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Potential of Waste-to-Energy (WTE) in Malaysia

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Abstract: The research of Potential of Waste-to-Energy (WTE) in Malaysia aims to find out the potential of applying the process of Waste to Energy in Malaysia in terms of energy generated and potential revenue gained. Incineration and Anaerobic Digestion (AD) were the two methods that were taken to assess the feasibility to be run in Malaysia. The calorific value of the waste and the amount of waste generated were sought after before the energy calculations could take place. The waste generated was found to be 33,000 tonnes/day for the whole Malaysia while only 45% of the waste, which are the food waste, can be used for AD. Incineration can make use of most of the waste to produce energy while for AD, only methane that was produced from the food waste were used for energy generation. Thus, the calorific value of waste for Incineration and the amount of methane produced for AD were calculated. From those calculations, the electrical energy that could be generated using the total waste produced in Malaysia using Incineration was found out to be 68 GWh while for AD was 16 GWh. The results showed good potential to apply the processes in Malaysia as these wastes can provide value when, at the moment, it is being thrown away. Comparatively, Incineration is better than AD based on this research as the amount of waste is considerably larger than the amount of methane that could be produced.
Keywords: Waste-to-Energy; Renewable and Sustainable Energy; Energy; Economic; Environment.

I. INTRODUCTION

Human populations are increasing rapidly that causes the amount of wastes produced harms the environment. Energy demand in areas such as industrial, houses, etc. is increasing, however, the source of these energy is depleting overtime. Hence, finding alternative energy sources is a must to overcome this problem. Waste-to-Energy is one of the solutions that can overcome the energy crisis, in the same time can solve the waste problem [1-19]. Municipal waste from the residential areas required a proper management as this wastewater will cause the health risk and discomfort of the house owners. The waste usually will be transported to another area and be dealt with through landfills, or incineration of the waste. Filling up landfills will not be a sustainable method of waste management as there are limited land available for human use. Hence, the other way of waste management is through incineration, which convert the municipal wastes into a useful energy, and this process is called Waste to Energy, or WTE [6]. Municipal Solid Waste, or MSW is defined as everyday waste that has been thrown away from homes, schools, hospitals and businesses. The study will focus on household wastes that contributed up to 70% of waste disposed in 2012 [6]. WTE process can be done in few ways, however, some of the methods requires pre-treatment process prior to proceeding to the process. Incineration is a process where the wastes are burned to be converted into energy. The wastes fed into the incinerator does not need any pre-treatment as most wastes can be burnt up. AD is a process where the wastes are left in a chamber in the absence of oxygen. This process activates the bacteria to digest the waste, producing methane as a byproduct and this is captured and stored to be burned as fuel [7-10]. WTE is characterized in three main categories namely thermal conversion, biological conversion and landfill [7]. In this study, the biological conversion which is the Incineration and Anaerobic Digestion (AD) was chosen as the method is well-established.

In Malaysia, the wastes have high moisture content, contributed from mostly food and also from the influence from the hot and humid climate [20]. Besides that, the wastes are not properly separated get mixed up into the same container. An extra step is required in separating the waste prior to WTE process. There are certain countries practice to separate their wastes, hence WTE process can easily be done direct from the waste. These factors need to be taken into consideration before implementing the WTE processes [11-12]. Research on the implementation of WTE are related to the calculation and there is no discussion on the results. Besides that, the model studies are too complex for the common people to understand. This paper aims to fill that gap by using simpler models and display them in a concise manner. The aim is to find out the potential of applying waste to energy method in Malaysia, specifically in Subang Jaya area. The outcome of the study will on the energy and economic impact of WTE that helps in assessing the potential of WTE in Malaysia.

II. METHODOLOGY

2.1 Amount of Waste Generated Daily and the Output of Waste Based on Calorific Value and Methane Produced for Incineration and Anaerobic Digestion

To calculate the potential energy from the water, amount of waste produced was acquired from governmental organizations and research papers. Next, multiplication of the amount of waste with calorific value results in the gain the energy produced from burning of the waste. The conversion to electrical energy will be through a steam turbine was taken account in the process. Thus, the method to calculate calorific value was sought after.

In incineration process, generally, all waste can be burned, however, for anaerobic digestion, only food waste that can be burned and other wastes are considered inability to undergo anaerobic digestion. The burning of organic waste produces methane and burning of methane produces energy via AD. Formula for the analysis requires the amount of methane produced from the waste was sought after. Data on the specific waste and the amount of methane produced are required for the calculation of calorific values. To calculate the energy from incineration, the calorific value is used as it measures the energy content of the waste. The calorific value is acquired from the following formula [21].

$$CV = 99.5 \times C - 136.2 \times H + 61.9 \times O + 143.1 \times N - 1392.6 \qquad (1)$$

The calorific value is an equation of carbon, hydrogen, oxygen and nitrogen. The values for these components was acquired from ultimate analysis of waste that has been done on another research in Malaysia.

Equations for Anaerobic Digestion (AD) was modelled based on the reactions of the bacteria involved. The general equation for anaerobic digestion can be defined as [22]:

$$C_aH_bO_c + \left(a - \frac{b}{4} - \frac{c}{2}\right) H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right) CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4}\right) CO_2 \qquad (2)$$

Where a, b, and c are unknown numbers that depend on the organic matter inserted into the digester. Nitrogen and Sulphur is added into the following modified equation [22]:

$$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3 \cdot d}{4} + \frac{e}{2}\right) H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3 \cdot d}{8} - \frac{e}{4}\right) CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4} + \frac{3 \cdot d}{8} + \frac{e}{4}\right) CO_2 + d\, NH_3 + e\, H_2S \qquad (3)$$

This equation shows the overall reaction of AD without looking into the four steps of hydrolysis, acidogenesis, acitogenesis and methanogenesis. These values would be used to quantify the amount of methane acquired based on the ultimate analysis of waste and the amount fed into the digester. The equation would yield the mole of methane per mole of waste which would be converted into mass by multiplying the molar mass.

$$\frac{Mass\ of\ methane\ produced}{mole\ of\ waste} = Mole\ of\ Methane\ \times Molar\ Mass\ of\ Methane \qquad (4)$$

$$\frac{Mass\ of\ methane\ produced}{Mass\ of\ waste} = \frac{Mass\ of\ methane\ produced}{mole\ of\ waste} \times \frac{1}{molar\ mass\ of\ waste} \qquad (5)$$

Since molar mass is mass per mole, the mass of methane per mole was multiplied by molar mass of waste.

$$Mass\ of\ methane\ produced = \frac{Mass\ of\ methane\ produced}{Mass\ of\ waste} \times Mass\ of\ waste \quad (6)$$

2.2 Amount of Energy Regenerated by Quantifying the Potential Generated Electrical Energy from Incineration and Anaerobic Digestion

Based on the calculated calorific value and the amount of methane, the energy can be calculated based on the following formula. It was taken that the methane and waste would be burned and converted into electricity using a steam turbine. The steam turbine efficiency was taken 0.42.

$$Heat\ Energy = amount\ of\ waste \times calorific\ value \quad (7)$$
$$Electrical\ Energy = Heat\ energy \times steam\ turbine\ efficiency \quad (8)$$

The acquired electrical energy will be compared with the electrical energy generation in Malaysia. This will serve as a baseline for comparison on the viability of running the WTE plant in Malaysia.

2.3 Economic Impact of Implementing Incineration and Anaerobic Digestion in Malaysia Based on Potential Revenue Generated

The economic impact would be quantified by acquiring the revenue based on the value of electrical energy that is generated. This is done by basing the value of electrical energy based on the tariff set by the electrical authority in Malaysia which is Tenaga Nasional Berhadas show in Table 1 [20]. This would give an estimation of the revenue that would be gained by the association selling the electricity generated.

Table 1. The tariff based on Tenaga Nasional Berhad.

Tariff Category	Current Rate, sen/kWh (2018)
For the first 200 kWh	21.80
For the next 100 kWh	33.40
For the next 300 kWh	51.60
For the next 300 kWh	54.60
For the next kWh	57.10
The minimum monthly charge is RM 3.00	

III. RESULTS AND DISCUSSION

3.1 Amount of Waste Generated Daily and the Output of Waste in Terms of Calorific Value and Methane Produced for Incineration and Anaerobic Digestion.

Table 2. Waste produced in all of Malaysia

Year	2005	2012	2016
Total Waste Generated (Tonne/Day)	19,000	33,000	38,200
Waste disposed in Landfill (Tonne/Day)	18,050	30,129	35,335
Disposal Percentage	95%	91.3%	82.5%

Assumption Factors:
1. Rapid population growth increases 4% per year
2. Waste generation rate average from 0.8kg/cap/day – 1.12kg/cap/day
3. Increasing recycling rate from 5.0% in 2005 to 17.5% in 2016
And the composition of the waste above were as follows:

Table 3. Composition of waste

Main Waste Component	2005 (%)	2012 (%)
Organic/Food Waste	45	44.5
Paper	7	8.5
Plastic	24	13.2
Metal	6	2.7
Glass	3	3.3
Diapers	(no data)	12.1

Others (textiles, tetrapek, leather, etc)	15	15.7

To implement the equation for calorific value of waste for Incineration process, the ultimate analysis of waste is necessary as the equation makes use of ultimate analysis. Waste in Kuala Lumpur was the basis for the composition of waste as it has a high number of residents and a good place to implement WTE (Table 4).

Table 4. Elemental analysis of waste in Kuala Lumpur [23]

Elemental analysis (dry)	
Carbon content	46.11
Hydrogen content	6.86
Nitrogen content	1.26
Oxygen content	28.12
Sulfur content	0.23
Ash content	17.06

While for AD, the ultimate analysis is as follows [24].

Table 5. Ultimate analysis of the food waste in Sungai Ikan Landfill in Terengganu

Ultimate Analysis (dry wt %)						Proximate analysis (dry wt %)		
C	H	N	O	S	Cl	Ash	VM	FC
47.39	6.9	3.32	38.67	0.27	3.45	16.89	75.92	7.19

The ultimate analysis above was done on food waste. Food waste is produced at 14,685 tonnes/day since food waste is 44.5 % of 33,000 tonnes/day. While the calorific value of methane was taken as 55,000 kJ/kg. The graph resulted from the calculation of calorific value and amount of waste (and methane for AD) is shown in Figure 1).

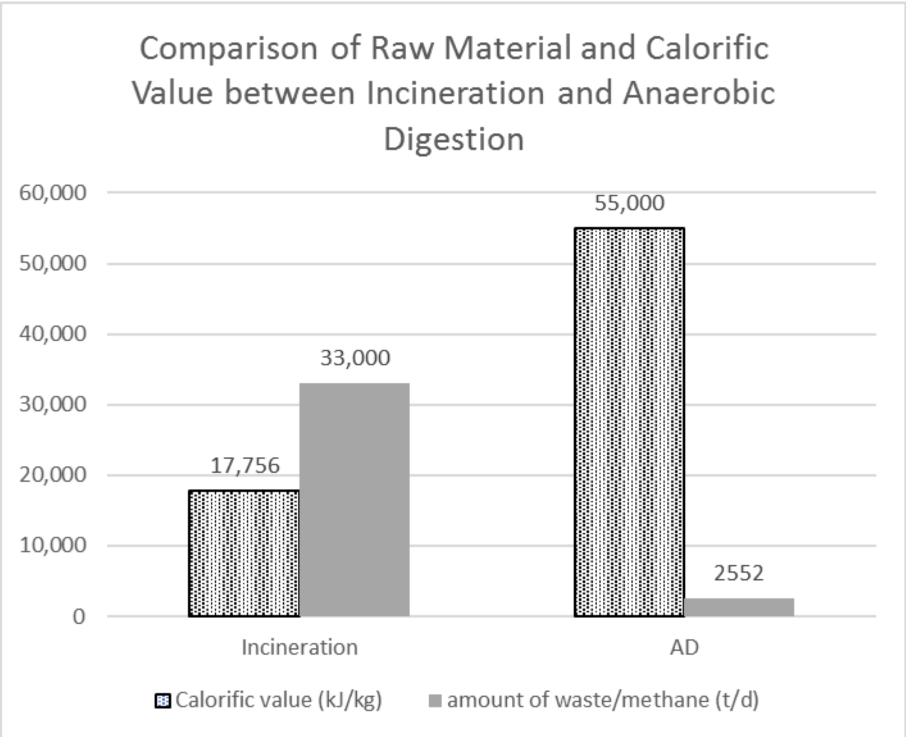

Figure 1. Comparison of Raw Material and Calorific Value between Incineration and Anaerobic Digestion

The graph shows a very high calorific value of methane compared to incineration's calorific value of waste. However, the amount of raw material is higher for incineration than AD. This is due to the weight of methane, being a gas would not give out such a high amount. Additionally, the amount of time necessary to collect the methane is not specified as the model regarding the rate of production was not considered. Therefore, without considering the amount of time to collect the gas, figure 1 shows the result of the calculations and were the basis of the energy calculation that follows.

3.2 Amount of Energy Regenerated by Quantifying the Potential Generated Electrical Energy from Incineration and Anaerobic Digestion

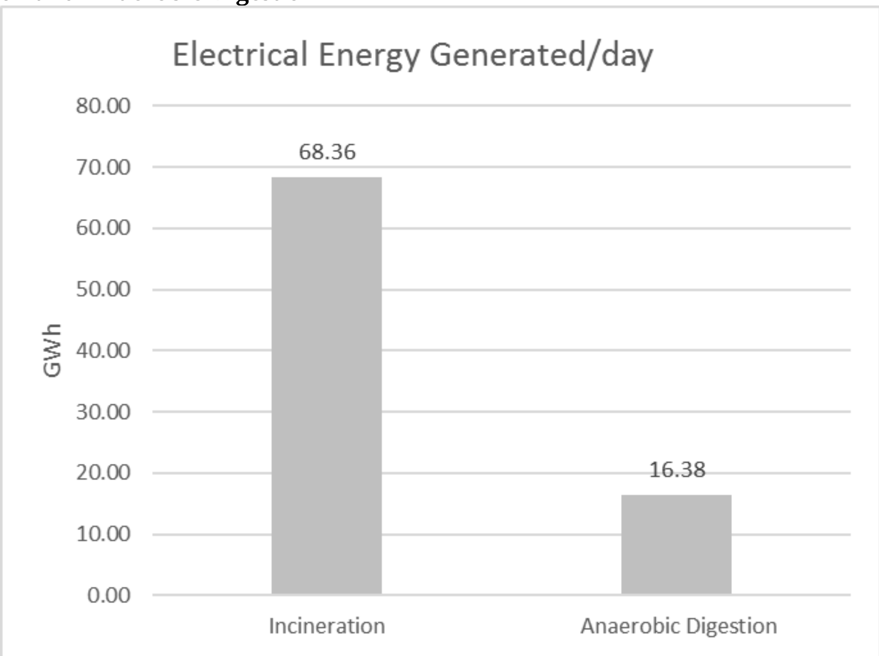

Figure 2. Electrical Energy Generated per day

Based on the calculations made, incineration provides more electrical energy as compared to AD. This agree to the result gained previously in which there is more input for incineration compared to AD in terms of weight. However, there might be certain loss of efficiencies that might not be considered in this calculation such as incomplete combustion. Thus, the value of electrical energy produced for incineration might be slightly lower than what is displayed here. However, as this is just an estimation of the electrical energy produced, these values are relevant for the discussion of this research [16].

This result was against with the pre-conceived idea from literature review as literature suggests Anaerobic Digestion to have almost similar energy output compared to Incineration [7]. Taking only comparison of Incineration and AD, the results of electrical energy production were 1200 MWh/day while AD had 1050 MWh/day. These results were based on a single landfill and thus for a single WTE plant. When amplified to a national scope, the disparity is clearer.

The different outcome could be from the model used for the calorific value of incinerated waste and the amount of methane produced for Anaerobic. However, the result supports the facts that incineration provides a higher energy output.

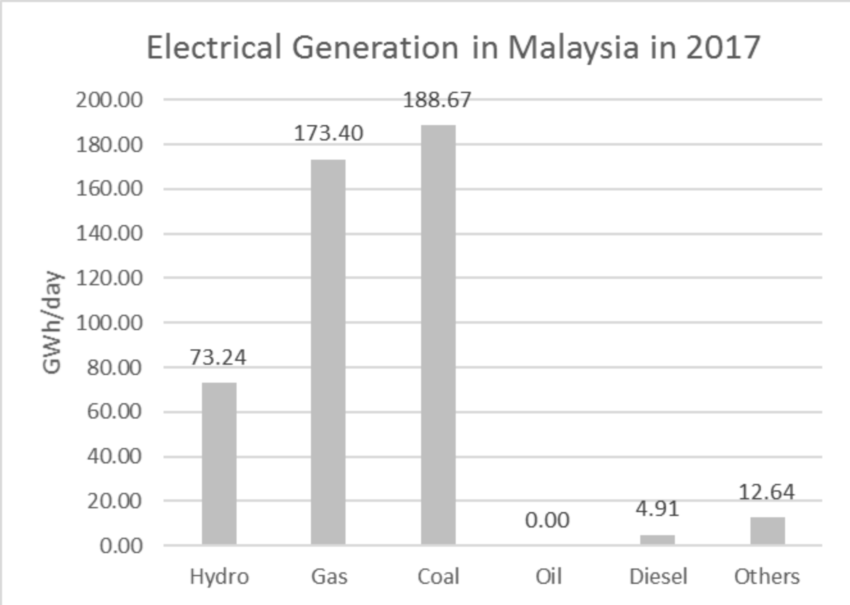

Figure 3. The electrical generation of various sources in Malaysia

Comparatively, Figure 3 shows the amount of electricity generated from the available sources in Malaysia as in year 2017. The data given was based on the electrical energy produced throughout the whole year which was converted into energy per day. This data can be compared with the calculations made for incineration and anaerobic digestion in this research. Referring to Figure 2 and Figure 3, the amount of electrical energy produced is comparable to hydroelectrical energy and diesel. This shows that the amount of energy produced can be used for daily consumption by the citizens, as the raw materials, which is waste, allows for enough electrical energy to be produced. With better technologies, more waste will be produced and as human beings continue to increase in number, there is high chance for the implement of WTE.

3.3 Economic Impact of Implementing Incineration and Anaerobic Digestion in Malaysia Based on Potential Revenue Generated

The electrical energy values were multiplied with the tariff chosen at 21.80 sen/kWh and the Figure 4 shows the revenue gained from the electrical energy produced. The chart shows a higher gain from applying incineration. This reflects the previously acquired data of electrical energy generated.

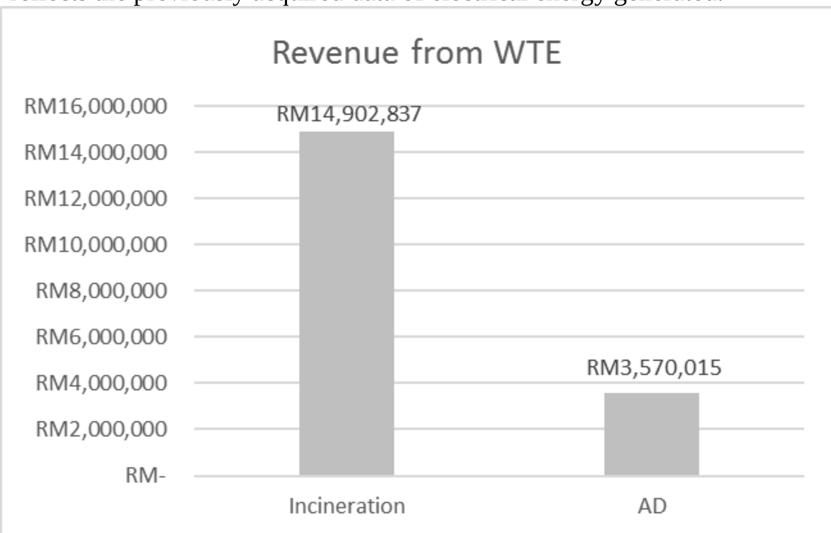

Figure 4. The amount of revenue gained from applying Incineration and AD

IV. CONCLUSION

In Malaysia, it was estimated that the amount of waste produced in the year 2012 was 33,000 tonnes per day. From these values, the total amount of potential from applying WTE in Malaysia was found to be 68 GWh/day for incineration and 16 GWh/day for AD using the calculations of calorific value and amount of methane produced. Accordingly, the revenue that could be gained is approximately RM 15 million a day for incineration and RM 3 million a day. These figures show that the incineration has a higher value to be applied in Malaysia due to large amount of waste produced as compared to the amount of methane that can be produced from the organic waste. It aligns with other sources of literature that incineration produces more from wastes compared to AD. In the future, other methods can be considered to measure its potential. This can further improve the possibilities of WTE implementation as other methods might be more suitable in Malaysia. As new methods are made, the calculation can be simplified similar to this research to allow a better understanding of the method.

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