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Potential for energy recovery and greenhouse gas mitigation from municipal solid waste using a waste-to-material approach

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ABSTRACT

Energy recovery and greenhouse gas (GHG) emissions from wastes are getting noticed in recent years. This study evaluated the potential for energy recovery and GHG mitigation from municipal solid waste (MSW) with a waste-to-material (WTM) approach. Waste generated in Taiwan contains a large amount of paper, food waste, and plastics, which previously were mostly sent to waste-to-energy (WTE) plants for incineration. However, the mitigation of GHGs by the WTM approach has been especially successful in the recycling of metals (averaging 1.83×10^6 kg CO_2-eq/year) and paper (averaging 7.38×10^5 kg CO_2-eq/year). In addition, the recycling of paper (1.33×10^{10} kW h) and plastics (1.26×10^{10} kW h) has contributed greatly to energy saving. Both metal and glass are not suitable for incineration due to their low energy content. The volumes of paper and food waste contained in the MSW are positively related to the carbon concentration, which may contribute to increased GHGs during incineration. Therefore, the recycling of paper, metals, and food waste is beneficial for GHG mitigation. Measures to reduce GHGs were also suggested in this study. The development of the WTM approach may be helpful for the proper management of MSW with regards to GHG mitigation. The results of this study can be a successful example for other nations.

1. Introduction

Rapid urbanization, population growth, and socio-economic development have led to the increased production of municipal solid waste (MSW). Globally, waste volumes are increasing even faster than the rate of urbanization (Hoornweg and Bhada-Tata, 2012). Two billion tones of MSW was generated worldwide in 2011 (Amoo and Fagbenle, 2013) and it is expected to reach 9.5 billion by 2050 (FAO, 2009). In Taiwan, 2.3 million people live in a relatively small land space (ca. 36,000 km^2), and the annual MSW generation is about eight million tones (Taiwan EPA, 2014a). Due to great efforts in the implementation of waste management policies, MSW generation has been reduced from 2.0 kg/day/capita in 1990 to approximately 0.8 kg/day/capita recently (Taiwan EPA, 2014b), which is less than the global average of 1.20 kg/day/capita (Hoornweg and Bhada-Tata, 2012). The MSW of Taiwan is predominantly from households, with a small fraction from commerce. The MSW in Taiwan has been treated as a valuable resource, principally through treatment by local waste-to-energy (WTE) plants for volume reduction and energy recovery (Chen and Lo, 2016).

According to Taiwan's Waste Disposal Act, the general public is held responsible for sorting its daily MSW into the categories of general, recyclable, and food waste for daily disposal. About 55% of the total MSW corresponds to general waste, and 44% and 1% are recyclables and food waste, respectively (Taiwan EPA, 2014b). The recycling rate of MSW in Taiwan is higher than those of Malaysia (5.5% in 2014), Spain (17% in 2012), but lower than Hong Kong (52% in 2013) (Bueno et al., 2015; Tan et al., 2014; Woon and Lo, 2013). Recyclable waste includes paper, textiles, metals, glass, and plastics (except plastic bags). Food waste includes raw or post-consumption food waste. General waste is the largest component of MSW. The strategies of waste treatment in Taiwan have shifted from landfilling to incineration within the past two decades. The percentage of MSW disposed as landfill was reduced from 59% in 1991 to 1% by 2014, and almost 53% of MSW is now treated by incineration (Taiwan EPA, 2014b). However, waste incineration can produce toxic substances which have negative effects on the environment. Waste minimization at source and the development of a waste-to-material (WTM) approach are promising alternatives for waste management (Tan et al., 2014).

A strong correlation between waste generation and greenhouse gas (GHG) emissions has been found (Hoornweg and Bhada-Tata, 2012). Globally, total waste disposal is responsible for about 3–4% of anthropogenic GHG emissions (IPCC, 2006). To achieve a reduction in GHGs, both energy and resources must be applied more efficiently (Corsten et al., 2013). Waste management is a key element in achieving sustainable energy and resource management

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(Ryu, 2010). Such management includes waste minimization, reuse, and the recycling of materials. The European Commission has established the importance of resource efficiency and declared an initiative to deliver sustainable, smart and inclusive growth (European Commission, 2011). The U.S. Environmental Protection Agency (EPA) has analyzed the GHG outputs of 29 categories of materials and concluded that waste minimization and the recycling of materials are recommended alternatives with regards to GHG mitigation (US EPA, 2006). Studies have been conducted on the effects of recycling behavior and on the minimization of environmental impacts (Corsten et al., 2013; Rigamonti et al., 2010; Ryu, 2010; Tan et al., 2014). Waste recycling is essential to improve the performance of waste management (Tan et al., 2014). In addition, both waste minimization and recycling are highly beneficial in terms of GHG reduction (Björklund and Finnveden, 2005). Studies have been demonstrated that waste incineration can be a GHG sink (Astrup et al., 2009; Gohlke, 2009; Yang et al., 2012); however, energy recovery via production of heat or electricity could mitigate GHG emissions (Damgaard et al., 2010; Tchanche et al., 2011). Our previous study indicated that recycling and landfilling emit less GHGs than incinerating for handling MSW (Chen and Lo, 2016). Taiwan has scarce natural resources with a huge energy demand; therefore, development of the WTM approach plays a vital role in the production of renewable energy while mitigating GHGs.

The objective of this study was to explore the potential for energy recovery and GHG mitigation of recycling items in waste streams by a WTM approach. The current strategies of waste management in Taiwan and relevant statistical data were reviewed in this study. The potential for energy recovery and corresponding GHG mitigation were analyzed based on the constituents and chemical analysis of MSW. The role of the WTM approach in waste management was also evaluated and suggested. Some proposed and implemented measures related to energy recovery and GHG mitigation from wastes were also introduced in this study. The results of this study may help decision-makers to evaluate the proper management of MSW with the WTM approach with regards to GHG mitigation and can be a successful example for other nations.

2. Materials and methods

2.1. System boundary of this study

The system boundary of this study is shown in Fig. 1. Calculations were made of the energy recovery and GHG mitigation of various materials, from generation through to final processing, by recycling (WTM approach) or incineration in WTE plants. Recyclable items sent to material recovery facilities were further categorized into paper, textile, plastics, metals, and glasses. Food waste was independently collected to be recycled by the WTM approach. MSW containing paper, textile, food waste, plastics, metals, glass, and other materials (including combustible wastes smaller than 5 mm and incombustible wastes, i.e., ceramics, sand, or cement) was evaluated for its suitability to be recycled (WTM approach) or sent to WTE plants for incineration. Landfilling was not included in this study, as the current policies in Taiwan are to minimize waste landfilling due to constraints on available land space.

2.2. Physical and chemical characteristics of MSW

Table 1 summarizes the constituents and the results of the chemical analysis of MSW. The physical characteristics of MSW include its constituents and moisture content. Compositional analysis was carried out on samples collected randomly each month during the study period, January 2003 to December 2014. The collection method was followed the NIEA R124.00C method in Taiwan (Taiwan EPA, 2014b). All of the MSW samples were put on a $10 \times 10\ m^2$ plate and then collected by a quartering sampling method to 1 kg. The collected samples were shredded (diameter <1 mm) and segregated into different constituents (i.e., paper, textiles, food waste, plastics, metals, glass, and others). They were then sealed in metallic containers before testing. All the tests had to finish within the sampling day. The annual compositions were the averages of the monthly samples. The moisture content of the MSW was determined by the oven-drying method (NIEA R213) (Taiwan EPA, 2014b). The chemical analysis of the MSW was expressed in weight percentages of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), chlorine (Cl), and others, determined by an elemental analyzer (EA) according to the NIEA R409 method (Taiwan EPA, 2014b).

2.3. Calorific value estimations

The calorific values (CV) of the MSW were determined by using a bomb calorimeter according to the NIEA R214 method in Taiwan (Taiwan EPA, 2014b). The samples were dried at 105 ± 5 °C for 2 h and grounded using a soil pulverizer. The powders were then

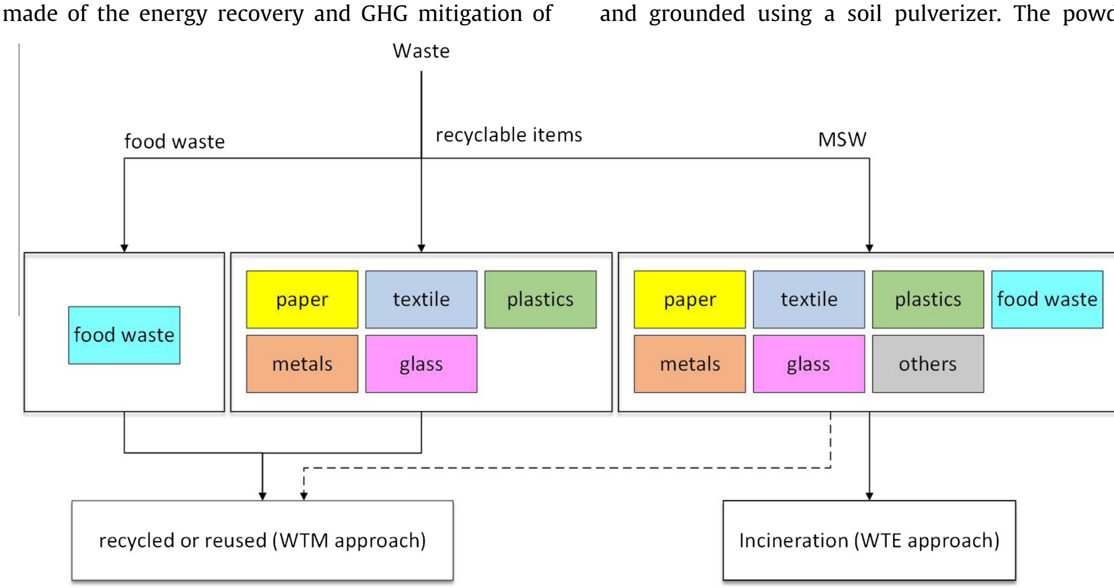

Fig. 1. System boundary of this study.

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