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Information Sheet

Paper title	:	A Life Cycle Eco-efficiency Analysis of the Proposed Landfill Extension and Advanced Incineration Facility in Hong Kong

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Abstract :

The relentless growth in the volume of municipal solid waste (MSW) has created a major environmental challenge afflicting people in Hong Kong. It is anticipated that the current three strategic landfills in Hong Kong will be exhausted by 2020. Due to this imminent issue, landfill extension (LFE) and advanced incineration facility (AIF) have been proposed by the Hong Kong Environmental Protection Department. This paper evaluates the environmental and economic aspects of LFE and AIF for MSW disposal in Hong Kong using life cycle assessment (LCA) and life cycle costing (LCC) methodologies. On the basis of the data collected, assumptions made, and system boundary defined, the mid-point results of LCA study show that the LFE performs more poorly than the AIF in view of climate change and respiratory inorganics, but vice versa for carcinogens and respiratory organics. For the human health category (i.e., end-point result), which is obtained by combining the four mid-point results, the AIF performs better than the LFE on this category. For the LCC study, 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. A modified eco-efficiency indicator (EEI) is developed in order to integrate the LCA (with a focus on human health category) and LCC results associated with these two waste disposal facilities. By integrating the LCA (with a focus on human health category) and LCC results using a modified EEI portfolio, the AIF falls under the fully eco-efficiency category, indicating that the AIF is more eco-efficient relative to the LFE. The evaluation of the environmental and economic aspects of waste disposal facilities from a life cycle perspective simultaneously facilitates the stakeholders in decision making processes for pursuing a sustainable management of MSW disposal in Hong Kong.

Keywords : Eco-efficiency, incineration, landfill, life cycle assessment, life cycle costing, municipal solid waste

A LIFE CYCLE ECO-EFFICIENCY ANALYSIS OF THE PROPOSED LANDFILL EXTENSION AND ADVANCED INCINERATION FACILITY IN HONG KONG

ABSTARCT

The relentless growth in the volume of municipal solid waste (MSW) has created a major environmental challenge afflicting people in Hong Kong. It is anticipated that the current three strategic landfills in Hong Kong will be exhausted by 2020. Due to this imminent issue, landfill extension (LFE) and advanced incineration facility (AIF) have been proposed by the Hong Kong Environmental Protection Department. This paper evaluates the environmental and economic aspects of LFE and AIF for MSW disposal in Hong Kong using life cycle assessment (LCA) and life cycle costing (LCC) methodologies. On the basis of the data collected, assumptions made, and system boundary defined, the mid-point results of LCA study show that the LFE performs more poorly than the AIF in view of climate change and respiratory inorganics, but vice versa for carcinogens and respiratory organics. For the human health category (i.e., end-point result), which is obtained by combining the four mid-point results, the AIF performs better than the LFE on this category. For the LCC study, 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. A modified eco-efficiency indicator (EEI) is developed in order to integrate the LCA (with a focus on human health category) and LCC results associated with these two waste disposal facilities. By integrating the LCA (with a focus on human health category) and LCC results using a modified EEI portfolio, the AIF falls under the fully eco-efficiency category, indicating that the AIF is more eco-efficient relative to the LFE. The evaluation of the environmental and economic aspects of waste disposal facilities from a life cycle perspective simultaneously facilitates the stakeholders in decision making processes for pursuing a sustainable management of MSW disposal in Hong Kong.

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INTRODUCTION

Hong Kong is facing a pressing burden on municipal solid waste (MSW) disposal. Currently, Hong Kong relies solely on the landfill approach for MSW disposal. It is expected 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 by 2020 (HKEPD, 2014). In consideration 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). The proposals of the LFE and AIF, however, have raised a lot of concerns from different stakeholders (Lai, 2013; Pratt, 2013). It has aroused hot disputes over the environmental sustainability and economic feasibility of these two waste disposal options (i.e., LFE and AIF) on the MSW management practices in Hong Kong.

In order to investigate the environmental sustainability and economic feasibility of these two waste disposal options, a scientific evaluation on the environmental and economic perspectives from a life-cycle perspective is of importance. In this light, life cycle assessment (LCA) and life cycle costing (LCC) can be applied to provide systematic analyses to the LFE and AIF by synthesizing information from collected data and decoding the complexity of the problem (Linkov and Seager, 2000). Although the three LFEs and AIF have been recently approved by the Legislative Council Finance Committee and will be implemented in Hong Kong, a holistic and locally relevant analysis of potential environmental burdens and economic valuation on the proposed LFE and AIF from a life cycle perspective is yet to be studied. Through the LCA and LCC study, the major emission compounds and cost categories that provide most burdens to the waste disposal facilities can be identified, thereby facilitating improvements on the design criteria for the waste disposal facilities. It is hoped that this study can provide a greater certainty on the environmental and economic performances of these two waste disposal options, thus aiding the stakeholders in decision making processes for the context of sustainable MSW management development in Hong Kong.

The integration of the LCA and LCC results is imperative to deliver an effective way in communicating the environmental and economic aspects simultaneously to the policy makers. Eco-efficiency is found to be a feasible concept for integrating the environmental and economic aspects. An eco-efficiency indicator (EEI) has been developed by the BASF Company to support this concept. However, the normalization issue (i.e., expressing potential impacts in ways that can be compared) makes it difficult to be applied for some impact categories such as human carcinogenicity and respiratory inorganics, in which regional/country specific normalization factors are difficult to obtain. Hence, a modified EEI is proposed in this study to evaluate the eco-efficiency of the LFE and AIF.

MATERIAL AND METHODS

This study consists of three parts. Part one evaluates the LCA study of the proposed LFE and AIF in Hong Kong. Part two investigates the life cycle costs of these two proposed waste management options using LCC methodology. Part three integrates the LCA and LCC results using a modified EEI.

Modeling of LCA Study

Goal and Scope of LCA Study

In part one, the LCA study follows the LCA methodology as described in the international standard ISO reports (ISO 14040, 2006; ISO 14044, 2006). The goal of the LCA study is to evaluate the environmental performances of the proposed LFE and AIF, as well as to compare the environmental impacts of these two waste disposal options in Hong Kong. The functional unit used in this study is defined as “one tonne of MSW (wet basis) being discarded into the proposed waste disposal facility”. West New Territories (WENT) LFE, which is located at Tuen Mun, is chosen as the subject of study as it has the highest filling capacity (81 Mm^3) among the three proposed landfill extensions in Hong Kong. In addition, the current WENT Landfill receives the highest MSW disposal rate compared to the existing SENT and NENT Landfills (HKEPD, 2015). Meanwhile, the first phase of AIF is planned to be located at an artificial land near Shek Kwu Chau Island. The schematic process flow diagrams of the LFE and AIF, depicting the defined system boundary, are presented in Figure 1.

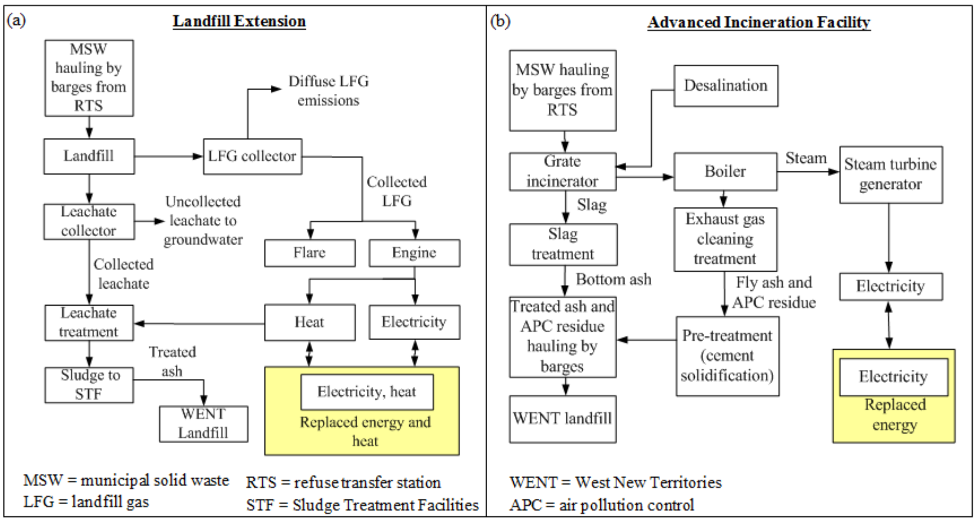

Figure 1. Schematic process flow diagram depicting the system boundary of (a) LFE; and (b) AIF

Life Cycle Inventory Data

Tables 1 and 2 provide the consolidated life cycle inventory data on the air and water-borne emission compounds, as well as the consumption and generation of heat and electricity in the LFE and AIF, respectively. The data inventory for LFE and AIF is categorized into their respective major sub-processes. To ensure the reliability of the study results, major emission compounds, such as CO_2, NO_x, SO_2, respirable suspended particulates (RSP) and heavy metals, contributing to the selected impact categories, are included in this study. The same source of data is used where possible to ensure that the data are relatively standardized by the methodology and year.

Table 1. Summary of data inventory for landfill extension (Woon and Lo, 2014)

Sub-process	Compound	Quantity per FU[a]	Emission	Source
Waste transport	CO_2	1.10 kg	Air	DEFRA, 2011; Woon and Lo, 2013
	NO_x	2.11×10^{-2} kg	Air	HKEPD, 2009
	SO_2	2.01×10^{-4} kg	Air	
	RSP[b]	2.30×10^{-4} kg	Air	
Biological reactions at landfill cells	CH_4	20.2 kg	Air	IPCC, 2006; Woon and Lo, 2013
	CO_2 (biogenic carbon storage)	-322 kg	Air	
Flare system	NO_x	3.21×10^{-2} kg	Air	HKEPD, 2009
	SO_2	1.96×10^{-3} kg	Air	
	CO	3.79×10^{-1} kg	Air	
	HCl	7.84×10^{-2} kg	Air	
	Vinyl chloride	1.39×10^{-5} kg	Air	
	Benzene	2.06×10^{-5} kg	Air	
Leachate collection and treatment	NO_x	3.91×10^{-2} kg	Air[c]	HKEPD, 2009
	SO_2	1.68×10^{-3} kg	Air[c]	
	CO	9.47×10^{-3} kg	Air[c]	
	HCl	6.69×10^{-3} kg	Air[c]	
	Vinyl chloride	1.19×10^{-6} kg	Air[c]	
	Benzene	1.75×10^{-6} kg	Air[c]	
	Total suspended solids	2.48×10^{-2} kg[d]	Water	Lo, 1996; Kurniawan and Lo, 2009
	BOD_5	2.02×10^{-2} kg[d]	Water	
	COD	2.53×10^{-1} kg[d]	Water	
	Fe	3.12×10^{-3} kg[e]	Water	
	Cd	8.53×10^{-6} kg[d]	Water	
	Cu	2.90×10^{-4} kg[d]	Water	
	Ni	6.66×10^{-5} kg[d]	Water	
	Cr	4.02×10^{-4} kg[d]	Water	
	Zn	5.38×10^{-5} kg[e]	Water	
	As	6.32×10^{-6} kg[e]	Water	
	Se	1.74×10^{-7} kg[e]	Water	
	Total suspended solids	2.09×10^{-2} kg[f]	Water	
	BOD_5	3.70×10^{-1} kg[f]	Water	
	COD	1.16 kg[f]	Water	
	Fe	4.95×10^{-2} kg[f]	Water	
	Cd	8.37×10^{-7} kg[f]	Water	
	Cu	9.70×10^{-4} kg[f]	Water	
	Ni	8.37×10^{-4} kg[f]	Water	
	Cr	5.86×10^{-4} kg[f]	Water	
	Zn	1.26×10^{-4} kg[f]	Water	
	As	3.01×10^{-4} kg[f]	Water	HKEPD, 2009
	Se	3.14×10^{-6} kg[f]	Water	
	Water consumption	0.11 m^3	N/A[h]	

Ash disposal after sludge treatment	Dioxins & furans	5.00×10^{-13} kg[g]	Water	HKEPD, 2011
	Cd	5.00×10^{-9} kg[g]	Water	
	Cr	2.50×10^{-8} kg[g]	Water	
	Cu	1.25×10^{-7} kg[g]	Water	
	Ni	1.25×10^{-7} kg[g]	Water	
	Pb	2.50×10^{-8} kg[g]	Water	
	Zn	1.25×10^{-7} kg[g]	Water	
	Hg	5.00×10^{-10} kg[g]	Water	
	Sn	1.25×10^{-7} kg[g]	Water	
	Ag	2.50×10^{-8} kg[g]	Water	
	Sb	1.25×10^{-7} kg[g]	Water	
	As	2.50×10^{-8} kg[g]	Water	
	Be	5.00×10^{-9} kg[g]	Water	
	Ti	2.50×10^{-8} kg[g]	Water	
	V	1.25×10^{-7} kg[g]	Water	
	Se	5.00×10^{-10} kg[g]	Water	
	Ba	5.00×10^{-7} kg[g]	Water	
	Ash	1.00×10^{-2} kg	N/A[h]	HKEPD, 2009
Energy recovery system	Electricity generation	157 kWh	N/A[h]	HKEMSD, 2002
	Heat generation	188 kWh	N/A[h]	
	Electricity consumption	157 kWh	N/A[h]	
	Heat consumption	188 kWh	N/A[h]	
	NO_x	2.46×10^{-3} kg	Air	HKEPD, 2009
	SO_2	2.76×10^{-4} kg	Air	
	RSP[b]	3.44×10^{-3} kg	Air	
	CO	1.16×10^{-3} kg	Air	
	HCl	1.11×10^{-3} kg	Air	
	Vinyl chloride	1.98×10^{-7} kg	Air	
	Benzene	2.92×10^{-7} kg	Air	

[a]FU stands for functional unit, which is per tonne of MSW (wet basis) in this study.
[b]RSP refers to respiratory suspended particulates, with PM_{10} in this context.
[c]Pollutants are emitted to ambient air due to the ammonia stripping plant used to destroy the ammonia to nitrogen gas prior to releasing it to the atmosphere at the landfill leachate treatment plant.
[d]Raw leachate that is uncollected and leached into the groundwater. The composition of raw leachate is obtained from Kurniawan and Lo (2009).
[e]Raw leachate that is uncollected and leached into the groundwater. The composition of raw leachate is obtained from Lo (1996).
[f]Raw leachate that is collected and treated by the landfill leachate treatment system. The treated effluent is complied with Water Discharge License issued by HKEPD under Water Pollution Control Ordinance prior to discharging it to the marine water.
[g]Values shown are part of the Toxicity Characteristics Leaching Procedure (TCLP) control limit values as recommended by the HKEPD.
[h]N/A stands for "not available".

Table 2. Summary of data inventory for advanced incineration facility (Woon and Lo, 2014)

Sub-process	Compound	Quantity per FU[a]	Emission	Source
Waste transport	CO_2	1.30 kg	Air	DEFRA, 2011; Woon and Lo, 2013
	NO_x	2.07×10^{-2} kg	Air	HKEPD, 2011
	SO_2	1.98×10^{-4} kg	Air	
	RSP[b]	2.26×10^{-4} kg	Air	
Stack discharge system	CO_2	454 kg	Air	Woon and Lo, 2013
	NO_x	1.32 kg	Air	HKEPD, 2011
	SO_2	1.32 kg	Air	
	RSP[b]	1.98×10^{-1} kg	Air	
	CO	6.61×10^{-1} kg	Air	
	VOCs	1.32×10^{-1} kg	Air	
	HCl	3.97×10^{-1} kg	Air	
	HF	2.65×10^{-2} kg	Air	
	Total of 9 heavy metals[c]	3.31×10^{-3} kg	Air	
	Hg	3.31×10^{-4} kg	Air	
	Total cadmium & thallium	3.31×10^{-4} kg	Air	
	Dioxins & furans	6.60×10^{-10} kg	Air	
Desalination	Total suspended solids	9.12 kg	Water	HKEPD, 2011
	BOD_5	8.61×10^{-1} kg	Water	
	Total residual chlorine	5.07×10^{-1} kg	Water	
	Water consumption	0.51 m^3	N/A[e]	
Ash treatment and disposal	Dioxins & furans	1.30×10^{-8} kg[d]	Water	HKEPD, 2011
	Cd	1.30×10^{-4} kg[d]	Water	
	Cr	6.50×10^{-4} kg[d]	Water	
	Cu	3.25×10^{-3} kg[d]	Water	
	Ni	3.25×10^{-3} kg[d]	Water	
	Pb	6.50×10^{-4} kg[d]	Water	
	Zn	3.25×10^{-3} kg[d]	Water	
	Hg	1.30×10^{-5} kg[d]	Water	
	Sn	3.25×10^{-3} kg[d]	Water	
	Ag	6.50×10^{-4} kg[d]	Water	
	Sb	3.25×10^{-3} kg[d]	Water	
	As	6.50×10^{-4} kg[d]	Water	
	Be	1.30×10^{-4} kg[d]	Water	
	Ti	6.50×10^{-4} kg[d]	Water	
	V	3.25×10^{-3} kg[d]	Water	
	Se	1.30×10^{-5} kg[d]	Water	
	Ba	1.30×10^{-2} kg[d]	Water	
	Bottom ash	220 kg	Water	
	Fly ash and air pollution control residues	80 kg (after cementation)	Water	
Energy recovery system	Electricity generated	760 kWh	N/A[e]	HKEPD, 2010, Tchobanoglous and Keith, 2002
	Electricity consumption	228 kWh	N/A[e]	HKEMSD, 2002

[a]FU stands for functional unit, which is per tonne of MSW (wet basis) in this study.
[b]RSP refers to respiratory suspended particulates, with PM_{10} in this context.
[c]Including Sb, As, Pb, Co, Cr, Cu, Mn, V and Ni.
[d]Values shown are part of the Toxicity Characteristics Leaching Procedure (TCLP) control limit values as recommended by the HKEPD (2011).
[e]N/A stands for “not available”.

Life Cycle Impact Assessment and Life Cycle Interpretation

The collected LCA data are assessed using SimaPro 7.2.4 software with Eco-Indicator 99 (E) method. This method is chosen as it is one of the most widely used impact assessment methods for the implementation of LCA in MSW management (Cleary, 2009). Four mid-point impact categories, namely climate change, carcinogens, respiratory organics, and respiratory inorganics are selected for comparison in this study. These four impact categories are generally considered relevant for waste management studies.

Damage category provides an end-point outcome in the environmental evaluation for aggregating the chosen impact categories. In the Eco-indicator 99 (E), human health is defined as an environmental damage category, in which the four mid-point impact categories are classified under the human health. In this phase, the results of mid-point and end-point categories are analyzed, particularly focus on the rationale for explaining the results’ phenomena. By doing so, it helps to identify areas that are critical for the investigated waste management facilities and recommend area of improvements as appropriate. The results of human health (i.e., end-point category) obtained in this study are further integrated with the LCC results using a modified EEI.

Modeling of LCC Study

Categories of Life Cycle Costs and Benefits

In part two, major private and external costs relevant to the LFE and AIF 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. The functional monetary unit is defined as Hong Kong dollar per unit tonne of MSW being disposed of at the respective waste disposal facility (i.e., HKD/tonne MSW). The total life cycle cost per tonne of MSW is defined mathematically in Equation 1.

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

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).

Private Costs and Benefit

Private costs and benefit refer to the costs and benefit internal to the MSW disposal in LFE and AIF. In this study, the private costs consist of capital cost, operating cost, and transportation cost, while private benefit includes energy saving due to energy recovery system. The private costs and benefits, and key input parameters of proposed LFE and AIF are summarized in Table 3. The capital cost of the proposed LFE and AIF are annualized to 15 years. It is assumed that the demolition cost of the waste disposal facility at the end of the life cycle is equal to its residual value, so that the demolition cost can be neglected in this study (Dong et al., 2014). It is noted that there is no MSW charging fee being imposed on the public in Hong Kong. There is, however, an initiation for the HKSAR Government to launch the polluter-pays principle via the MSW charging scheme to the public in future.

Table 3. Summary of private cost/benefit and key input parameters for proposed LFE and AIF

Parameter	Unit	Value	Reference year[a]	Source
Landfill extension (LFE)				
Capital cost[b]	HKD	8,424 million	2014	LegCo, 2014a
Operating cost	HKD/year	260 million	2014	LegCo, 2014a
Transportation cost	HKD/tonne	200	2007	HKEPD, 2012
Energy saving benefit due to heat generation	HKD/MJ	0.219	2013	Towngas, 2013
Energy saving benefit due to electricity generation	HKD/kWh	0.891	2013	CLP, 2013
Heat generation	MJ/tonne	677	2013	HKEMSD, 2002
Electricity generation	kWh/tonne	15.7	2013	HKEMSD, 2002
Land area	ha	60	N/A[c]	HKEPD, 2009
Advanced incineration facility (AIF)				
Capital cost[d]	HKD	18,246 million	2014	LegCo, 2014b
Operating cost	HKD/year	402 million	2014	LegCo, 2014b
Transportation cost[e]	HKD/tonne	200	2007	HKEPD, 2012
Energy saving benefit due to electricity generation	HKD/kWh	0.891	2013	CLP, 2013
Electricity generation	kWh/tonne	760	2013	Tchobanoglous and Keith, 2002
Land area	ha	10	N/A[c]	HKEPD, 2011

[a]All private costs and benefits are discounted to year 2014 using a 4% discount rate.
[b]To provide a fair analysis between the proposed LFE and AIF, the MSW disposal rate and life span of the proposed LFE are assumed to be same as the proposed AIF. The capital cost of WENT LFE is calculated based on the average capital costs (HKD/m^3 void space) of SENT LFE and NENT LFE. By assuming a 3,000 tpd and 15-year operation, the void space of WENT LFE is 24 million m^3.
[c]N/A stands for not applicable.
[d]As the AIF is proposed to be built on an reclaimed site (artificial land) at Shek Kwu Chau Island, the capital cost includes costs for reclamation works, berths and breakwaters and submarine cables.
[e]It is assumed that the transportation cost of the AIF is same as the LFE due to similar transportation mode (by barges) and the small geographic area of Hong Kong.

External Costs and Benefit

Three main types of external costs associated with the environmental impacts of the waste disposal facilities are investigated. These include the opportunity cost of land, disamenity cost, and external environmental costs due to air pollution. The external benefit includes the external environmental benefit due to avoided air pollution from the power plant. Assumptions on the external costs and benefit are made through a detailed meta-analysis of the literature with reasonable justifications.

Opportunity Cost of Land

Land use is one of the major issues in coping with the sustainability management of MSW, especially in densely populated cities such as Hong Kong. By making the land available for MSW disposal, an opportunity cost is involved. The opportunity cost of land for the proposed LFE is estimated based on the sales comparison approach. It can be estimated by comparing the land characteristics with those of comparable land in Hong Kong. The proposed LFE is built near to an existing landfill, in which the land is considered sub-urban and suitable to be used for non-living activities (e.g., a recreational facility or an entertainment park). Therefore, the land premium cost of Disneyland in Hong Kong (i.e., 1.9 billion in year 1999) is the most representative example for evaluating the opportunity cost of land of the proposed LFE (LegCo, 2005).

As abovementioned, the AIF is planned to be built on a reclaimed site near the Shek Kwu Chau Island. If the AIF is not proposed, the reclaimed site will not be built; no opportunity cost of land is expected for the proposed AIF in this context. Nevertheless, it should be noted that the capital cost of the AIF includes costs for reclamation works, berths and breakwaters and submarine cables. The costs of reclamation works, berths and breakwaters and submarine cables are about HKD 5,000 million (LegCo, 2012).

Disamenity Cost

The disamenity impacts of waste disposal facilities refer to the local nuisance caused by noise, dust, odours, visual pollution, and the potential presence of vermin. To estimate the disamenity cost, housing unit price reduction is used. It is assumed that the housing properties located near landfills and incinerators would suffer a decline in their attractiveness, which all other things being equal would decrease the price of the properties. In this respect, the Hedonic Price Model (HPM) is a practically favoured approach to quantify disamenity cost. The housing unit price reduction is obtained through the detailed meta-study provided by Brisson and Pearce (1996), which is based on the regression of the HPM results from eleven studies. The findings of Brisson and Pearce (1996) were rather similar to the valuations conducted by Hite et al. (2001). A linear relationship is commonly formulated between the distance from a waste disposal site and the change in housing unit price. In this study, the percentage of housing unit price reduction for distances 3.2-4.8 km and 4.8-5.5 km away from the waste disposal facility are 5.2% and 1.4%, respectively.

The number of domestic households surrounding the waste disposal facility is obtained from 2011 Hong Kong population census (HKCSD, 2013). Based on the housing unit sale transaction records from January to December 2013 provided by the Hong Kong GoHome website, the average housing unit prices in the Tuen Mun district and Islands district (Cheung Chau Island) are HKD 2.95 million and HKD 2.22 million, respectively. Assuming that the lifespan of the housing unit is 30 years with a discount rate of 4%, the disamenity cost of the proposed LFE and AIF are 476.2 HKD/tonne MSW and 47.2 HKD/tonne MSW, respectively.

External Environmental Costs and Benefit due to Air Pollution

The external environmental costs include the global warming effect of the landfill gas and flue gas emission, major local air pollution from the LFE and AIF, and air damage due to the waste transport. Only the environmental externality due to air pollution is considered in this study as the waste emission to air is found to be the most significant, as reported by Woon and Lo (2014), for the proposed waste disposal facilities.

The external environmental costs of the air pollutants are calculated based on impact pathway analysis. To improve the representativeness of these external environmental values to Hong Kong, benefit transfer, an econometric tool for transferring the monetary values of environmental commodities from completed valuation studies in one place to a new different place (i.e., Hong Kong condition), is used for the economic valuation in this study (Silalertruksa et al., 2012). Wong et al. (2002) reported that air pollution has remarkably similar associations with daily cardiorespiratory admissions in both Hong Kong and London. Due to this circumstance, the external environmental values for Hong Kong are calculated by adjusting the reported external environmental values for the UK using gross domestic product (GDP) at purchasing power parity (PPP) per capita (as shown in Equation 2).

$$EC_{HK} = \frac{EC_{UK/EU} \times GDP\ (PPP)_{percapHK}}{GDP\ (PPP)_{percapUK/EU}} \tag{2}$$

where EC_{HK} = externality cost for Hong Kong (HKD/tonne); $EC_{UK/EU}$ = externality cost for the UK or EU (HKD/tonne); $GDP(PPP)_{percapHK}$ = gross domestic product at purchasing power parity per capita for Hong Kong (HKD/capita); $GDP(PPP)_{percapUK/EU}$ = gross domestic product at purchasing power parity per capita for the UK or EU (HKD/capita)

Table 4 shows a summary of the external environmental values of the air emission compounds. In the case of values for the UK are unavailable, the data from the EU is applied instead.

Table 4. Summary of external environmental values of air emission compound

Category	Air emission compound	Unit	Value	Year[e]	Value (HKD/tonne emission compound)[f,g]
Waste transport	CO_2	RMB/tonne	80[a]	2013	103
	NO_x	GBP/tonne	1,728[b]	2006	38,505
	SO_2	GBP/tonne	2,780[b]	2006	61,946
	RSP	GBP/tonne	91,618[b]	2006	2.04 million
Urban pollution	CO_2	RMB/tonne	80[a]	2013	103
	NO_x	GBP/tonne	955[b]	2010	18,190
	SO_2	GBP/tonne	1,633[b]	2010	31,105
	RSP	GBP/tonne	20,862[b]	2010	397,368
	Total of 9 heavy metals[d]	EUR/kg	228.2[c]	2005	3.37 million
	Mercury	EUR/kg	8,000[c]	2005	118 million
	Total cadmium & thallium	EUR/kg	39[c]	2005	576,781
	Dioxins & furans	EUR/kg	185 million[c]	2005	273.6 billion

[a]Since Hong Kong does not have its own carbon trading price, the carbon trading price is taken from the nearest region, which is based on Shenzhen Emissions Rights Exchange (Lunsford and Loh, 2012).
[b]External environmental values are developed by the United Kingdom Department of Environment, Food, and Rural Affairs (DEFRA, 2013).
[c]External environmental values are based on the average values from the EU (Rabl et al., 2008).
[d]Total 9 heavy metals include Sb, As, Pb, Co, Cr, Cu, Mn, V and Ni.
[e]All external environmental values are discounted to year 2014 using formula $F = P(1+i)^n$, where F = future worth, P = present worth, i = discount rate (4%), n = number of period (base year 2014).
[f]Currency exchange rate: HKD 1 to RMB 0.81; HKD 1 to GBP 0.085; HKD 1 to EUR 0.12.
[g]External environmental values for Hong Kong is calculated by adjusting the reported external environmental values for the United Kingdom and the European Union using gross domestic product (GDP) at purchasing power parity (PPP) per capita. GDP (PPP) in USD/capita at year 2013: Hong Kong – 53,216, UK – 38,452, EU – 42,679.

Integration of LCA and LCC Results using a Modified EEI

To execute the eco-efficiency of the proposed LFE and AIF, a modified EEI portfolio is developed in order to integrate the results of LCA (with a focus on human health category) and LCC by finding the relative impact of the economic aspect on the environmental perspective of the proposed LFE and AIF. The modified EEI portfolio is presented using a two-dimensional graph. The first dimension is calculated through the LCC index and the second one by the LCA impact index. When integrating the LCA with LCC, the external environmental costs and benefit are excluded from the LCC in order to avoid potential double counting. This is because the damage impacts due to air pollutants have been taken into account by the LCA (i.e., human health category) results of the proposed LFE and AIF.

Each part of this dimension can be expressed negatively or positively in a Cartesian coordinate system (i.e., a reduction or increase from the economic costs and an improvement or damage from the environmental aspects). Thus, one of the processes would serve as a reference or be the basis for calculating the percentage variation of both dimensions. By doing so, axis normalization can be avoided. All positive results indicate a worse situation than the reference; all negative results indicate better conditions than the reference. Taking the LFE as the reference point, the AIF is compared with the LFE by calculating the relative change in percentage of the LCA and LCC of the AIF to LFE.

RESULTS AND DISCUSSION

LCA Results of Proposed LFE and AIF

Figure 2 shows the relative percentage for the comparison of LFE and AIF from different impact and damage categories. Relative percentage (calculated by dividing the respective absolute value with the highest absolute value for that particular impact or damage category) is used to investigate the relative environmental burden between the LFE and AIF under studied impact and damage categories. Positive percentage indicates negative environmental performance from the waste disposal facility and vice versa for negative percentage. The absolute value is expressed in the unit of disability adjusted life year (DALY). It is a unit that is widely adopted by World Health Organization in the field of public health and health impact assessment, involving the combination of number of years lost due to disease, injury or early death.

As observed from Figure 2a, the LFE incurs 81.6% higher impact than the AIF in terms of climate change. For the LFE, the biological reactions at landfill cells contribute the highest burden on climate change. This is because not all landfill gas (with about 50% CH_4 and 50% CO_2 by volume) is collected for the energy recovery system and flaring process. The portion of the landfill gas that is uncollected and diffused from the surface of the landfill cells releases greenhouse gas (i.e., CH_4) to the atmosphere and provides an impact on climate change.

For the carcinogens, the AIF exhibits 54.2% higher burden as compared to the LFE, respectively. The sub-process of AIF that provides most burden on the carcinogens is ash treatment and disposal system (5.20×10^{-8} DALY), which contributes 67.7% for the overall category, while the remaining 32.3% is attributed by the stack discharge system (2.48×10^{-8} DALY). The substantial impact of the ash treatment and disposal system on carcinogenicity is primarily caused by the arsenic and cadmium from the incinerated ash being discarded in the landfill. To reduce the adverse impact of heavy metals on the carcinogenicity, post-combustion treatment process such as cement stabilization and solidification on fly ash can be developed to reduce its leachability property before landfill disposal. In addition, the treated ash can be used as material construction (e.g., aggregate in concrete) and for geotechnical application (e.g., road pavement) instead of landfilling. One of the caveats in this study is that Toxicity Characteristics Leaching Procedure (TCLP) limits are used to estimate the toxicity of incinerated ash being dumped in the landfills because existing data are not available for the proposed waste disposal facilities. This assumes a worst case scenario and they might not necessarily to reflect the actual potential for leaching from the same waste material in a sanitary landfill.

It is interesting to point out that the dioxins and furans released from the stack discharge system impose an insignificant burden (1.18×10^{-10} DALY or 0.48% of the total impact for the stack discharge system) in the carcinogens category. Therefore, it should not be a major public concern. With the application of strict process control of incineration (e.g., complete combustion) and incorporation of advanced flue gas treatment technology such as activated carbon injection, the adverse impact of dioxins and furans can be minimized.

The AIF performs more poorly than the LFE in view of respiratory organics, notably because of the release of volatile organic compounds from the stack discharge system during MSW combustion. For the respiratory inorganics, the LFE incurs 62.1% higher impact than the AIF on respiratory inorganics. NO_x is the emission compound contributing most to this impact category, which accounts for 67.9% (2.86×10^{-9} DALY) and 97.2% (3.48×10^{-9} DALY) for the flare system and leachate collection and treatment system (due to the ammonia stripping process) of the LFE, respectively. Nevertheless, the recovery of energy embedded in the waste stream credits a positive environmental impact (i.e., a negative value in the scale of impact category) with respect to the respiratory inorganics (due to RSP displaced from China Light & Power company), which lead to avoided damage values of -7.81×10^{-8} DALY and -2.84×10^{-7} DALY for LFE and AIF, respectively. Combining the results of four mid-point categories, the AIF is advantageous over the LFE from the standpoint of human health (i.e., end-point result) as demonstrated in Figure 2b. The AIF provides an environmental benefit on human health mainly due to the electricity generated from the energy recovery system, in which it displaces the electricity generated from the China Light & Power company (mainly generated by fossil fuel such as coal) and offsets the air pollutants emitted from the power plant. The offset of the air pollutants are higher than those air pollutants released from the AIF, thus contributing to a positive environmental performance on human health.

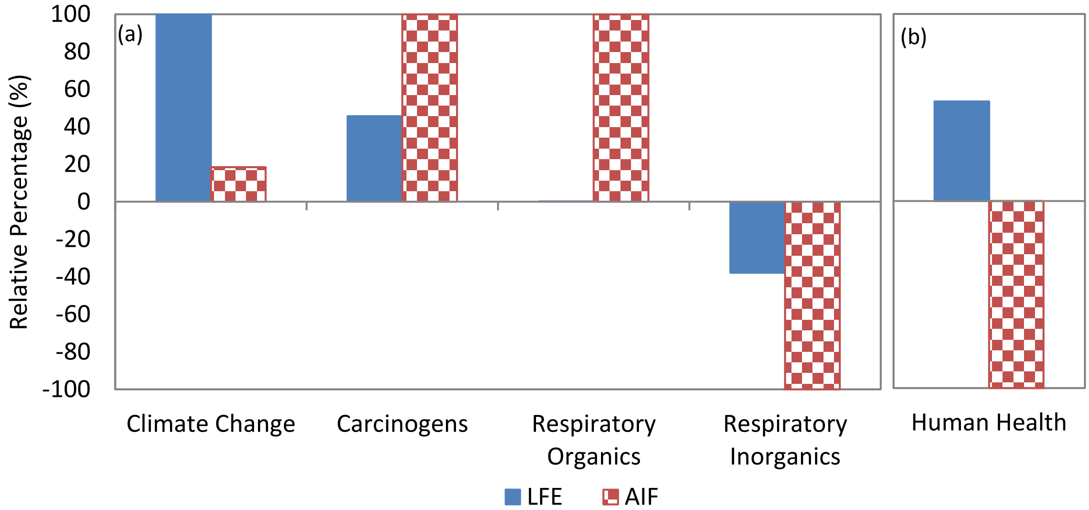

Figure 2. Relative percentages for comparison of LFE and AIF in (a) impact category (i.e., mid-point result); and (b) damage category (i.e., end-point result). Positive percentage indicates negative environmental performance from the waste disposal facility and vice versa for negative percentage

LCC Results of Proposed LFE and AIF

As shown in Table 5, the life cycle costs of AIF and LFE are 1619.2 HKD/tonne MSW and 1782.4 HKD/tonne MSW, respectively. The proposed AIF has a slightly lower life cycle cost (i.e., 163.2 HKD/tonne MSW or 9.2% lower) than the proposed LFE. For the proposed LFE, the capital cost incurs the highest economic burden (34.5%), followed by the disamenity cost (24.3%) and the opportunity cost of land (14.4%). In addition, the capital cost of the proposed AIF accounts for 60.2% of the total cost, contributing to the highest cost category. As abovementioned, the high capital cost includes the costs of reclamation works, berths and breakwaters and submarine cables that amount to about HKD 5,000 million, accounting for 27.5% of the total capital cost of the proposed AIF.

In view of the economic benefits, the energy recovery systems of the LFE and AIF provide huge advantages on the life cycle cost. Besides generating revenue for the waste disposal facility, the avoided pollutants emissions from the power plants provide external environmental benefits to the LFE and AIF. Valorisation of waste to energy is a promising technique to make revenue in the waste stream as well as to reduce the environmental impact. It promotes the waste-to-wealth concept and boosts the share of renewable energy for electricity generation in Hong Kong. Owing to the higher amount of electricity generated from the AIF, the recovery of energy for electricity generation in the AIF is more apparent than that of the LFE, creating about 4 times more economic benefits than the LFE. In addition, economic valuation of the cost-benefit analysis has indicated that the AIF is advantageous over the LFE, in which the cost-to-benefit ratio of the AIF and LFE are 2.88 and 10.94, respectively. This is mainly ascribed to the energy recovery system of the AIF, which produces more electricity and generates more economic benefits than that of the LFE.

It is worthwhile to note that by only considering the private costs, the LFE has a lower life cycle cost compared to the AIF (i.e., life cycle cost of the LFE is 520.7 HKD/tonne MSW or 20.9% lower than that of the AIF). On the contrary, with the inclusion of external costs, the result is reversed, in which the AIF is a more favourable alternative than the LFE. The findings signify the importance of including the external costs when evaluating the life cycle cost of a waste disposal facility. Considering the land scarcity issue and the close proximity to the Tuen Mun District in Hong Kong, the LFE is not that cost-effective relative to the AIF when the opportunity cost of land and disamenity cost are taken into consideration. As abovementioned, the AIF has no opportunity cost of land as it is built on a reclaimed site. In addition, since the proposed AIF is expected to be located on an artificial land near the Shek Kwu Chau Island, which is far from the residential areas, the disamenity cost of the AIF is thereby relatively lower as compared to the LFE. It should also be noted that the land used for positioning the AIF can be returned for beneficial use much sooner than the land used for LFE. Typically, post-closure management of landfills over a period of at least 30 years is required to avoid adverse effects on human health and the environment.

For the external environmental costs and benefit, there are mainly affected by different air pollutants from different sub-processes of the LFE and AIF. It is, therefore, of paramount importance for us to identify the major air pollutants and sub-processes of the waste disposal facility. The external environmental cost of the LFE is mainly contributed by the biological reactions at the landfill cells, particularly due to the CO_2e emission. The result is consistent with the findings reported by Jamasb and Nepal (2010), in which the price of carbon is important in assessing the desirability of various waste disposal options. It should be noted that the carbon price can vary significantly due to different regions and the volatility of the carbon price is high. Meanwhile, emission compounds such as SO_2 and RSP incur negative costs, providing external environmental benefits to the overall LFE. This is mainly due to the electricity generated by the energy recovery system in the LFE, which offsets the air pollutant emissions from the local power plant.

The external environmental cost of AIF is mainly contributed by the stack discharge system, mostly due to the emissions of RSP, followed by CO_2e and cadmium. Similar to the LFE, the avoided burdens from the energy recovery system incur a positive externality to the AIF. This is mainly attributed to the avoided emissions of CO_2e and RSP from the local power plant. Yet, only RSP contributes an external environmental benefit to the overall AIF. This is because the CO_2e emissions from the stack discharge system during the MSW combustion outweigh the avoided CO_2e due to electricity generation from the energy recovery system of the AIF.

Table 5. Summary of cost/benefit categories for proposed LFE and AIF

	Landfill extension (LFE)		Advanced incineration facility (AIF)	
	Value (HKD/tonne MSW)	Percentage (%)	Value (HKD/tonne MSW)	Percentage (%)
Private cost				
Capital cost	677.0	34.5	1494.9	60.2
Transportation cost	263.2	13.4	263.2	10.6
Operating cost	237.4	12.1	367.1	14.8
External cost				
Opportunity cost of land	281.8	14.4	0.0	0.0
Disamenity cost	476.2	24.3	47.2	1.9
External environmental cost	26.2	1.3	310.1	12.5
Total cost	1961.8	100	2482.5	100
Private benefit				
Energy saving due to energy recovery system	-169.2	94.4	-684.5	79.3
External benefit				
External environmental benefit	-10.1	5.6	-178.7	20.7
Total benefit	-179.3	100	-863.2	100
Life cycle cost	1782.4		1619.2	

Results of Integrated LCA and LCC Studies using a Modified EEI

As abovementioned, it is found that the proposed AIF has a lower human health impact as compared to the LFE for the LCA analysis (as shown in Figure 2b). A modified EEI portfolio is used to integrate the LCA (with a focus on human health category) and LCC results. The modified EEI portfolio can be divided into six categories as illustrated in Figure 3. All positive results indicate a worse situation than the reference; all negative results indicate better conditions than the reference. The fully eco-efficiency category indicates that the system has a lower life cycle environmental impact and lower life cycle cost as relative to the reference system. Taking the LFE as a reference system, it is observed that the proposed AIF falls under the fully eco-efficiency category (as shown in Figure 3), exhibiting that the proposed AIF has a lower LCA (with a focus on human health category) and a lower life cycle cost than the LFE. Besides investigating on the human health category, the human health category on the LCA index in the modified EEI can be replaced to other environmental damage categories (e.g., damage to the ecosystem quality or resources) for further evaluation.

A successful waste management policy should address the link between economic valuation and environmental assessment. Connecting the economic valuation with the environmental assessment is ultimately significant for policy-making purposes. The modified EEI is an exemplary indicator to explicitly explain the relative position of the comparison between the proposed LFE and AIF, with respect to LCA and LCC impact, which is substantially pivotal for investigating the environmental efficiency and economic valuation for investment on the proposed waste disposal facilities.

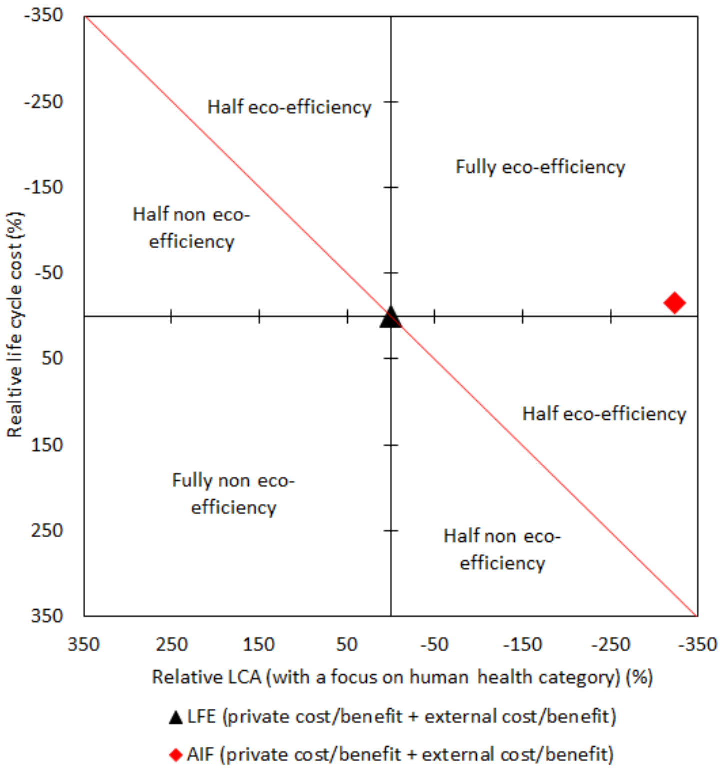

Figure 3. Modified eco-efficiency indicator portfolio of proposed LFE and AIF with respect to LCA (with a focus on human health category) and life cycle cost

CONCLUSIONS

On the basis of the data collected, assumptions made, and system boundaries defined in the LCA study, the mid-point results show that the AIF performs better than the LFE in view of climate change and respiratory inorganics, but vice versa for carcinogens and respiratory organics. Combining these four mid-point results which contribute to the human health category (i.e., end-point result), the AIF is advantageous over the LFE on this category. For the LCC results, the life cycle cost of the AIF is slightly better (i.e., 163.2 HKD/tonne MSW or 9.2% lower) than that of the LFE with the inclusion of private and external costs. However, the result is reversed if only private cost is considered, in which the LFE has a lower life cycle cost than the AIF. Based on the modified EEI portfolio, the AIF is more eco-efficient than the LFE with respect to LCA (with a focus on human health category) and LCC results. The findings in this paper identify major emission compounds and cost categories that provide most burdens to the proposed and funded waste disposal facilities, thereby facilitate improvements on the design criteria for the waste disposal facilities. It is hoped that the simultaneous evaluation of the environmental and economic aspects from a life cycle perspective can provide a sustainability approach to the MSW policy framework in Hong Kong, thus achieving more environmentally responsible and economically affordable behaviour in decision-making processes.

REFERENCES

Brisson, I., Pearce, D., 1996. Benefits Transfer for Disamenity from Waste Disposal. CSERGE working paper WM 95-06. UK.

Cleary, J., 2009. Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. Environ. Int. 35, 1256-1266.

CLP, China Light & Power, 2013. CLP Tariff Overview. Available from https://www.clponline.com.hk/myBusiness/CustomerService/TariffOverview/Pages/Default.aspx?lang=en (Accessed on 2013 October 12).

DEFRA (Department for Environment, Food and Rural Affairs), 2011. Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors.

DEFRA, Department for Environment, Food and Rural Affairs, 2013. Air Quality: Economic Analysis. Available from https://www.gov.uk/air-quality-economic-analysis#damage-costs-approach. (Accessed on 2014 February 14).

Dong, J., Chi, Y., Zou, D., Fu, C., Huang, Q., Ni, M., 2014. Energy–environment–economy assessment of waste management systems from a life cycle perspective: Model development and case study. Appl. Energy 114, 400-8.

Hite, D., Chern, W., Hitzhusen, F., Randall, A., 2001. Property-value impacts of an environmental disamenity: The case of landfills. J. Real. Estate. Financ. 22(2/3), 185–202.

HKCSD, Hong Kong Census and Statistics Department, 2013. 2011 Hong Kong Population Census. Available from http://www.census2011.gov.hk/en/index.html (accessed 2014 January 10).

HKEMSD, Hong Kong Electrical & Mechanical Services Department, 2002. Study on the Potential Applications of Renewable Energy in Hong Kong. Stage 1 Study Report.

HKEPD, Hong Kong Environmental Protection Department, 2005. A Policy Framework for the Management of Municipal Solid Waste (2005-2014)

HKEPD, Hong Kong Environmental Protection Department, 2009. West New Territories (WENT) Landfill Extensions Environmental Impact Assessment Report

HKEPD, Hong Kong Environmental Protection Department, 2011. Engineering Investigation and Environmental Studies for Integrated Waste Management Facilities Phase 1–Feasibility Study Environmental Impact Assessment Report

HKEPD, Hong Kong Environmental Protection Department, 2012. Hong Kong SAR Government Press Release: Waste Management Strategies. Available from http://www.info.gov.hk/gia/general/201204/25/P201204250243.htm (accessed on 2013 July 10).

HKEPD, Hong Kong Environmental Protection Department, 2014. Waste. Available from http://www.epd.gov.hk/epd/english/environmentinhk/waste/waste_maincontent.html (accessed 2014 December 10).

HKEPD, Hong Kong Environmental Protection Department, 2015. West New Territories (WENT) Landfill. Available from http://www.epd.gov.hk/epd/english/environmentinhk/waste/

prob_solutions/msw_went.html (accessed 2015 January 10).
HKPD, Hong Kong Planning Department, 2007. Hong Kong 2030 Planning Vision and Strategy: Economic and Financial Assessments Final Report. Hong Kong.
IPCC (Intergovernmental Panel on Climate Change), 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5. Waste.
ISO 14040, 2006. Environmental management - life cycle assessment principles and framework. International Standards Organization: Geneva.
ISO 14044, 2006. Environmental management - life cycle assessment - requirements and guidelines. International Standards Organization: Geneva.
Jamasb, T., Nepal, R., 2010. Issues and options in waste management: A social cost-benefit analysis of waste-to-energy in the UK. Resour. Conserv. Recy. 54, 1341-52.
Kurniawan, T.A., Lo, W., 2009. Removal of refractory compounds from stabilized landfill leachate using an integrated H_2O_2 oxidation and granular activated carbon (GAC) adsorption treatment. Water Res. 43, 4079-4091.
Lai, Y.K., July 14, 2013. Legislators, Residents Protest against Landfill Expansion Plan. South China Morning Post
LegCo, Legislative Council of Hong Kong, 2005. Panel on Economic Services. Background Brief on Hong Kong Disneyland. Report no. CB(1)1063/04-05. Hong Kong.
LegCo, Legislative Council of Hong Kong, 2012. Reduce, Recycle and Proper Waste Management. Report no. CB(1) 1628/11-12(01). Hong Kong
LegCo, Legislative Council of Hong Kong, 2014a. Environmental Infrastructure Projects. Report no. CB(1)931/13-14(01): Hong Kong.
LegCo, Legislative Council of Hong Kong, 2014b. Development of Integrated Waste Management Facilities Phase 1. Report no. PWSC(2014-15)7: Hong Kong.
Linkov, I., Seager, T.P., 2011. Coupling Multi-Criteria Decision Analysis, Life-Cycle Assessment, and Risk Assessment for Emerging Threats. Environ. Sci. Technol. 12, 5068-5074.
Lo, I.M.C., 1996. Characteristics and treatment of leachates from domestic landfills. Environ. Int. 22 (4), 433-442.
Lunsford, D., Loh, C., 2012. Hong Kong's Participation in the Carbon Intensity Reduction Activities and Carbon Trading Pilots in the Pearl River Delta region. Civic Exchange. Hong Kong.
Pratt, M., Dec 21, 2013. Incinerator Not the Answer to Hong Kong's Waste Problem. South China Morning Post
Rabl, A., Spadaro, J.V., Zoughaib, A., 2008. Environmental impacts and costs of solid waste: a comparison of landfill and incineration. Waste Manage. Res. 26, 147-62.
Silalertruksa, T., Bonnet, S., Gheewala, S.H., 2012. Life cycle costing and externalities of palm oil biodiesel in Thailand. J. Clean. Prod. 28, 225-32.
Tchobanoglous, G., Kreith, F., 2002. Handbook of Solid Waste Management, Second Edition; McGraw-Hill: New York. Chap 13, pp 13.7.
Towngas, 2013. Towngas Tariff. Available from https://www.towngas.com/Eng/Cust/Household /CustService/Tariff.aspx (Accessed on 2013 October 12).
Wong, C., Atkinson, R., Anderson, H., Hedley, A., Ma, S., Chau, P., Lam, T.H., 2002. A tale of two cities: Effects of air pollution on hospital admissions in Hong Kong and London compared. Environ. Health Perspect. 110, 67-77.
Woon, K.S., Lo, I.M.C., 2013. Greenhouse gas accounting of the proposed landfill extension and advanced incineration facility for municipal solid waste management in Hong Kong. Sci. Total Environ. 458, 499-507.
Woon, K.S., Lo, I.M.C., 2014. Analyzing environmental hotspots of proposed landfill extension and advanced incineration facility in Hong Kong using life cycle assessment. J. Clean. Prod. 75, 64-74.