues (mainly ashes) after incineration are c.a. 20% of total feed in volume. Scenario 3, when compared to scenario 2, represents an elimination of landfilling to encourage MSW recycling. This scenario is to eliminate the landfilling MSW, thus it will extend the usable life of the current and future landfills. Scenario 4 represents an increase of MSW recycling and a decrease in incineration, when compared to scenario 3. Scenario 5 represents 100% of MSW incineration without landfilling or recycling. This study focused on scenarios 3 and 4 to reduce MSW volume and GHG emissions which might be adopted by relative MSW management policies.

Table 1
Five different scenarios in this study.

Scenario	MSW to landfill site (tonnes/day)	MSW to WTE plant (tonnes/day)	MSW to MRF (tonnes/day)	Ash from WTE plant to landfill site (tonnes/day)
1	20,000	N/A	N/A	N/A
2	2000	10,000	8000	2000
3	N/A	10,000	10,000	2000
4	N/A	5000	15,000	1000
5	N/A	20,000	N/A	4000

The basis used in this study is one tonne of MSW (wet basis). The sub-processes relevant to GHG emission or mitigation in a WTE plant consist of (a) transport of MSW from household to the WTE plant and/or an MRF, ashes from the WTE plant to a landfill site, and separated recyclables from the WTE plant to the MRF; (b) GHG emissions from the MSW incinerators and (c) electricity replaced by energy recovery with regards to GHG emissions. For MSW recycling, some recyclable items found from the WTE plant were also sent to the MRF. Some GHGs have found to be emitted from the MRF. Recycling and sorting different categories of MSW would lead to different ranges of GHG mitigation; however, it currently would not be discussed further in this study. The interrelations among a WTE plant, a landfill site, and an MRF used in this study are shown in Fig. 1.

Information and data of the physical and chemical compositions of MSW used in this study are tabulated in Table 2. The GHG inventory includes CO_2, methane (CH_4), and nitrous oxide (N_2O) which are listed in the Kyoto Protocol. When MSW is burned for energy, carbon in the waste is released as CO_2, together with a small amount of other GHGs such as CH_4 and N_2O (Ryu, 2010). CH_4 emission was only considered for landfilling. The waste is usually incinerated at 850–1050 °C to avoid generation of dioxins; however, raising the temperature from 850 to 930 °C may already have the N_2O emissions (Lyngfelt and Leckner, 1993). Therefore, N_2O emissions should not be ignored when calculating GHG emissions from incineration of wastes. The effectiveness of each gas was converted to CO_2-equivalent (CO_2-eq) using its global warming potential (GWP). The assumed global warming potentials (GWP) for CH_4 and N_2O are 21 kg CO_2-eq/kg CH_4 and 298 kg CO_2-eq/kg N_2O, respectively (IPCC, 2006).

2.2. GHG emissions from MSW transportation

Transportation means moving collected waste by a collection vehicle (mostly trucks) from a loading point to an unloading point (Braschel and Posch, 2013). The distance traveled was evaluated based on the average distance among three WTE plants and one landfill site in Taipei region. They are all managed by the local government and have sufficient data with a long-term operation. The MSW transport distance was assumed to be 50 km (round trip), and the distance traveled, for ashes hauling from a WTE plant to the landfill site, is about 80 km (round trip). Recyclables found in a WTE plant were sent to an MRF with an average distance of 20 km (round trip). It was assumed that one trip per day for MSW hauling from household to a WTE plant and/or an MRF. Fuel efficiency of the truck fleet was assumed 1.3 km/L (Mohareb et al., 2008). The GHG emission factor which accounts for MSW hauling was assumed to be 19.1 g CO_2-eq/tonne/km (DEFRA, 2011). Production of GHGs from maintenance of collection and transport equipment and facilities were not addressed in this study. The greenhouse impact of black carbon from the combustion of diesel fuel was not considered in this study although it may contribute to climate change (Jacobson, 2002).

2.3. GHG emissions from WTE plants

On the basis of the GHG emission and mitigation, an estimate on the net GHG emissions from a WTE plant can be derived using Eq. (1) below (Woon and Lo, 2013):