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Optimal Planning of Waste-to-Energy through Mixed Integer Linear Programming

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Abstract**—**Rapid economic development and population growth in Malaysia had accelerated the generation of solid waste. This issue gives pressure for effective management of municipal solid waste (MSW) to take place in Malaysia due to the increased cost of landfill. This paper discusses optimal planning of waste-to-energy (WTE) using a combinatorial simulation and optimization model through mixed integer linear programming (MILP) approach. The proposed multi-period model is tested in Iskandar Malaysia (IM) as case study for a period of 12 years (2011 -2025) to illustrate the economic potential and tradeoffs involved in this study. In this paper, 3 scenarios have been used to demonstrate the applicability of the model: (1) Incineration scenario (2) Landfill scenario (3) Optimal scenario. The model revealed that the minimum cost of electricity generation from 9,995,855 tonnes of MSW is estimated as USD 387million with a total electricity generation of 50MW /yr in the optimal scenario.

Keywords**—**Mixed Integer Linear Programming (MILP), optimization, solid waste management (SWM), Waste-to-energy (WTE).

I. INTRODUCTION

THE rapid generation of solid waste due to economic development and population growth forces the management of municipal solid waste (MSW) to be one of Malaysia's most critical environmental issues. The amount of solid waste generated in Malaysia increased from 16,200 t/day in year 2001 to 19,100 t/day in year 2005 with an average of 0.8 kg/capita/d [1]. Due to population growth, it is estimated that the daily solid waste generated will be 31,000 t/day by 2020 in Malaysia [2]-[6]. The composition of MSW in Malaysia is dominated by organic waste (food waste, 44.8%), followed by paper (16%), plastics (15%) and wood and garden waste (6.7%). Other categories of solid waste such as metals, textile and glass contributed to approximately 3% each [7].

The present municipal solid waste management (MSWM) method in Malaysia is very depending on landfilling as only 5.5% of the MSW is recycled and 1.0% is composted while the remaining 94.5% of MSW is disposed on landfilling site [7]. Landfilling is the simplest technique to handle waste in large quantity. Nevertheless, the degradation of valuable land resources and the creation of long-term environmental and human health problems arise as a result of ineffective management of waste. Sustainable and more capable waste treatment solutions are needed to reduce or replace the reliance on landfill. Among the various types of waste treatment methods, WTE is recognized as a promising alternative to overcome the waste generation problem as well as a potential source for renewable energy (RE) [8]-[11]. WTE is considered as an important and crucial factor for successful waste management as the concept includes all three factors for sustainable development: economy, environment, and social [12]. Moreover, in the waste management hierarchy, WTE has higher priority for the recovery of resources prior to the ultimate waste disposal in landfill [13], as shown in Fig. 1.

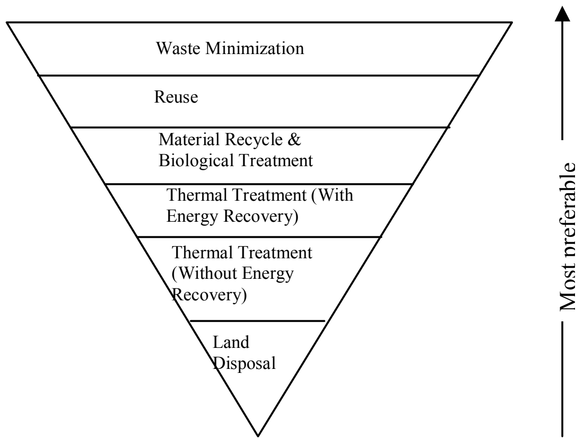

Fig. 1 Waste management hierarchy [13]

There are several existing methods for converting MSW to energy [14]. MSW can be converted to energy through thermal conversion of direct combustion, gasification, or pyrolysis; biological conversion through anaerobic digestion and fermentation; chemical conversion of etherification and non-thermal conversion through landfill gas recovery system (LFGRS). Some of them have been commercialized at large scale. However, their economic feasibility is highly dependent on local conditions such as the quantity of waste generated and composition, heat and power demand, presence of recycling services, incentive for the implementation and cost involved [15]. Malaysian Government has promoted the generation of RE since 2001 under the 8th Malaysia Plan. The

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latest 10th Malaysia Plan has targeted to increase the share of RE for up to 11% (2080 MW) in its energy mix by 2020. RE from MSW is one of the promising options to achieve the target [41].

In response to this concern, the development of an effective and sustainable WTE model, considering the Malaysian specific condition that would satisfy both the economic and environmental viabilities, is essential for decision making. This paper examines the feasibility of two WTE alternatives in Malaysia, incineration and LFGRS to fulfill the targeted demand for RE. A two-stage simulation and optimization model, developed through mixed integer linear programming (MILP), is able to simulate waste related data and generate an optimal cost effective solution for the MSWM. The MILP model was tested in Iskandar Malaysia (IM). Section II reviews the current status of the two WTE options in Malaysia and the existing mathematical models for WTE. Section III presents the methodologies for the novel simulation and optimization of the MILP model developed in this study. The results and findings of the study are presented and discussed in section IV.

II. Review on WTE Technologies

A. Waste Incineration

Direct incineration of waste is the primary approach of waste treatment technology that converts biomass to electricity which allows large volume reduction of MSW. The waste feedstock consists of combustible waste materials which are combusted under high temperature with excess of oxygen in a furnace or boiler. Waste material is converted into incinerator bottom ash, flue gases, particulates and heat. The heat is then converted through the Rankine cycle in the steam turbine to generate electric power [16]. The first waste incinerator facility was built more than a century ago (1874) in Nottingham, United Kingdom by Manlove, Alliott & Co. Ltd to eliminate the increased amount of waste [17]. Various types of incinerators are currently being commercialized. The choice of incineration technology depends on the combustibility and characteristic of the wastes as liquid, sludge or solid.

Five incineration plants are currently running in Malaysia as shown in Table I. The incinerators are mostly installed in the islands and hill resorts where the areas are not suitable for landfill, i.e. Pangkor Island, Tioman Island, Labuan Island and Langkawi Island [18]. Challenges remained for the existing incinerators where many units require improvements as the moisture content of waste in Malaysia is rather high (80-85%) [19]. Concern about the incineration process emitting harmful pollutants like heavy metals, mercury, and other hazardous compounds such as dioxin, hydrochloric acid (HCl), nitrogen oxide (NOx) and sulphur oxide (SOx) [2] hindered the intensive commercialization of the incineration technology.

TABLE I
Incineration Plants in Malaysia [18]

No.	Location	Capacity (t/d)
1	Pangkor Island, Perak	20
2	Langkawi Island, Kedah	100
3	Tioman Island, Pahang	15
4	Cameron Highlands, Pahang	40
5.	Semenyih, Selangor	1000

B. Landfill Gas Recovery System (LFGRS)

As the process of incineration could create air pollution problems, green energy generation from LFG is increasingly gaining attention. LFGRS can reduce the emission of greenhouse gases (GHG) from the landfill sites as the Intergovernmental Panel on Climate Change (IPCC) identified the landfill as the major source of methane (CH_4) emission. 47% of the total CH4 emission in Malaysia is from the landfill sites as illustrated in Fig. 2.

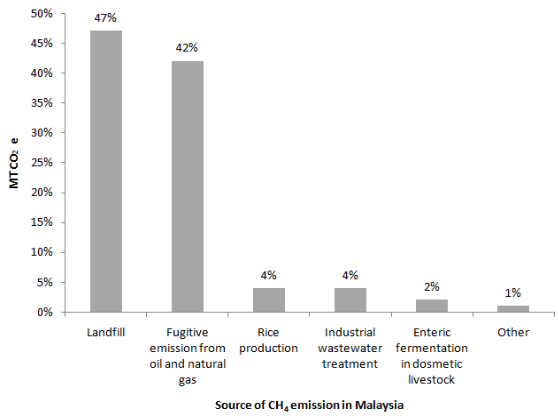

Fig. 2 Major source of CH_4 emission in Malaysia [20]

Most of the landfill sites in Malaysia involve small scales operational, controlled or uncontrolled open dumps with very minimum or no environmental control [21]. Until 2007, there are about 291landfill sites in Malaysia, however only 3% of the landfills sites in Malaysia are sanitary landfills. The high dependence on landfill as the main waste treatment in Malaysia encourages LFGRS to be implemented in the landfill sites as it reduces environmental problems such as GHG emission and river pollution due to leachate discharged [6]. Malaysian government has put effort to promote LFGRS power plant and generation of other RE under the Small Renewable Energy Project (SREP) [23]. Up to date, there are four LFGRS power plants in Malaysia; the basic information for the plants is summarized in Table II. The last two plants do not generate electricity [6], [22].

TABLE II
LANDFILL GAS RECOVERY SYSTEM (LFGRS) IN MALAYSIA [6],[22]

Location	State	Utilization
Bukit Tagar	Kuala Lumpur	Electricity generation for own consumption and sale
Seelong	Johor	Electricity generation for own consumption and sale
Terman Beringin	Kuala Lumpur	Combustion with generation of heat to evaporate leachate
Kampung Kelichap	Johor	Combustion with generation of heat to evaporate leachate

The first grid connected to RE facility in Malaysia was commissioned at Air Hitam Sanitary Landfill (AHSL) in year 2004 with an actual capacity of processing 7 million tonnes of MSW yet only 1.61 million tonnes of waste was in place and generated 2 MW electricity [22]. The plant was designed to generate electricity for 20 years with a processing rate of 40m^3 LFG/h but it fails to operate since year 2007 due to technical problems [6],[22].

C. WTE Models

Optimization approach for waste management have been developed since late 1960s with the overall objective to assist the decision making process in waste management for selection of the most cost efficient and environmentally sound approach under a specific scenario [24]. On the other hand, the optimization models can also be categorized based on the objectives of the optimization including transportation of waste, waste generation modeling and selection of waste treatment technology.

Previous studies have reported the optimal use of waste to recover energy in term of economic and environmental feasibility. Several models were developed to study the incineration and the potential of LFG energy recovery, cost, and emission evaluation. The methodology applied for energy models normally involve simulation and optimization methodologies through different mathematical approaches such as linear programming (LP), mixed integer linear programming (MILP), and dynamic programming [25].

A number of studies were carried out previously to investigate the optimal solution for waste treatment from different methods of waste disposal and processing, including energy recovery as the options. For example, [26] presented a LP model to study the refuse-to-energy facility planning by considering the refuse availability and cost. A LP model developed by [27] aimed to optimize the energy demands using RE source for Greece. A series of models were also developed to optimize the use of energy including the energy recovery from MSW as energy source for Greece. Reference [28] and [29] presented different strategies for their exploitation, while [30] proposed an integrated municipal energy supply system.

Reference [31] developed a short-term waste management strategy based on cost, energy, material recovery, and throughput requirements using pre-sorting process as a tuning tool for solid waste management. Their model was able to evaluate the amount of waste needed to be processed by the centralizing pre-sorting facilities to meet their objectives for the targeted incinerators. The estimation of this inflow rate to the incinerator was affected by the waste generation rates, physical and chemical compositions and heating value of the waste materials. However, the model did not take into account the environmental and technical aspects such as GHG emissions, sizing and capacity of treatment plants which are rather important nowadays. Reference [32] established a model with technical, normative and environmental impacts, particularly addressing the emission from the incineration process in their decision support system (DSS). Their methodology contributed to the development and integration of incineration, disposal, treatment and recycling programs. The only shortcomings that aroused from their research were that optimization of dioxin emissions or leachates produced in the landfills were neglected even though it had significant impact on the environment and public health. Reference [33] and [34] also conducted a similar study on WTE plants and the energy production systems; however, there is still lack of in-depth study on the integrated energy system that defines the remaining energy source for the MSW participating in the electricity generation process.

Although there are various WTE model designed by researchers, it can be inferred from the literature that no single method in isolation is specially designed for Malaysia case which can solve the problem of WTE in terms comprehensiveness of integrated waste management and mitigation of GHG emission. Therefore, this study aims to investigate the feasibility of WTE in Malaysia, notably through incineration and LFG technologies, using computer modeling and optimization approach that addressed the issues as mentioned.

III. MODEL FORMULATION

Mixed Integer Linear Programming (MILP) model was selected as the optimization model for WTE in this study due to simplicity and commonly in use. This model consists of two WTE options which are: LFGRS and incineration of waste. The objective of the study is to develop a simulation and optimization model of WTE system considering the real scenario in Malaysia. The WTE System is able to simulate the potential energy generation from the LFG and incineration power plants and to determine the best options for the WTE system by minimizing the electricity generation cost and to satisfy the nominal electricity. The cost considered for the plants under this model includes the capital cost, fixed and variable cost, and operation and maintenance cost (O & M). The model is then computed using Generalized Algebraic Modeling System (GAMS), a computer software for model simulation and optimization.

A. Simulation Model for Energy Production from MSW

The energy content of the waste is calculated by the Modified Dulong's Equation (MDE) [16] as shown in (1).

$$Energy\ content = 33801(C) + 144156[(H_2) - \{0.125(O_2) + 9413(S)\} - 2445] / 1000 \quad (1)$$

where, C, H_2, O_2, and S represent the weights of carbon, hydrogen, oxygen, and sulphur in the MSW respectively. The energy content is the net calorific value or lower heating value (LHV) of the waste.

B. Simulation Model for LFG Production from MSW

The landfill gas (LFG) is defined as the current CH_4 emission rate from the landfill and the quantity of available CH_4 to be captured. It requires simulation of the CH_4 emission of pre-installation year (from year 2000 to 2011) and projection of CH_4 emission from year 2012 until 2025. The potential energy generated from the landfill is calculated based on CH_4 produced from the anaerobic decomposition of various organic waste including food waste, paper, wood, and yard waste. The estimation of CH_4 generation from landfill is simulated based on the method developed by the IPCC [35], as shown by (2):

$$CH_4\ Emissio = MSW_T \times MSW_F \times DOC \times DOC_F \times F \times \frac{16}{12} \quad (2)$$

where MSW_T is the total waste generation (tonnes); MSW_F is the fraction of MSW disposed to landfills; *DOC* is the fraction of degradable organic carbon of waste '*w*' at time '*t*'; DOC_F is the fraction of total *DOC* that is dissimilatable under anaerobic conditions; *F* is the fraction of CH_4 by volume in the generated LFG, *16/12* is the conversion factor from C to CH_4.

There are several coefficients involved in the IPCC model as follow:

1. Methane Correction Factor (MCF)

MCF is a coefficient for different types of landfill practices. A default value ranges from 0.4 to 1.0 for different conditions of landfills; *MCF* of 0.4 is set for unmanaged and shallow landfills while *MCF* is set at 1.0 for properly managed sanitary landfill. For the case study in IM, *MCF* of 0.4 is set for landfill for year 2000 to 2011, assuming that the landfill condition is worst before the operation of sanitary landfill with LFGRS. *MCF* of 1.0 is set for year 2012 to 2025 by assuming the good condition of LFGRS.

2. Degradable Organic Carbon (DOC)

DOC is the organic carbon that is accessible to biochemical decomposition. Default settings in the IPCC model is used in IM: for food waste, the *DOC* factor is set at 0.17, for paper at 0.385 and for wood and yard waste at 0.4.

3. Dissimilatable Degradable Organic Carbon under Anaerobic Conditions (DOC_F)

DOC_F is the *DOC* proportion that dissimilates under anaerobic conditions. DOC_F explains that the *DOC* process does not happen totally for a long period. The default settings were also used for DOC_F, which is set at 0.5 for all types of waste.

4. Fraction of Methane in LFG (F)

The fraction of CH_4 production from LFG in Malaysia, *F* is 0.55 [22].

C. Optimization Model

The optimization model is formulation of an objective and several constraints. The objective function in the WTE model is to minimize the total cost of electricity generation. The objective function includes annualized capital cost, fixed operation and maintenance (O&M) cost and variable O&M cost of the new plants, as shown in (3).

$$Min\ f(i,j) = \sum_i \sum_j (C_{ij}^{inc} S_i^{inc} + F_{ij}^{inc} T_{ij}^{inc} S_i^{inc} + V_{ij}^{inc} E_{ij}^{inc})$$

(Cost of incineration: Capital cost + fixed O&M cost + variable O&M cost)

$$+ \sum_i \sum_j (C_{ij}^{lf} S_i^{lf} + F_{ij}^{lf} T_{ij}^{lf} S_i^{lf} + V_{ij}^{lf} E_{ij}^{lf})$$

(Cost of LFG: Capital cost + fixed O&M cost + variable O&M cost)

(3)

The '*i*' and '*j*' respectively represented the time period before and after the operating year of the power plants. C_{ij}, F_{ij} and V_{ij} represented the capita cost, O&M cost in terms of fixed and variable cost for the power plants, respectively. S_i represents the capacity of the power plant . T_{ij} is the construction trend of the power plant built in year '*i*' and operates in year 'j'. E_{ij} is the electricity generated from the power plant. The superscripts of *inc* and *lf* represent the types of the power plant, namely incineration and LFGRS respectively.

In order to define the relationship among the variables and parameters in this model, several linear inequality and matrix manipulation constraints are developed as follow.

- *The Supply of Waste Resource*

Two WTE technologies are considered: direct incineration and LFGRS. Each of them has different conversion rate of mass to energy as represented by R^{inc} and R^{lf}. This constraint indicates that the summation of waste disposal to landfill, M_j^{lf} and the waste allocated for incineration, M_j^{inc}cannot exceed the availability of the waste resource, W_j, as shown in (4).

$$\sum_j \frac{M_j^{inc}}{R^{inc}} + \frac{M_j^{lf}}{R^{lf}} \le W_j \quad (4)$$

- *Heat Value Constraints*

The heating value constraint of waste for incineration is shown in (5).

$$\sum_{i}\sum_{j} E_{ij}^{inc} + H^{inc} \leq M_{j}^{inc} L \qquad (5)$$

Equation (5) indicates that the summation of electricity generation from incineration, E_{ij}^{inc} and the heat rate, H^{inc} cannot exceed the multiplication of waste allocation for incineration, M_j^{inc} and the lower heating value, *L*. The same formula also applies for the LFGRS.

- *Capacity Limitation Constraints*

Capacity planned for each plant should be less than or equal to the maximum allowable capacity of the plant, as shown in (6).

$$\sum_{j} M_{j}^{inc} \leq S_{i}^{inc} \max \qquad (6)$$

S_i^{inc} represents the maximum capacity for the incineration plant. A similar concept also applies to the LFGRS.

- *Demand for Renewable Energy (RE) from MSW*

Demand for renewable energy (RE) generated from the MSW is set according to the RE target as specified by the case study. Hence, it is assumed that the total capacity of the power plants built cannot exceed the target of RE to avoid over investment and over supply of energy. This constraint is represented by (7).

$$\sum_{j} S_{i}^{inc} + S_{i}^{lf} \leq \mathrm{ED_j} \qquad (7)$$

This equation illustrates that the electricity generated from both WTE technology, incinerator and landfill cannot exceed the energy demands target, $\mathrm{ED_j}$.

IV. The Case Study: Iskandar Malaysia (IM)

South of Johor has long played an important and strategic role in the history and development of Malaysia and its surrounding region. Under the Ninth Malaysia Plan (9MP), this region was identified as the core development region in Malaysia and named as Iskandar Malaysia (IM) with the vision to be developed as a strong and sustainable metropolis of international standing [36]. IM covers an area of about 2,217 km_2 with an estimated waste generation rate of 1.4kg/capita/day by year 2025 [36]. As a future sustainable metropolis, the study of integrated SWM is important for IM to achieve the goal of a sustainable city. In this study, three different scenarios are described for IM in order to analyze the waste management planning under different circumstances. First scenario considered that only LFGRS exists in IM while the second scenario considered only the incineration plant. The third scenario considered the combination of LFGRS and incineration facility. All three scenarios considered the same RE demand according to the Blueprint of IM [39]. According to the model as developed and described in Section 3, it is crucial that all data collected represent IM as closely as possible.

A. Forecasting Solid Waste Generation

Table III presents the availability of waste in IM. This is a very crucial constraint in the study as it decides the feasibility of electricity generation from the waste sources as well as the capacity of the power plant.

B. Composition of Solid Waste

The composition of the solid waste determines the potential energy generation from itself. The composition of MSW in IM is shown in Table IV.

TABLE IV
AVERAGE COMPOSITION OF MUNICIPAL SOLID WASTE [38]

Types	Composition (%)
Food	49.3
Yard	18.2
Paper	17.1
Plastic	9.70
Glass	3.70
Metal	2.00

C. Renewable Energy (RE) Target

To achieve the status of a low carbon society, IM had set out a target to increase the share of RE up to 12% (459 MW) in its energy mix by 2025. The RE from MSW is one of the promising options to achieve the target. Table V shows the RE target in IM from year 2010 to 2025 according to its respective RE resources [39].

TABLE V
KEY TARGETS FOR RE IN IM [39]

Key Targets for RE	2010	2015	2020	2025
Total IM projected electricity Demand (MW)	1406	1997	2756	3828
RE target (MW)	-	120	276	459
RE from MSW (MW)	-	25	50	5

D. Cost of Power Plant

The objective function of the model is to minimize the cost of electricity generation. The costs of WTE for incineration and LFG considered in the model is taken from the U.S. Energy Information Administration, 2010 and tabulated in Table 6 [40].

TABLE VI
THE COSTS FOR INCINERATION AND LFG POWER PLANTS [40]

Power Plant	Capital Cost ($/MW)	Fixed O&M ($/MW)	Variable O&M ($/MW)
Incineration	3,860,000	100,500	43,800

LFG	8,232,000	373,760	72,970.8

TABLE III
FORECAST MSW GENERATION FROM 2010 TO 2025 FOR IM [37].

Types of waste	Composition, %	Waste availability (tonnes)								
		2010	2012	2014	2016	2018	2020	2022	2024	2025
Food	0.493	330,324	377,855	423,651	474,998	532,568	590,786	669,486	750,628	777,660
Yard	0.182	121,945	139,492	156,399	175,354	196,607	218,100	247,153	277,108	287,087
Paper	0.171	114,575	131,061	146,946	164,756	184,724	204,918	232,215	260,360	269,736
Plastic	0.097	64,993	131,061	83,355	93,458	104,785	116,240	131,724	147,690	153,008
Glass	0.037	24,791	28,358	31,795	35,649	39,970	44,339	50,245	56,335	58,364
Metal	0.02	13,401	15,329	17,187	19,270	21,605	23,967	27,160	30,451	31,548
Total		670,028	766,440	859,333	963,485	1,080,260	1,198,349	1,357,984	1,522,573	1,577,403
		9,995,855								

V. Result and Discussion

The WTE model proposed in this study consists of a MILP model that simulated and optimized on three different scenario settings for optimum SWM in the IM region. Two key technologies for WTE were considered, namely incineration and LFGRS. Scenarios 1 and 2 assumed LFGRS only or incineration only as the alternative for WTE approach, respectively. The two technologies were integrated in scenario 3 to optimize the cost of the WTE system.

A. Scenario 1- LFGRS only

The potential production of CH_4 from the LFGRS is simulated by the model using (2). Fig. 3 show the CH_4 generated from the landfill in IM for the year 2012 until 2025. There is a trend of gradual increase in the CH_4 production from year 2011 to 2025 as waste generation increased. Yard wastes showed the highest CH_4 generation due to its high carbon contain in the composition. Food waste and paper waste also generated a significant amount of CH_4 every year.

The demand for RE in IM is estimated to be 50 MW in year 2025, the simulation results based on Scenario 1 shows that it would not be feasible to fulfill the energy demand by relying solely on the CH_4 gas emission from the LFGRS. As shown in Fig. 4, the maximum power generated from the projected waste availability in IM (1,522,562 tonnes in year 2025) through the LFGRS is only 8 MW, which is very low from the targeted RE (50 MW). The result indicates that the LFGRS alone would not be able to meet the intended RE target due to insufficient waste source and low rate of CH_4 production. Landfill requires longer time to fully produce and assimilate sufficient CH_4. Therefore, LFGRS itself cannot be the solution for the WTE strategy in IM by 2025.

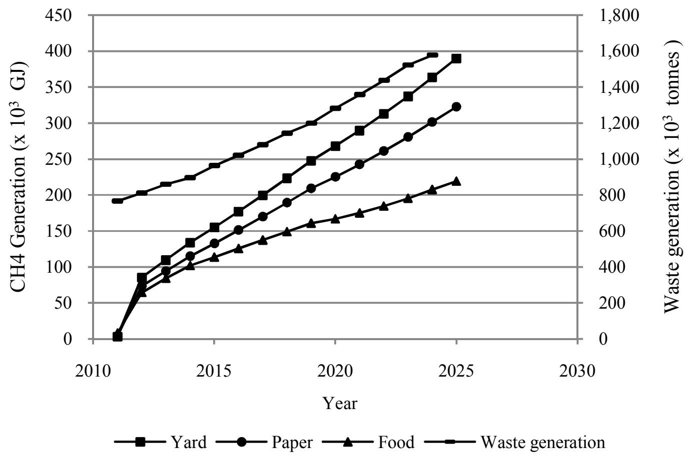

Fig. 3 CH_4 productions in landfill from year 2011 until 2025

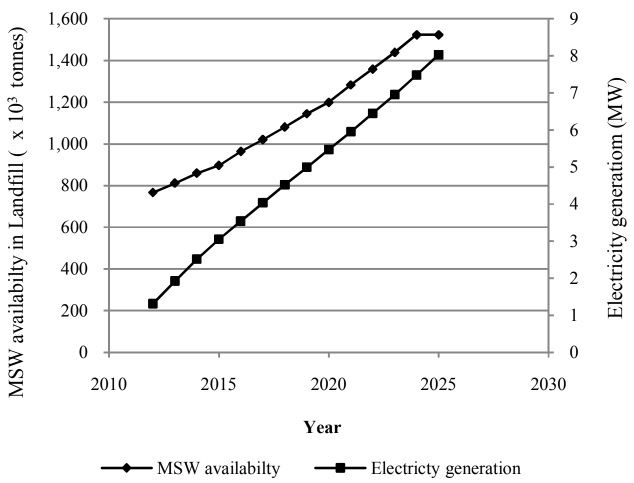

Fig. 4 Electricity productions from the LFG power plant in IM

B. Scenario 2 –Incineration only

In the incineration process, the simulation model could obtain the LHV of the MSW which is a variable to determine the energy potential from the incineration of MSW. The result shows that the potential energy generated from the incineration of MSW is 14.769 GJ/tonnes.

Scenario 2 recommended the installation of only incineration as waste treatment solution and energy generation in IM. Incineration of waste is successful to meet the RE target in IM (50 MW), as shown in Fig. 5. The operation of two incinerators with a capacity of 25 MW for each incinerator is suggested for the year 2012 and 2017. Under this scenario, 30% of the total MSW generated in IM is utilized to generate the targeted RE demand. This shows that incineration is useful to meet a certain energy demand within the period of the study (2012-2025).

The results obtained from Scenario 1 and 2illustrates that in order to satisfy RE demand in IM, incineration of SWM is more favourable as opposed to LFGRS.

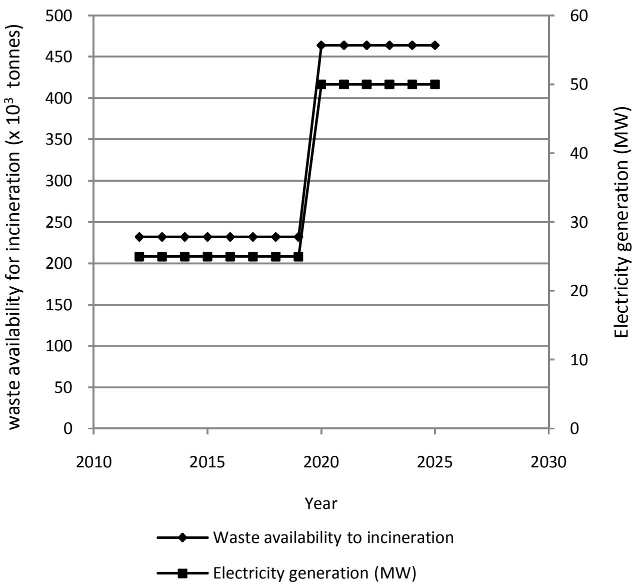

Fig. 5 Electricity productions from incineration of MSW in IM

C. Scenario 3– LFGRS and Incineration

The optimization model for integrated incineration and LFGRS as simulated through scenario 3 have demonstrated the optimum solution for the WTE strategy in IM. The optimization results revealed that, the minimum total cost for the WTE strategy is USD 387 million with a total electricity generation of 50MW/yr when both the incineration and LFGRS were considered for the planning year of 2011-2025. The optimizer suggested a combination of the selected WTE technologies to be implemented in IM in order to achieve the target as shown in Fig. 6. Two LFGRS and two waste incinerators are suggested to be built in IM for a period of 13 years from 2012 to 2025. At the beginning of the planning year (2012), a 16 MW of LFGRS with the annual electricity production of 1.40x 10^5 MWH is suggested to be built while only 9 MW (78,840 MWH) is suggested for incinerator. In contrast, on year 2017, a larger capacity of incinerator (14 MW) is suggested to be built as compared to the LFGRS (11 MW). LFGRS has a higher overall capacity (27 MW) than an incinerator due to its lower cost. This recommendation takes into account the true factors where at the beginning of the planning, the WTE technology has not reached the maturity level hence it would incur higher cost for installation and variable cost. To satisfy the objective function of minimizing the total cost of WTE, cheaper technology for LFGRS has been considered. Yet, LFGRS has a lower efficiency for energy generation; additional method (incinerator) should be operated to meet the targeted demand of electricity or RE as set in the current IM blue print. In year 2017, assuming that the cost of incineration is cheaper, larger capacity of the incinerator (14 MW) is suggested to be constructed.

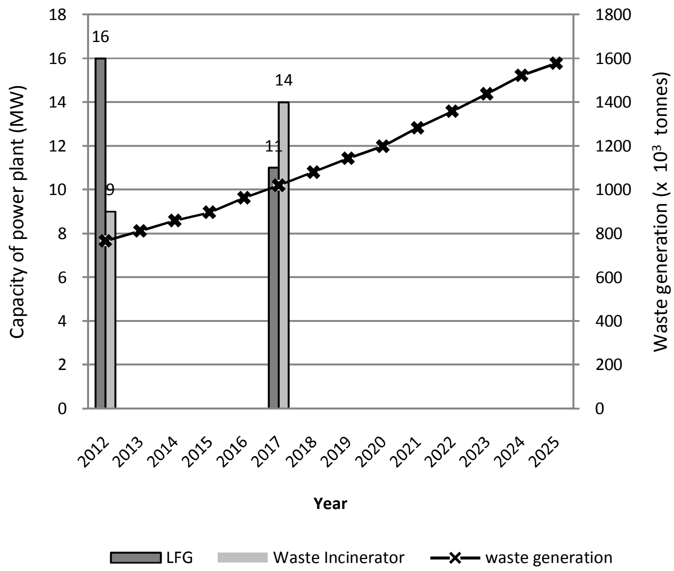

Fig. 6 Optimized capacity of WTE power plants

VI. Conclusion

A multi-period MILP model for optimizing the WTE strategy was developed for Iskandar Malaysia (IM) as a case study. The model was programmed in GAMS using the CPLEX 12.0 solver and represents an optimized model considering the WTE technology of LFGRS and incineration plants. Optimization results demonstrated that the selection and choice for power generation technology is driven by the cost efficiency factor and energy conversion of a technology. The model revealed that the minimum total cost of electricity generation from MSW is USD 387 million for the entire planning duration within 2011-2025 with an electricity generation of 50MW per year based on the case study of the IM region. A combination of WTE technologies with two LFGRS and two waste incinerators are suggested to be built in IM as a model city for a period of 13 years from 2012 to 2025, as presented by the analyses in Scenario 3.

This model can be adapted to perform analysis and planning for other provinces, states, and even for country wide scale of planning.

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