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Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia ☆

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ABSTRACT

The utilisation of municipal solid waste (MSW) for energy production has been implemented globally for many decades. Malaysia, however, is still highly dependent on landfills for MSW management. Because of the concern for greenhouse gases (GHG) emission and the scarcity of land, Malaysia has an urgent need for a better waste management strategy. This study aims to evaluate the energy, economic and environmental (3E) impact of waste-to-energy (WTE) for municipal solid waste management. An existing landfill in Malaysia is selected as the case study for consideration to adopt the advanced WTE technologies including the landfill gas recovery system (LFGRS), incineration, anaerobic digestion (AD), and gasification. The study presented an interactive comparison of different WTE scenarios and followed by further discussion on waste incineration and AD as the two potential WTE options in Malaysia. The 3E assessment reveals incineration as the superior technology choice when the production of electricity and heat were considered; however, AD is found to be more favourable under the consideration of electricity production only.

1. Introduction

Municipal solid waste (MSW), commonly known as refuse or rubbish, is discarded from residential, commercial, and institutional areas [13]. As the global population increases dramatically, and with changing consumption patterns, economic development, rapid urbanisation and industrialisation, MSW is being generated at a rate that outstrips the ability of the natural environment to assimilate it and municipal authorities to manage it. The situation is more severe in developing countries such as Malaysia. The rapid growth of the economy and population have caused MSW to proliferate by 28% in a period of a decade, from 5.6 Mt in 1997 to 7.65 Mt in 2007 [26], and it is predicted to further increase by 30% in 2020 and 39% in 2030 compared to the baseline year of 2007 [21]. Despite the government's efforts, waste management remains one of the critical environment issues in Malaysia. MSW in Malaysia is typically disposed of in a bin or container within the house premises and collected by regional private concessionaires. The waste is first sent to transfer stations for compaction, with a minimum of sorting, before being sent to the waste disposal sites [36]. Approximately 93.5% of MSW in Malaysia is in landfills or open dumpsites without gas recovery, meanwhile only 5.5% of MSW is recycled and 1.0% is composted [1]. Landfill is the cheapest technique to handle the waste in large quantities. On the other hand, there is public opposition and a shortage of available land for disposal purposes. The over dependency on landfilling and inappropriate waste disposal has been continuously pressing the environmental, health and safety issues for the citizens. It is also amplifying the share of total global anthropogenic greenhouse gas (GHG) emission, which is caused by the production of methane gas (CH_4) through the anaerobic decomposition of solid waste in landfills. GHG emission in the waste sector increased 54% from 1990 to 2008. Meanwhile, comparing the sub-sectors within the waste sector, the main release of GHG comes from waste landfill sites, which contributed up to 90% of the total emission from the waste sector in Malaysia [21].

The government of Malaysia is seeking practical solutions to improve the current waste management situation, including the

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sanitation and closure of illegal landfills, upgrading landfills with CH_4 recovery, waste incineration with energy recovery, composting of organic waste, and recycling and waste minimisation. Amongst the proposals, Waste-to-Energy (WTE) stood out as a promising alternative to overcoming the waste generation problem and a potential renewable energy (RE) source for Malaysia [37]. WTE encompasses thermal and biological conversion technologies that unlock the usable energy stored in solid waste [17]. The utilisation of MSW as a RE source could overcome waste disposal issues, generate power for fossil fuel displacement and mitigate GHG emissions from waste treatment by converting CH_4 to carbon dioxide (CO_2). Currently, more than 800 thermal WTE plants are operated in nearly 40 countries globally; they treat approximately 11% of MSW generated worldwide and produces up to about a total of 429 TW h of power [30]. Some large-scale alternatives for WTE have been implemented in developed countries, such as Japan, Germany, Sweden, the Netherlands, Denmark, and the United Kingdom. For example, over 80% of the MSW in Japan is incinerated; Japan also has the largest number of incineration plants in the world (1900 waste incineration plants) and 10% are equipped with power generation facilities [38]. In Germany, only 1% of waste was landfilled and the WTE share is approximately 35% of the waste treatment, which is higher than the Europe Union (EU)'s WTE ratio (∼24%) [11]. Sweden is another successful example of WTE in the EU, where nearly 50% of waste is incinerated with energy recovery [35]. In addition, Sweden also utilised the biogas from landfills for district heating, vehicle fuel, and power plants [7].

WTE has been practiced in Malaysia in recent decades and is implemented for biomass from agricultural waste and forestry residues (i.e., palm oil biomass, paddy straw and logging residues) [23]. WTE from MSW is still underutilised in Malaysia. Feasibility analyses of WTE from MSW in Malaysia have been conducted by local researchers over the past decade. For example, Kalantarifard and Goh (2011), Johari et al. [18], and Noor et al. [26] studied the potential of landfill gas in Malaysia for economic and environmental benefits. Those models forecasted the production of landfill gas from the existing landfill and calculated the energy production for economic analysis, nevertheless, they have not considered the investment of energy production in terms of capital and operation costs. In another feasibility study of MSW for WTE, Ng et al. [25] concluded that MSW utilisation is not economically profitable due to the high cost of technologies for incineration, gasification and pyrolysis. Ng's model did not address the environmental potential for WTE. On the other hand, Tan et al. [37] concluded that WTE for MSW could be profitable and could contribute to reducing GHG emission, however pre-treatment of MSW is crucial for better economic benefits of WTE. Nevertheless, Tan's research had a narrow scope by only considering two WTE technologies – landfill recovery and incineration.

Despite the previous work, none of the studies addresses the impact of WTE from MSW from the perspective of holistic sustainability, which includes energy, economics and environmental (3E); the current study aims to fill this gap.

2. Research objective, framework and methodology

This study aims to evaluate the 3E impact change from the baseline study in Malaysia represented by existing landfills that would result from the implementation of advanced WTE technologies, including landfill gas recovery system (LFGRS), incineration, anaerobic digestion (AD), and gasification. The four waste treatment alternatives are selected because they are considered by the Malaysia Government to be the best available technologies for WTE. In this study, the energy potential of MSW is in the form of electricity and heat. The economic assessment considers both the cost (capital cost, operation cost, and transportation cost), and profit (selling of energy, carbon credit through carbon avoidance, and additional profit from selling the by-products). Meanwhile, the environmental assessment includes the GHG emission during the energy conversion process, the transportation of MSW to the waste treatment plant, and carbon avoidance by fossil fuel replacement to renewable energy. Hence, the framework of this study, namely the 3E assessment of the four WTE technologies considered for Malaysia, is presented in Fig. 1.

A case study of Taman Beringin landfill in Malaysia was conducted with the proposed 3E framework. The work is novel as it is pioneer 3E assessment work framework for Malaysia case study. Another novelty lies in the discussion where the study comprehensively discusses the trade-off between waste incineration and anaerobic digestion for MSWM. Even though the case study is specific on Malaysia case, the novelty and discussion in the paper could be a good review for others case study worldwide.

A comprehensive review on each of the WTE technologies is performed in Section 3 to compare their advantages and disadvantages. The 3E parameters in this study are described in Section 4, followed by the information of the case study in Section 5. The results are reported and discussed in Section 4 with a comparison of 3E assessment for different WTE scenarios in Malaysia and a detailed analysis on the feasibility of both incineration and AD.

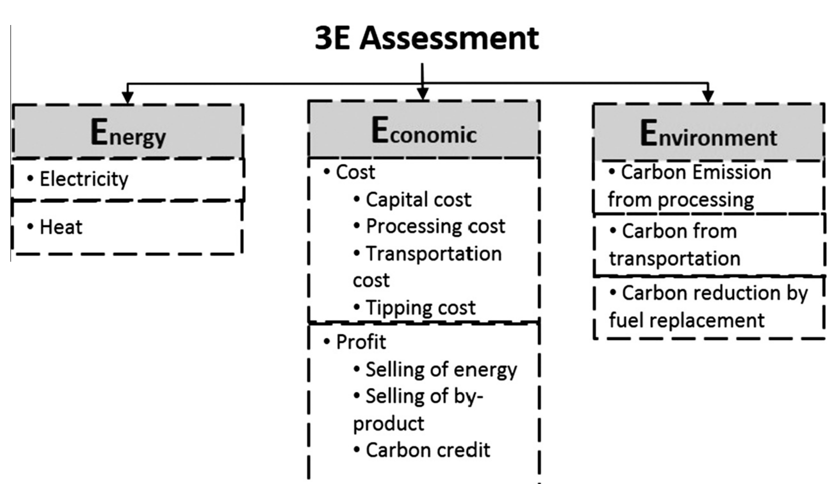

Fig. 1. 3E assessment framework for WTE technologies.