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An integrated life cycle costing and human health impact analysis of municipal solid waste management options in Hong Kong using modified eco-efficiency indicator

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ABSTRACT

This paper quantifies and compares the private and external costs of the proposed landfill extension (LFE) and advanced incineration facility (AIF) in Hong Kong using life cycle costing methodology. In addition, a modified eco-efficiency indicator is developed in order to integrate the life cycle cost and life cycle human health impact associated with these two proposed waste disposal facilities. With the inclusion of private and external costs, the life cycle costs of AIF and LFE are 1619.2 HKD/tonne MSW and 1782.4 HKD/tonne MSW, respectively. The AIF has a slightly lower life cycle cost (i.e., 163.2 HKD/tonne MSW or 9.2% lower) than the LFE. However, if only private cost is considered, the result is reversed, in which the LFE has a lower life cycle cost than the AIF. The life cycle cost of the AIF is mainly contributed by the capital cost and operating cost, while the life cycle cost of the LFE is mainly attributed to the capital cost and disamenity cost. The modified eco-efficiency indicator shows that the AIF is more eco-efficient relative to the LFE, revealing that the AIF is advantageous over the LFE in both life cycle human health impact and life cycle cost perspectives. The integration of environmental and economic aspects of the proposed waste disposal facilities from a life cycle perspective facilitates the stakeholders in developing policy guidelines for pursuing a sustainable management of MSW disposal in Hong Kong.

1. Introduction

With prospects of a rising global population and accelerating urban development, the relentless growth of municipal solid waste (MSW) disposal has created an insurmountable problem to society. The World Bank estimates that worldwide 1.3 billion tonnes of MSW are generated per year and it is predicted to reach 2.2 billion tonnes per year by 2025 (Hoornweg and Bhada-Tata, 2012). As a mega-city with increasing constraints on land resources and a high population density, Hong Kong is facing unrelenting pressure on MSW disposal. Currently, Hong Kong relies merely on the landfill for MSW disposal. It is anticipated that the current three strategic landfills in Hong Kong, namely South East New Territories (SENT), North East New Territories (NENT), and West New Territories (WENT), will reach their maximum capacities in 2015, 2017, and 2019, respectively (HKEPD, 2013). In view of this imminent issue, landfill extension (LFE) and advanced incineration facility (AIF) have been proposed by the Hong Kong Special Administration Region (HKSAR) Government (HKEPD, 2005). Nonetheless, the proposals of these two waste disposal facilities have stimulated contentious debates with the public and have become a major issue of public concern (Tang, 2011; Cheung, 2013).

Regarding the sustainability and feasibility of the proposed LFE and AIF in Hong Kong, a waste disposal facility must fulfil the requirements of sustainable environmental protection with economic affordability. The environmental impacts of the proposed waste disposal facilities have been evaluated by Woon and Lo (2014) using life cycle assessment methodology. For economic affordability, life cycle costing (LCC) methodology can be applied to provide a systematic economic analysis of the waste disposal facilities from a life cycle perspective. However, most of the recent LCC studies considered only private costs (e.g., capital cost, operating cost, transportation cost), but did not assess the external costs (e.g., disamenity cost, external environmental cost) to any depth. For example, Aye and Widjaya (2006), Zhao et al. (2011), and Assamoi and Lawryshyn (2012) only examined the private costs in their studies. Jamasb and Nepal (2010) included external environmental costs, but only evaluated the carbon dioxide equivalent (CO_2e) externality cost using the current carbon trading price within the studied region. Environmental damage renders mal-function of markets due to poor defined property rights of the natural environment (Gluch and Baumann, 2004). Besides, free-ridership problem

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can be taken into consideration if the external cost of public properties (e.g., waste disposal facilities) is analyzed comprehensively (Ertan et al., 2009). In this context, a comprehensive evaluation of the external costs of the proposed LFE and AIF is conducted in the study. Until externalities are quantified, internalization of external costs cannot be put into action. Hitherto, there is no economic valuation on the proposed LFE and AIF in Hong Kong from a life cycle perspective, and thus makes it challenging in generating decision criteria for formulating a MSW management framework in the context of economic sustainability. Therefore, an LCC study with locally specific data would be helpful in providing an additional dimension to policy makers for evaluating the financial aspect of the proposed LFE and AIF from a life cycle perspective. With the inclusion of external costs, the use of LCC methodology translates the environmental impacts into monetary units and provides a quantitative way to identify the sub-process or emission compound that contributes the most economic burden/benefit on the proposed LFE and AIF.

There is a concern that the evaluation of LCA and LCC constitute independent results of the environmental and economic considerations of the waste disposal facilities. The integration of the LCA and LCC results delivers an effective and scientific way in communicating the environmental and economic aspects simultaneously to the policy makers. However, no developed or sound tool is presently used to integrate the LCA and LCC results for the waste management sector (Emery et al., 2007; Hong et al., 2010; Franchetti, 2013). In response to linking the economic performance with its environmental impact, eco-efficiency, as proposed by the World Business Council on Sustainable Development, is found to be a feasible concept. An eco-efficiency indicator (EEI) has been developed by the BASF Company (Shonnard et al., 2003) to support this concept. The EEI has been used by Zhao et al. (2009) to integrate economic results with greenhouse gas emissions for the waste management sector based on a normalized factor. Nevertheless, the normalization issue makes it difficult to be applied for other impact categories such as human carcinogenicity and respiratory inorganics, in which regional or country specific normalization factors are difficult to obtain. Therefore, a novel and modified EEI is proposed in this study to facilitate the determination of eco-efficiency in the waste management sector.

This paper aims to address the above-mentioned conundrums; the objectives of this study are (1) to quantify and compare the life cycle costs (inclusive of local specific private costs/benefits and external costs/benefits) of the proposed LFE and AIF; (2) to identify the sub-process or emission compound that provides most external environmental burden/benefit on the proposed LFE and AIF; and (3) to evaluate the eco-efficiency associated with the proposed LFE and AIF using a modified EEI.

2. Material and methods

2.1. Geographical description of proposed LFE and AIF

The West New Territories (WENT) LFE is chosen as the subject of study as it has the largest estimated waste capacity (81 Mm^3) and the current WENT LFE receives the highest MSW disposal rate as compared to the existing SENT and NENT Landfills (HKEPD, 2010; LegCo, 2013). The WENT LFE could provide additional landfill capacity to maintain a continuous waste disposal service to the public in Hong Kong. Meanwhile, the AIF proposal, with a capacity of 3000 tonnes per day, aims to considerably reduce the bulk size of MSW, in the hope of lessening the burdens on current and future landfills in Hong Kong. The proposed locations of the WENT LFE and the AIF are illustrated in Fig. 1. The WENT LFE is proposed to be located at the west of the existing WENT Landfill in Nim Wan, Tuen Mun, while the AIF is planned to be situated on an artificial land near the Shek Kwu Chau Island. The system boundary of the LCC study covers the MSW transport from respective refuse transfer stations to the energy recovery of these two proposed waste disposal facilities.

2.2. Description of the LFE and AIF

The proposed LFE consists of major sub-processes such as waste transport, biological reactions as landfill cells, flare system, leachate collection and treatment system, and energy recovery system. Meanwhile, the proposed AIF encompasses major sub-processes such as waste transport, stack discharge system, and energy recovery system. The detailed descriptions of each sub-process of the waste disposal facilities were reported by Woon and Lo (2014). The landfill methane gas generated from the proposed LFE is collected and used for heat and electricity generation. The electricity and heat generation of the proposed LFE are 15.7 kWh/tonne and 188 kWh/tonne, respectively. The efficiency of the gas turbine is 0.35 for electricity generation, while the boiler is 0.80 for heat production. For the AIF, the heat produced during the combustion process in the incinerator is sent to the boiler to generate steam, which is used to power the steam turbine and generate electricity. The steam turbine in the AIF is assumed to have an efficiency of 0.197. The electricity generation of the proposed AIF is 760 kWh/tonne.

2.3. Categories of life cycle costs and benefits

Major private and external costs relevant to the proposed waste disposal facilities in Hong Kong are considered in this study. A discount rate is used to represent the time value of money by expressing the costs and benefits that accrue over different periods of time into monetary units in one period. A discount rate of 4% is used in this study, in which it is in line with the discount rate used by the Hong Kong Planning Department in studying the future development of Hong Kong (HKPD, 2007). Since the costs and benefits are cited at different year, all costs and benefits are discounted to year 2014 using Eq. (1).

$$F = P(1+i)^n \tag{1}$$

where F = future worth (HKD), P = present worth (HKD), i = discount rate (%), n = number of period (year).

The functional monetary unit is defined as Hong Kong dollar (i.e., HKD) per unit tonne of MSW being disposed of at the respective waste disposal facility. The LCC inventory data is not required to be aggregated via classification as the resulting results appear in a homogenous unit (i.e., HKD/tonne MSW). The total life cycle cost per tonne of MSW is defined mathematically in Eq. (2).

$$LCC_{FU} = \frac{\sum_{j=1}^{n}(PC_j + EC_j - PB_j - EB_j)}{Q_w} \tag{2}$$

where LCC_{FU} = life cycle cost per tonne of MSW (HKD/tonne); j = category of cost or benefit; PC_j = private cost (HKD/year); EC_j = external cost (HKD/year); PB_j = private benefit (HKD/year); EB_j = external benefit (HKD/year); Q_w = quantity of MSW disposed of in one year (tonne/year).

2.4. Private costs and benefit

Private costs and benefit refer to the costs and benefit internal to the MSW disposal in LFE and AIF. The private costs and benefit, and the key input parameters for the proposed LFE and AIF are summarized in Table 1. Major private costs such as capital cost, operating cost, and transportation cost of the proposed LFE and AIF are included in this study. All the relevant costs are collected from reliable sources such as HKSAR Government official press releases