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Incineration of municipal solid waste in Malaysia: Salient issues, policies and waste-to-energy initiatives

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Abstract

Municipal solid wastes (MSW) disposal and treatment essentially pose problems in many countries due to their voluminous characteristic. The customary means of MSW management is via landfill disposal but its dependency is gradually being limited by developed countries due to environmental concerns. Even though not apparent as it seems, Malaysia is gradually experiencing scarcity of available land for development. As such, the local government is currently looking into the possibility of employing high-end and large-scale incineration processes to address this issue. MSW as a combustion source for thermochemical conversion application, represents a two-pronged approach in solving its disposal dilemma as well as providing a source of energy fuel. This paper highlights the current issues and future directions as well as energy recovery initiatives associated with incineration of MSW in Malaysia. In Malaysia, energy recovery initiatives are focused on application of waste-to-energy (WTE) as well as refuse-derived fuel (RDF) technologies. Aspects regarding MSW landfill gas capture and energy generation are also discussed since they may directly influence (or potentially compete against) the widespread adoption of RDF technologies. A relatively successful RDF pilot plant in Malaysia is highlighted as a case study. It is deemed that application of large-scale incineration technologies in Malaysia is inevitable as opening of new landfill areas will ultimately cease in the future.

Keywords Energy recovery; incineration; Malaysia; municipal solid waste; refuse-derived fuel

1. Introduction

Malaysia occupies a total land area of 328,550 km^2 and is divided between Peninsular and East Malaysia. The country has a population of approximately 27 million and population density of 79.87 per km^2. Over the past 20 years, Malaysia has achieved remarkable economic growth which has brought about exponential population growth in addition to high influx of foreign workers. This has directly resulted in an increase in the amount of generated municipal solid waste (MSW). MSW is generated by households, commercial activities and other sources whose activities are similar to those of households and commercial enterprises, for example, wastes from offices, hotels, supermarkets, shops, schools, institutions, and from municipal services such as street cleaning and maintenance of recreational areas [1,2]. The average MSW generation is 0.5–0.8 kg/person/day while in urban areas, the figures have escalated to 1.7 kg/person/day with an average of 2500 tons collected every day for the city of Kuala Lumpur (capital of Malaysia) [3].

Waste management in Malaysia is the responsibility of the Ministry of Housing and Local Government under the purview of the local authority as stipulated in Section 72 of the *Local Government Act 1976* [4]. However, in order to facilitate handling of MSW through an integrated management system, Malaysia initiated privatization in 1993 in which four concessionaires were involved. These four concessionaires were *Alam Flora Sdn Bhd, Northern Waste Industries Sdn Bhd, Southern Waste Management Sdn Bhd* and *Eastern Waste Management Sdn Bhd*. These organizations are in charge of the collection and transportation of waste from residential and commercial sites to final disposal centers. Due to their inability to generate revenue and maintain operation efficiency, *Northern*

Waste Industries Sdn Bhd and *Eastern Waste Management* failed during their concession period and their contracts were terminated [5]. Therefore, only the other two concessionaires remain and currently in operation.

The traditional method of MSW disposal in Malaysia is via landfilling practices but its dependency is gradually being limited due to acute land shortage, aesthetic factors as well as pollution arising from odors and pests. Landfill is an area of land (normally derelict) where waste is deposited [2] and concentrated for up to 20 years before permanently 'sealed'. Due to the lack of emphasis on landfill management aspects, Malaysia is currently facing grave problems associated with landfill pollution and improper waste disposal practice; the latter is considered as one of the three main environmental problems faced by most municipalities, besides water and air pollution [5]. Recently, new problems from both active and closed landfills due to water source pollution have forced the government to form a special cabinet committee to propose a more comprehensive waste management structure for the country, especially within densely populated regions. One of the recommendations is incineration which acts as an alternative to landfill for MSW treatment [6]. This paper, therefore, highlights current salient issues and future direction as well as energy recovery initiatives related to incineration of MSW in Malaysia. The usage of Malaysian MSW as a combustion source for thermochemical conversion application represents a two-pronged approach in solving its disposal dilemma as well as providing a source of energy fuel (similar to local indigenous biomass) [7,8,9]. It should be noted that clinical waste incineration is precluded from this review and readers interested in such wastes are directed to a related report [10].

2. Composition of Malaysian MSW

The composition of MSW in Malaysia differs from one place to another. Among some of the factors that might influence the composition of MSW produced in a specific location are the extent of reduction, reuse and recycling (3R's) programs and also the duration of year [11]. The latest research data on composition of Malaysian MSW are given in Table 1. The main components of Malaysian MSW are food, paper and plastics, which make up approximately 80% of the waste by weight. The average moisture content of the MSW is about 55%, making incineration a challenging task [12,13]. Nonetheless, it should be noted that high percentages of combustible materials such as organics and paper may somewhat offset this concern. This is because organic materials are generally amenable to incineration since it destroys the organic fractions and convert them to CO_2 and water vapor [14]. A recent study indicates that typical Malaysian MSW have good potential for energy generation via incineration [15].

3. Current issues on incineration of MSW

The main rationale of using incineration technology for MSW management is to reduce the volume of the MSW by as much as 95%. In Malaysia, almost 99% of MSW management is via landfilling while incinerators have been used only on a very small scale basis [16]. Most MSW are currently disposed into poorly-managed "controlled tipping" systems with little or no pollution protection measures [17]. Many landfills in Malaysia are located within the vicinity of water bodies, i.e. Taman Beringin, Jinjang Utara, Kampung

Paka 1, Kampung Paka 2 and Sri Petaling [18]. In the year 2006, the highly-publicized landfill leachate contamination of the Klang Valley potable water source had led to the passing of the Solid Waste and Public Cleansing Management (SWPCM) Act 2007 [5,19]. As a result, non-sanitary landfills have been prohibited and currently being phased out while more stringent measures and practices are enforced on sanitary landfills. This will have an implication on the future of incineration technology in Malaysia since such direct restrictions on open and unsanitary dumping practices ultimately means relevant stakeholders will need to source alternative methods for prudent MSW management.

Incineration has been used on a small scale in the resort islands of Labuan, Langkawi, Pangkor, and Tioman since 1996. Fig. 1 shows a small-scale incineration system currently in operation in Pangkor island. MSW management at these touristy islands is under the jurisdiction of the local authorities. Tioman Island, a famous tourist attraction east of Peninsular Malaysia, presents a rather interesting case study in terms of MSW incineration. The Tioman Development Authority (TDA) is the local authority of Tioman Island responsible for collecting, transporting and incinerating solid waste. It subcontracts collection of solid waste to five local village heads and their village committees within the island. In the year 2001, a total of 3221 tonnes MSW per year was incinerated using the island's two 3-tonne incinerators [20]. However, the use of these incinerators has been discontinued recently due to the high cost of operation arising from the high moisture content of the waste, which contributed to high fuel costs and poor technical expertise in maintaining the incinerators. As a consequence, it has become a challenge to find an incineration technology that is capable of incinerating wastes with high moisture content accompanied by a low calorific value and at the same time operates at a low cost in comparison to the relatively cheap landfilling method [6].

Generally, the cost of landfilling is lower than the cost of incineration but over the years, environmental specialists have proven that landfills generated more net CO_2 emissions and incineration of the waste coupled with recycling and recovery of energy reduces the emission while saving cost of energy production through fossil fuel [21]. In Malaysia, prior to construction and installation of incinerators, an Environmental Impact Assessment (EIA) report must be produced and subsequently approved. In addition, the Department of Environment (DOE), Malaysia, may impose requirement of air pollution control systems and other operating conditions [22]. Once the installation process is approved, operation of the installed incinerator must comply with the imposed dioxin/furan emission limit of 0.1 ng-TEQ/Nm^3 listed under the *Environmental Quality (Dioxin and Furan) Regulations 2004*.

4. Large-scale and centralized incineration system

Since 2000, the Malaysian government as well as solid waste management experts have suggested the construction of a centralized and high-scale incineration system to assist in alleviating the huge volume of MSW in urban areas. However, this proposal faced many challenges such as unsuitability of available technology for incineration of local wastes, unfavorable representation of incineration technology in the media and protest by local residents. The last challenge is particularly significant as pressures from various non-governmental organizations have stagnated efforts to build a large-scale incinerator. The opposition of incineration has been based on both technical and socio-economics arguments which involve health risks associated with the emissions of toxic organic compounds and metals from stack, complications caused by disposal of inorganic residue and difficulty of monitoring facilities after the preliminary test burns have been conducted [23]. Other challenge faced by the incineration industry is to meet the very stringent emission standards as compared to other combustion devices. This is evident from the development of various control measures applied internationally to safeguard the public health as well as the environment [23]. Currently, an environmental emission standard for incineration processes in Malaysia is virtually non-existent. The Department of Environment, Malaysia, however, adopted a certain benchmark in line with international standards, e.g. United States Environmental Protection Agency (USEPA). However, proponents of incineration processes argue that toxic emissions from such processes (dioxin and furan) are significantly lower in concentrations compared to other processes which are deemed safe (for example, sewage processes). Many proponents also added that many developed countries such as Japan have been using incineration technologies in urban areas for decades.

4.1 Broga incinerator project

A very high-profile case that concerns the incineration of MSW in Malaysia is the proposed and subsequent scrapping of the controversial Broga incinerator project [24]. This proposed 1500-ton incinerator project, if built, will become one of the biggest incinerators in Asia. It was to be built by a consortium consisting of an overseas contractor and a local industrial partner and the proposed site was located near a university and water catchment area as well as surrounded by vegetable farms, palm oil and fruit plantations [25]. Due to a highly publicized public outcry as well as high capital expenditure (approximately USD400 million) and maintenance costs, it was subsequently scrapped. In the past few years, there have been many more proposals to install incinerator plants in Kuala Lumpur, Selangor, Kuantan, Cameron Highlands, Penang and other major towns in the country [24].

5. Energy recovery from incineration of MSW

5.1 *Small Renewable Energy Power* Program

Renewable energy has been a focus of Malaysia since 2001 which aims to lessen her dependence on fossil fuels. A premier policy mechanism called *Small Renewable Energy Power* (SREP) program was implemented by the national government to promote small-scale renewable electricity in Malaysia from 2001 to 2010 [25,26]. One of SREP's main objectives was to promote Malaysia's *Fifth Fuel Policy* of diversifying from oil, gas, coal, and conventional hydroelectricity into alternative renewable energy sources such as biomass, biogas, municipal solid waste, solar, and mini-hydroelectricity and achieving 5 % of national electricity supply from renewable resources by 2005 [27]. This program was not a success, though it did churn out a few viable renewable energy initiatives such as incineration of MSW and landfill gas capture (the former will be further discussed as follows).

5.2 Refuse-derived fuel

Energy recovery from incineration of MSW has been practiced in many developed nations since several decades ago in an effort to promote sustainable development initiatives. Table 2 lists the various treatment technologies capable of recovering energy from MSW. It is obvious that incineration-based technologies produce high amount of recoverable energy which is comparable, if not more than other technologies such as anaerobic digestion. In Malaysia, energy recovery initiatives are focused on application of waste-to-energy (WTE) as well as refuse-derived fuel (RDF) technologies. It is important to note that RDF is basically a specialized subset of WTE technology in which the latter requires more pre-processing steps prior to actual incineration. Fig. 2 shows the general process flow of a typical RDF plant. There are four main processing steps associated with an RDF process, namely, physical separation of incombustible materials, drying of MSW, size reduction and palletizing. The main rationale for palletizing MSW is to ensure size homogeneity, facilitate handling and combustion of MSW.

5.3 Case study: *Core Competencies Sdn Bhd* RDF pilot plant in Semenyih, Selangor, Malaysia

A Malaysian company, *Core Competencies Sdn Bhd* (CCSB) owns Malaysia's first RDF pilot plant in Semenyih, Selangor, Malaysia. The plant was commissioned in 2008, and currently processes 700 tons of waste per day with generation of 8.0 MW of electricity, although it should be noted that its maximum rated capacity is 1,000 tons of MSW per day and 8.9 MW of electricity generation [27]. The facility employs in excess of 200 people and exports approximately 5 MW to the national grid. The power plant is comprised of a single 8.9-MW extraction condensing turbine generator set (equipped with a water-cooled condenser and a fan-mounted induced draft cooling tower) and a steam generator of 55 tons maximum continuous rating for combustion of RDF [28]. A boiler operates at around 46 tons per hour (tph) load and delivers 38 tons of steam to the turbine and 8 tons to the process plant at 338 pounds per square inch absolute pressure through a pressure-reducing valve for hot air generation in the waste-drying system by secondary heat exchanger [28].

This particular facility is unique whereby its development came about from a technological link-up between CCSB, Malaysian Institute for Malaysia Nuclear Agency (a governmental research agency) and Universiti Putra Malaysia (an academic institution) in which the three organizations collaborate in the area of emission monitoring and RDF pellets development for industrial and commercial usage. Another advantage afforded by this facility is its capability of incorporating visual, mechanical and magnetic sorting of MSW to ensure that only materials with high caloric value are combusted [27]. This benefit is made more apparent in light of the highly heterogeneous Malaysian MSW which contain high organic content. It is, nonetheless, important to point out, that its combustion process is not carbon neutral; incineration of one ton of municipal waste produces about one ton of carbon dioxide albeit this quantity is much less than if waste was left to degrade in an open landfill [27].

5.4 MSW landfill gas capture and energy generation in Malaysia

On a separate but not totally unrelated aspect, there is the possibility of utilizing MSW landfill gas for low-cost energy generation in Malaysia even though the amount of energy generated may not be substantial. At MSW landfills, organic waste is essentially decomposed by microbes into carbon dioxide and methane gas of which the latter can be flared or converted into useful energy. There are two good examples of such initiatives in Malaysia; Bukit Tagar and Air Hitam sanitary landfills located in Hulu Selangor and Puchong, respectively. In the case of the former, approximately 3,600 m^3/hr of landfill gas (60% methane) is captured to generate power through a 1-MW gas engine while unused methane is destroyed using flares [27]. For the Air Hitam sanitary landfill, its gas contains about 55% methane and its generated 2 MW energy is transported to the national grid [25].

Overall estimates on the generation of MSW landfill gas in Malaysia have been recently reported [29, 30] by using on the Intergovernmental Panel on Climate Change (IPCC) methodology [31]. The results of these estimates are presented in Figs. 4 and 5. The relatively high methane generations from landfills in Selangor (60,370 tonnes) and Kuala Lumpur (45,500) in year 2010 [29] are not surprising given the very high household food and commercial products consumption in these two highly urbanized states. An interesting fact is that the equivalent electricity generation in 2010 alone is *ca* 2.20×10^9 kWh which is estimated to be about 1.5% of the total Malaysia energy requirement [30, 32]. In addition, it can be clearly seen that the estimated methane emission and its corresponding equivalent electricity generation undergo rapid increases year after year which are projected to culminate to 371,696 tonnes and 2.63×10^9 kWh, respectively, in 2020. These figures evidently point to the significance of this type of energy in the future which may directly affect (or compete against) the use of RDF as a prominent type of alternative/renewable energy in Malaysia.

6. Future directions on incineration of MSW

It can be said that utilization of more incinerators, be it small- or large-scale in Malaysia, is inevitable in the future. The Prime Minister of Malaysia, Dato' Seri Najib Tun Razak (who chairs a cabinet committee on solid waste management) indicated in 2007 that incinerators or a cluster of incineration plants would be built in the near future, regardless of public opposition [33]. The gazetted SWPCM Act 2007 permits a centralized and coordinated solid waste management by the Federal Government. The Act allows for more 3R (reuse, reduce and recycle) initiatives to be implemented via mandatory garbage sorting requirement, deposit refund scheme and take-back system. As such, it may have a direct bearing on the future directions on incineration of MSW and its subsidiary energy.

With this recent turn of events, the local as well as foreign industrial backdrop will be affected in one way or the other. This may result in more service procurement of contractors and foreign incineration experts since local expertise is relatively lacking. Nonetheless, this may also have a positive impact on local sustainability initiatives in terms of recycling of solid wastes and waste energy generation. Since there are costs associated with incineration processes and if landfilling option is not available, recycling may be a more economically viable option. Yunus [23] proposed an Integrated Waste Management approach that considers a combination of recycling initiatives, biological treatment, direct landfilling as well as incineration which may be significant for the future of solid waste management in Malaysia.

For the case of small incinerators located within the aforesaid tourist islands, there are already several key economic instruments recommended by the Economic Planning Unit (EPU) aimed at improving their MSW management. These recommendations, if implemented, will directly affect application of incinerators. The recommendations include (1) application of tourist eco tax on island visitors; (2) application of consumption tax on goods; (3) application of assessment tax on commercial establishments; (4) application of recycling subsidy; and (4) application of waste disposal charge [20]. The general concept of these key economic instruments is illustrated in Fig. 5. These applications, if successfully implemented, would lessen the reliance on small incinerators in the future.

7. Conclusions

It is deemed that application of large-scale incineration technologies in Malaysia is inevitable as opening of new landfill areas will ultimately cease in the near future. It is apparent that both the proponents and opponents of such technology have merits in their own interpretations and arguments. It is therefore, vital to take into account both side of the arguments before formulating a holistic action plan on development and erection of any incineration plant. The issue of the technical and financial viabilities of future waste-to-energy incineration systems remains very much significant as renewable energy generation in Malaysia gathers pace. It is crucial that proposed incineration plants be appropriately managed by an efficient organization and with proper budget allocated. The existing pilot RDF plant is a step forward to a more efficient, safe and larger-scaled MSW incineration processes. Nonetheless, plants with lower capacities at 300–500 tons/day using rotary kiln or fluidized bed technologies should also be given due consideration by relevant authorities in gaining public acceptance as solid waste thermal treatment methods. One can allay the fears of the public by proper promotion of the technology and education through the local media. Through these media, sufficient proof of safety of incineration technologies should be highlighted.

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Figure captions

Fig. 1. Small-scale incinerator in Pangkor Island, Malaysia (operated by XCN Technology Sdn Bhd). (a) Incineration system; (b) scrubber system; (c) shredder (Photos courtesy of XCNT Sdn Bhd).

Fig. 2. Process flow of a typical RDF plant.

Fig. 3. Estimated methane emission from several states in Malaysia – year 2010 [29].

Fig. 4. Estimated methane emission and equivalent electricity generation from landfill gas in Malaysia (1997-2020) [30].

Fig. 5. General concept of key economic instruments for improving MSW management at Malaysian tourist islands [18].

Table 1. Composition of MSW [6].

Composition	Percentage (%)
Organics	46.94
Plastics	20.28
Paper	17.89
Metals	4.31
Glass	2.60
Inorganics	0.17
Others	7.81

Table 2. Recoverable energy from MSW by various treatment technologies (adapted from [21]).

Treatment technology	Calorific value of fuel	Recoverable energy [a] (kWh)
WTE Incineration (25%)	2,200 kcal/kg	639
MSW to RDF – (30 %) and WTE incineration (25%)	3,500 kcal/g	305
MSW to anaerobic digester (60%), biogas to energy (25%)	5,000 kcal/m^3	131
MSW to anaerobic digester (60%), biogas to steam energy (80%)	5,000 kcal/m^3	418

[a] normalized to per ton of MSW input

Fig. 1.

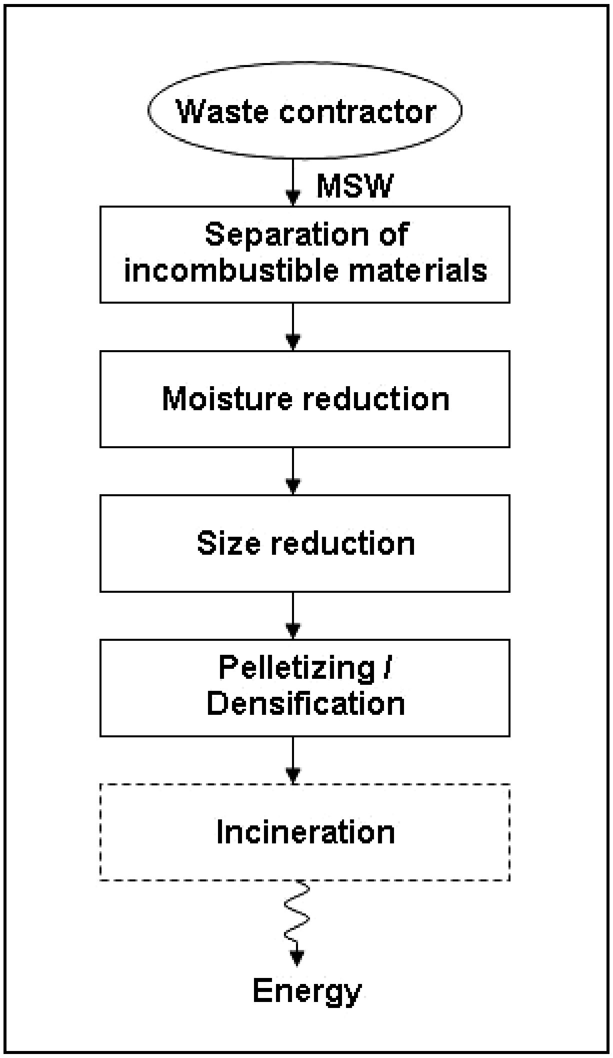
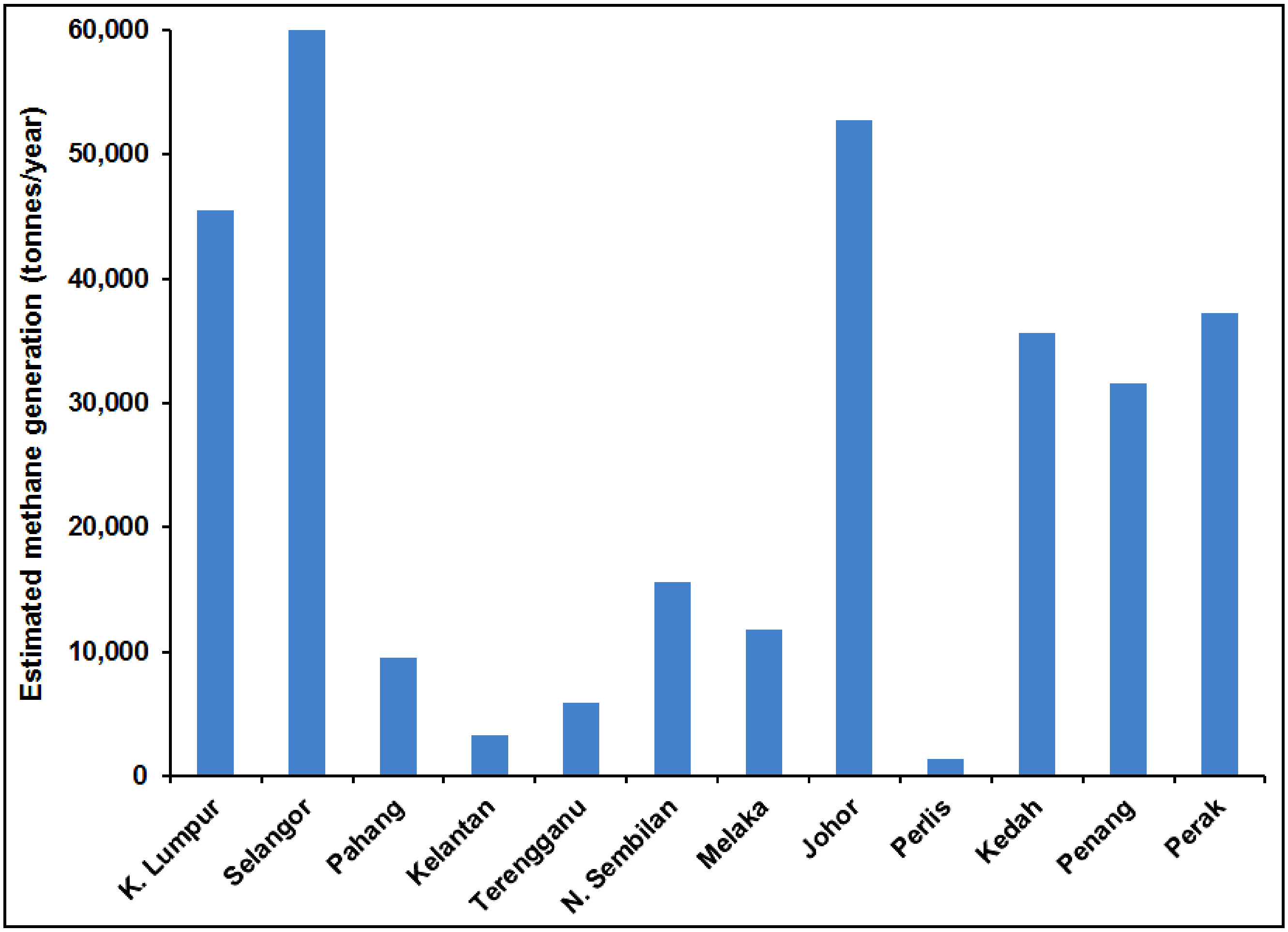
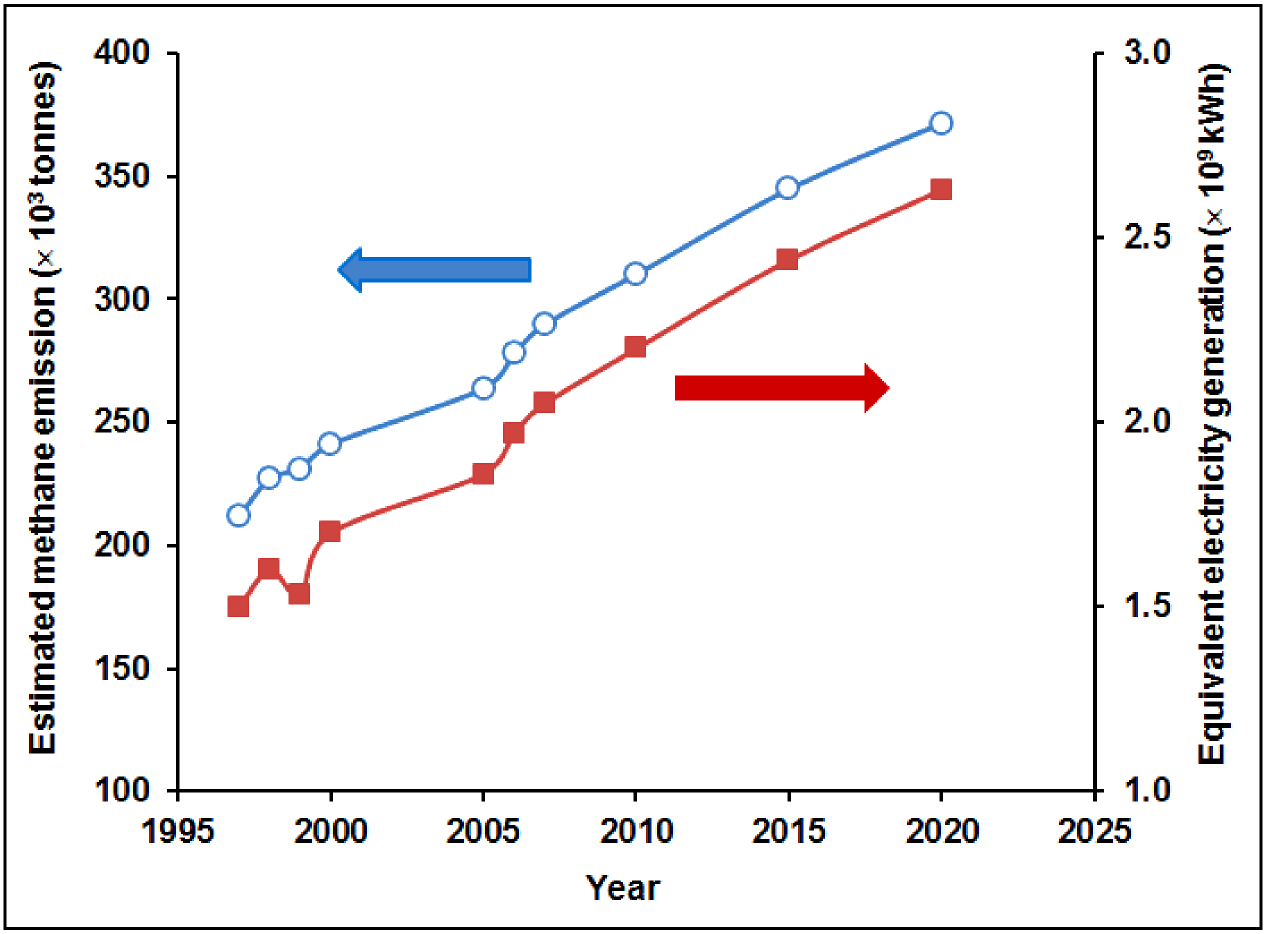

Waste contractor
MSW
Separation of incombustible materials
Moisture reduction
Size reduction
Pelletizing / Densification
Incineration
Energy

Fig. 2.



Estimated methane generation (tonnes/year)
60,000
50,000
40,000
30,000
20,000
10,000
0
K. Lumpur
Selangor
Pahang
Kelantan
Terengganu
N. Sembilan
Melaka
Johor
Perlis
Kedah
Penang
Perak

Fig. 3.



400
350
300
250
200
150
100
Estimated methane emission (× 10³ tonnes)
3.0
2.5
2.0
1.5
1.0
Equivalent electricity generation (× 10⁹ kWh)
1995
2000
2005
2010
2015
2020
2025
Year

Fig. 4.

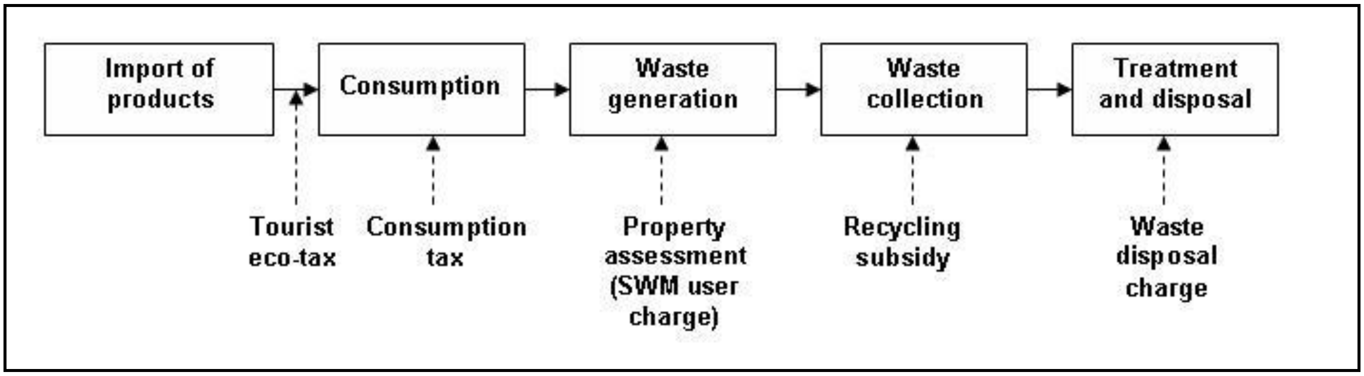

Import of products
Consumption
Waste generation
Waste collection
Treatment and disposal
Tourist eco-tax
Consumption tax
Property assessment (SWM user charge)
Recycling subsidy
Waste disposal charge

Fig. 5.