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Environmental life-cycle assessment of municipal solid waste incineration stocks in Chinese industrial parks

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ABSTRACT

Mitigating coal dependence of Chinese industrial parks is crucial to reducing their environmental footprints. Municipal solid waste incineration (MSWI) is a promising measure for such purpose and has been increasingly implemented in Chinese industrial parks. In the study, the inventory of MSWI facilities in Chinese industrial parks was established for the first time, which accounted for 55% of total MSWI capacity of China in 2014. The life-cycle environmental impacts of MSWI in a typical Chinese industrial park were assessed, associated with critical literature comparison and a sensitivity analysis. Then the life cycle assessment results were applied to the in-use stocks of MSWI facilities in Chinese industrial parks to uncover the potential environmental benefits during their remaining service lifetime. The results indicated that the MSWI in-use stocks have positive environmental benefits for global warming potential, human toxicity potential, and acidification potential, while negative performance for eutrophication potential mainly due to inadequate implementation of end-of-pipe pollution control. In the case study, a MSWI-driven combined heat and power (CHP) in a typical Chinese industrial park can achieve a 32% reduction in greenhouse gas (GHG) emission as compared with coal-fired CHP to generate the same energy outputs. The replaced coal consumption of the in-use MSWI stocks during their remaining lifetime is about 2.9% of annual coal consumption of China in 2014, and the GHG mitigation potential was estimated as 101.3 million tonne of CO_2 eq., equivalent to 0.9% of annual GHG emissions from China.

1. Introduction

The generation of municipal solid waste (MSW) in China has experienced an unprecedented rise since the 1980s due to rapid urbanization and economic growth. The amount of MSW collection reached 191.4 million tonne in 2015 (NBS, 2016), and is still growing rapidly. The majority of MSW is currently landfilled in China and MSW management are experiencing numerous stress, such as land scarcity and heavy pollution (Zheng et al., 2014). As a result, the government is strongly promoting incineration as an alternative to handling the waste (Nie, 2008). Between 2011 and 2015, the MSW incineration capacity increased from 89,000 tonne per day to 235,000 tonne per day, accounting for 31% of the total MSW treatment capacity in China (NDRC, 2017a). In the grand plan of the 13th Five-year Period (2016–2020), Chinese government set up ambitious goals in terms of waste management. During this period, municipalities and provincial capitals must implement landfill-free policies. By the end of 2020, MSW incineration is expected to account for more than 50% of MSW treatment capacity of the country, and this figure should exceed 60% in eastern provinces (NDRC, 2017a).

Moreover, Chinese government is emphasizing the importance of developing circular economy, such as facilitating eco-industrial parks (EIPs) (Chertow and Park, 2015; Shi et al., 2012). As the laboratories of circular economy on a large scale, EIPs provide a strong basis for creating symbiotic relationships thanks to the geographical proximity of plants; the sharing of infrastructure and information; financial benefits; organizational structure; and legal and regulatory framework (Chertow, 2000; Sakr et al., 2011). The EIP also facilitates energy clustering and can provide environmental and economic benefits (Maes et al., 2011). Nevertheless, the energy infrastructure in Chinese EIPs still relies massively on fossil fuel. Recent studies have found that in the 106 Chinese EIPs, 87.5% of the total capacity of energy infrastructure is

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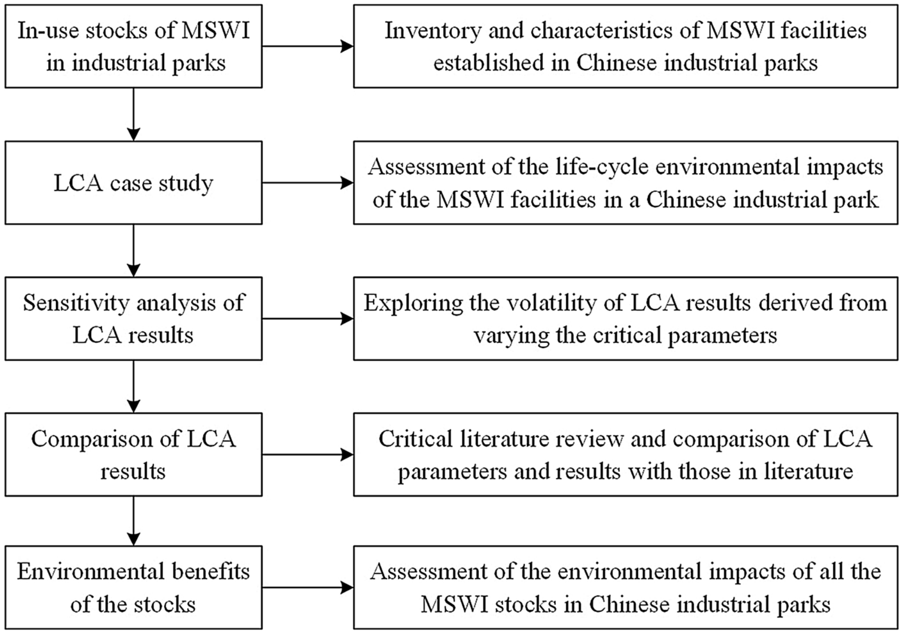

Fig. 1. Schematic diagram of the research framework.

coal-fired, and a large number of small-capacity facilities are used (Guo et al., 2018). Converting MSW to energy is proposed as one of the key measures of mitigating greenhouse gas (GHG) emissions from Chinese EIPs and reducing their dependence on coal (Guo et al., 2016).

Some studies have focused on the life-cycle environmental impacts of municipal solid waste incineration (MSWI) in China (Dong et al., 2014; Havukainen et al., 2017; Liu et al., 2017a,b; Zhao et al., 2018, 2012), which reflected a positive contribution of MSWI to environmental improvement compared with fossil fuel firing. These encouraging results are mainly due to the substitution of MSWI-based energy for coal-derived secondary energy. Currently, electricity generation is still heavily coal dependent in China. In 2014, coal-fired facilities contributed 70.5% of total electricity production (CEC, 2015), associated with a high environmental impact. MSWI generates fewer emissions of GHG and some regular pollutants such as SO_2, then results in overall environmental gains when used to replace coal-fired electricity generation.

MSWI also has some limitations. Among them, the water content of MSW is the most critical factor. It was reported that reducing food waste in MSW by 50% would result in a 9–44% decrease in water content and a substantial improvement of approximately 20–80% in low heating value (LHV) (Yang et al., 2012). Thus, the source separation of MSW is imperative and urgent (Zhang et al., 2016). Additionally, public resistance to MSWI is another limiting factor. There is strong disapproval of such projects when located close to residential area (Huang et al., 2015). The “not in my backyard” (NIMBY) reaction is mainly motivated by weak environmental regulations, the non-transparency of emission data and vicious economic competition among companies (Huang et al., 2015). Chinese MSWI plants also have low energy recovery efficiencies; for example, the comprehensive energy efficiency of MSWI plants is only averagely 17% in China but 30% in Europe (Astrup et al., 2009; Yang et al., 2012). Recent studies also came to the conclusion that the performance of MSWI plants could be improved if the steam produced could be used in district heating or industrial sectors (Astrup et al., 2009; Damgaard et al., 2010; Havukainen et al., 2017; Udomsri et al., 2011; Yang et al., 2012). Presently, most MSWI plants only produce electricity, as many studies focused on (Ayodele et al., 2017; Havukainen et al., 2017; Rocco et al., 2017). Considering many cities are not equipped with urban heating, industrial sectors, particularly industrial parks, could provide an opportunity for heat demand. Notably, industrial parks are characterized by efficient steam utilization because steam is required throughout a whole year, and the associated steam users are limited to industrial complexes instead of city districts.

To the best of our knowledge, very few studies have examined the status of MSWI development in Chinese industrial parks and assessed the life-cycle environmental impacts of MSWI stocks thereof. The major differences between MSWI in or out of an industrial park is generally whether there is MSMI-based heat used by industrial processes, which will affect environmental life cycle impacts to some extent. Chinese industrial parks are potential locations for MSWI plants because they can address the issue of low energy efficiency with combined heat and power (CHP), and the steam produced could be transmitted to surrounding industries in geographic proximity based on the principles of industrial symbiosis (Chertow, 2007; Lombardi et al., 2015; Ohnishi et al., 2018). The installation of MSWI facilities inside industrial parks is also a means of reducing coal dependence and mitigating GHG emission in Chinese industrial parks (Guo et al., 2016). Even without solid evidence, such practice can partly neutralize the arguments of NIMBY because industrial parks are generally far from population-intensive communities in China.

The goals of this study are to uncover the in-use stocks of MSWI facilities in ~1600 Chinese industrial parks and then assess the cumulative life-cycle environmental benefits of the stocks. To achieve the goals, we first established a high-resolution inventory of in-use MSWI facilities stock in Chinese industrial parks. Meanwhile, a case study of MSWI-driven CHP in a Chinese EIP was conducted for life cycle assessment (LCA). The LCA results of the case were critically compared with those reported in literature, and then were applied to the in-use MSWI stocks to quantify the cumulative life-cycle environmental impacts during their remaining service lifetime by a vintage stock model. This study could serve as a reference for decision makers in facilitating MSWI, mitigating coal dependence, and improving the environmental performance of MSWI in Chinese industrial parks.

2. Materials and methods

Fig. 1 presents a five-step schematic diagram of this research. Each step is further explained as follows.