2018 Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Vol. 1 Issue 1 (Special Issue - NaCoSC'18)

QUANTIFICATION OF METHANE EMISSION AS ENERGY RESOURCE FROM MUNICIPAL SOLID WASTE DISPOSAL IN IPOH

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ABSTRACT

A primary concern of global warming is greenhouse gases effect. Converting landfill biogas such as methane to energy resource is an opportunity that not only decrease greenhouse emissions from landfill, but it also aims to produce renewable energy for residential sectors near landfill sites. This involves quantification of methane emission as energy resource from municipal solid waste disposal. The objectives of this study were to determine total municipal solid waste generation in Ipoh city, to quantify methane emissions based on the total of municipal solid waste generation and to estimate electricity power production based on methane emission at Papan Landfill. Municipal solid waste (MSW) was determined based on transportation cost and Ipoh city population. Methane emission from MSW disposed at the landfill was estimated using Intergovernmental Panel on Climate Change (IPCC) methodology. Meanwhile, the amount of methane gas was calculated using Reciprocating Internal Combustion Engines (RICE) method to determine the estimated amount of electricity that can be generated at the landfill. From the results of this study, the amount of methane gas produced is equivalent to 80.4 m^3 of methane/tons of waste and is estimated to generate 10.1 MW of average electricity per year.

Keywords: municipal solid waste, methane emission, renewable energy

1. Introduction

The issue of global warming has received considerable critical attention worldwide. A primary concern of global warming is greenhouse gases effects. Most important greenhouse gases directly emitted by humans include CO_2, methane (CH_4), nitrous oxide (N_2O), and several other fluorine-containing halogenated substances (United States Environment Protection Agency, 2017). Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations (Intergovernmental Panel on Climate Change, 2013). Abushammala *et al.* (2011) found that, a site of municipal solid waste (MSW) can produce about 50-60% methane (CH_4) and 30-40% carbon dioxide (CO_2) by volume on the anaerobic decomposition. It will give rise to a serious environmental problem because CH_4 has a global warming potential 21 times greater than

CO_2. CH_4 emission from landfills is continually increasing due to increase in population growth and per capita waste generation.

Various attempts and studies have been made to address the problem of methane emissions. Among them is to convert methane gas emitted from landfills into electricity. The great energy value in methane results in that methane gas is captured and used as a renewable energy source, as fuel or to generate electricity or heat, but only 10% of possible energy is captured globally (Themelis *et. al,* 2007). Methane is an important GHG and is ranked second only to carbon dioxide in global warming (Chai *et al*., 2010). Methane gas is emitted during the production and transport of coal, natural gas, and oil. It emissions also results from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills (United States Environmental Protection Agency, 2016).

Malaysia is a developing country where a population is growing and the development of economic activities, particularly in the manufacturing sector has been a major contributor to the increasing demand for energy supply (National Energy Efficiency Action Plan, 2014). Some landfills control methane gas emissions simply by burning or flaring methane gas. Methane gas can also be used as an energy source. Many landfills collect biogas, treat it, and then sell methane. Some landfills use methane gas to generate electricity. The electric power consumption in Malaysia is growing substantially from 1970 until now. Over the last 4 decades, the usage of electricity in the country has been largely increased due to rapid economic growth attributed to industrialisation and high density of development (World Bank, 2016). Converting landfill biogas such as methane to energy is an opportunity that not only decreases greenhouse emissions from landfill, but it also aims to produce renewable energy for residential sectors near landfill sites (Broun & Sattler, 2015).

A number of researchers have reported about methane emissions (Serrona *et al*., 2006; Surroop *et al*., 2011; Abushammala *et al*., 2015). A study was done by Serrona *et al*. (2006) estimated methane emissions using Intergovernmental Panel on Climate Change 2006 at Manila landfill. Her study leads to conducting of methane gases to energy generation. Meanwhile, a study conducted by Surroop *et al*. (2011) also suggested that in Mauritius, electrical power supply to be generated using methane produced by municipal solid waste. Another study was done by Abushammala *et al*. (2015) in Selangor using Intergovernmental Panel on Climate Change 2006 estimation method found that.

The conversion of methane to energy also has been implemented in Malaysia such in Selangor and Negeri Sembilan. The body that responsible for managing the power supply from local authorities. The biogas plant produces from that landfill was manage to supply power to that area. So, this can reduce depending on main power supply provider in Malaysia. In western country, the same concept has been implemented in order to provide electrical such as in Patayas Landfill, Mariannhill Landfill and Mahoning Landfill.

Although, it has been well known that the production of electricity from methane emissions from landfills is very crucial but in Perak, especially in Ipoh the implementation of this method is still not available. In order to proposed biogas plant at the landfill, quantification of methane needs to be done. Thus, this study was conducted to quantify methane emissions from landfill and propose a new energy generation resource.

2. METHOD

The aim of this study as mentioned earlier is to quantify methane emissions from municipal solid waste in the landfill as a new resource for energy generation. In order to achieve this aim the location of the study was selected to determine the amount of waste generated in the study area. Then, the results were used to determine methane emission and electricity generation.

2.1. Landfill Selection

In order to determine CH_4 emissions for Ipoh city, it depended on municipal solid waste generated at study location selected. The landfill was selected from the Perak state based on the landfill operational type, landfill status, location in Perak the availability of an inactive area at operational landfills, and ease and safety of landfill access. Thus, Papan Landfill that was located 16 km from Ipoh City was selected as a study location (Figure 1). Table 1 provides a summary of the specification of the selected landfill.

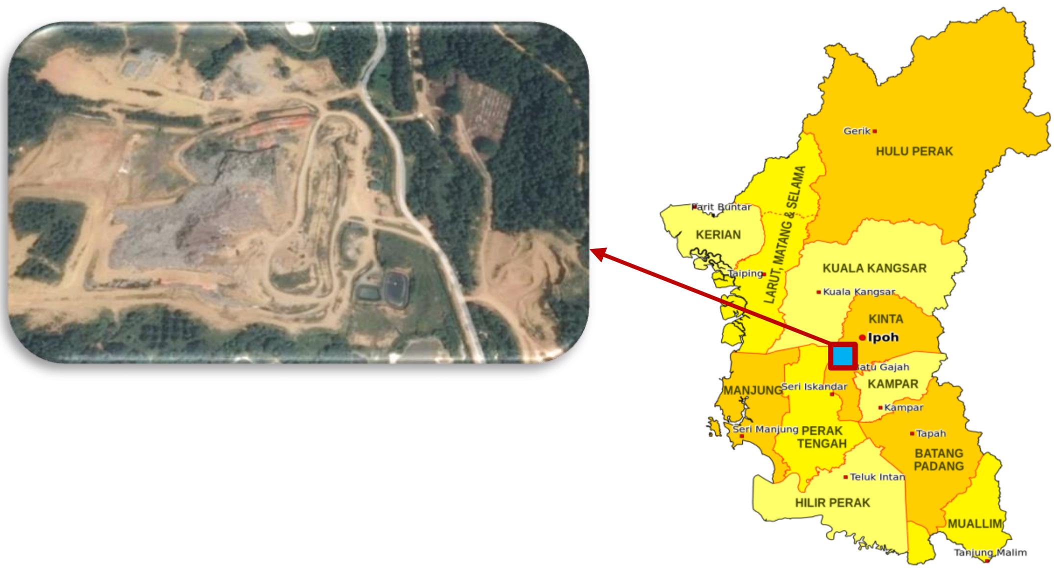

Figure 1: Study Location

Table 1: Landfill Specifications

Characteristic	Papan, Landfill
Dispose Practice	Sanitary
Status	In Operation
Area (ha)	227
Operation year	2012
Closure year	2032

2.2. Determination of Municipal Solid Waste (MSW) Generation

In order to determine the volume of methane from municipal solid waste, the calculation of the actual and estimates have been made. It was to know the significant value between the both values.

2.2.1. Total MSW based on population projection

Population projection data for Ipoh Municipal Council was obtained from Department of Statistics, Perak. MSW generation rate in Malaysia 1.2kg/capita/day used in MSW per capita per year using equation 1.

$$\text{Total MSW (kg/capita/yr)} = \text{Unit generation rate (kg/capita/day)} \times 30 \text{ Days} \times 12\text{Months} \quad (1)$$

Then, the total MSW for population projection in Ipoh City was estimated using equation 2.

$$\text{Total MSW (tons/yr)} = \frac{\text{Unit generation rate (kg/capita/yr)} \times \text{Population (capita)}}{1000} \quad (2)$$

2.2.2. Total MSW based on transportation costing

Data of MSW transportation costing was obtained from Ipoh City Council (MBI). The actual price had paid to the transported waste was RM20/tonne (Ipoh City Council, 2017). Therefore, total MSW was calculated based on equation 3.

$$\text{Total of MSW (tons)} = \frac{\text{Total Transportation Cost (RM)}}{\text{Transportation Price (RM/tonne)}} \quad (3)$$

2.2.3. Quantification of Methane Emission Potential

IPCC has proposed the method for estimation of methane emission from waste disposal rites by default method as per the following equation 4.

$$CH_4 \text{ emissions (Gg/yr)} = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F16/12\text{-}R) \times \quad (4)$$

where,
MSW_T : Total MSW generated (Gg/yr)
MSW_F : Fraction of MSW disposed to solid waste disposal sites
MCF : Methane correction factor (fraction)
DOC : Degradable organic carbon (fraction) (kg C/ kg SW)
DOC_F : Fraction DOC dissimilated
F : Fraction of CH4 in landfill gas
16/12 : Conversion of C to CH_4
R : Recovered CH_4 (Gg/yr)
OX : Oxidation factor

The method assumes that all the potential CH4 emissions were released during the same year the waste is disposed of. The method is simple and emission calculations require the only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available. The IPCC Guidelines introduce various specific default values and recommendations, (particularly for use in countries with a lack of SW statistics):

MSW_T : A selection of national specific MSW generation (in kg/capita/day) figures are provided, but information appropriate for many low and medium income countries and regions is missing
MSW_F : A selection of national specific MSW disposal figures (in kg/capita/day) are provided (to be used instead of MSW_T)
MCF : Three default values ranging from 1.0 to 0.4 are included, depending on the site management and with 0.6 as general default value
DOC : A selection of national values for DOC in MSW is provided, although a more limited selection than for MSW_T and MSW_F. In addition, an equation is provided together with default values related to MSW fractions to estimate country-specific figures based on national MSW composition. The value from IPCC Waste Model use that is 0.17 (IPCC, 2006)

DOC_F : The IPCC default value is 0.77 as suggested by Surroop (2011).
F : 0.55 is the IPCC default value
OX : 0 is the IPCC default value
R : 0 is the IPCC default value

2.4. Electricity recovery from landfill biogas

Electricity potential of landfill biogas was derived from methane content, while biogenic carbon dioxide content is incombustible and has zero fuel value. The quantity of electricity produced from capturing landfill biogas was estimated using equation 5:

Annual electricity generated (kWh) = CLB x LHV x 1/HR x (1- PL) x AF (5)

where;
CLB : Collected landfill biogas (m^3/year); represent the magnitude of landfill biogas per year which is recovered and transferred to electricity generation equipment.
LHV : Lower heating value of methane (MJ/m^3); ranges from 13 to 23 MJ/m^3; however, a median value of 18 MJ/m^3 was assumed in this study (United States Environmental Protection Agency, 2015)
HR : Heat rate (kWh/MJ); the amount of energy used by RICE to generate one kilowatt-hour (kWh) of electricity, with ranges from 9.5 to 12.5 MJ/kWh. Average 11 MJ/kWh used for this study.
PL : The energy required to operate compressors and other supporting equipment for converting landfill biogas to electricity. The U.S EPA has estimated that parasitic loads range from 0.04 to 0.08 (United States Environment Protection Agency, 2008). The assumed average parasitic load was 0.06.
AF : The share of hours in a year that the RICE is producing electricity. It is between 0.92 and 0.96 based upon energy recovery equipment downtime for regular maintenance, landfill biogas availability, and plant design. The assumed average engine availability factor was 0.94 (Steffens, 2013).

3. Results & Discussion

3.1. Municipal Solid Waste (MSW) Generation

Total solid waste generation rate for each person is about 1.2 kg/capita/day, and generation rate of solid waste is shown in Table 2. Based on the total of population projection in Ipoh city, the value increased year by year. In 2012 total MSW generated was 197,338 tons and 204,768 tons in 2016. This shows the increase in population, the amount of waste generated will also increase.

Table 2: MSW Generation based on Population Projection 2012 to 2016

Year	Total of Population (capita)	Total MSW Generated (kg/capita/yr.)[a]	Total MSW generated (tons/yr.)[b]
2012	456800	432	131558[c]
2013	460900	432	199109
2014	465200	432	200966
2015	469500	432	202824
2016	474000	432	204768

[a] Calculated from Eq. (1)
[b] Calculated from Eq. (2)
[c] The value for 1 year is 197338 tons, so (197338 tons / 12 month) x 8 months (May – Dec) = 131558.40 tons

Table 3 shows the result of actual total MSW generated at Papan landfill based on transportation cost per tonne of MSW. The operation started on May 2012 and fully operated in 2013 to December 2016. The calculation was based on RM20/tonne transportation price. A total of 113450 tons waste was generated in 2012, while in 2013 and 2014 an increased to 179,480 tons and 190,627 tons respectively. This amount also was increased to 191157 tons in 2015 and increased again to 196797.84 tons in the following year.

Table 3: Total of Municipal Solid Waste at Papan Landfill from 2012 to 2016 (Calculated from Eq. 3)

Month	2012 (tons)	2013 (tons)	2014 (tons)	2015 (tons)	2016 (tons)
January	-	16137	18073	16667	16848
February	-	14253	14702	15725	16665
Mar	-	13998	14931	15952	15144
April	-	14581	15533	15810	14499
May	16999	14541	15741	15047	16712
June	13237	14708	15090	16492	16398
July	10308	14131	17757	17405	17575
August	14314	15704	16271	16172	17474
September	14410	15099	14440	15235	17575
October	13522	14451	15938	15315	15538
November	14683	16114	15191	14859	16664
December	15977	15762	16961	16479	15706
TOTAL	**113450**	**179480**	**190627**	**191157**	**196798**

The amount of waste generation has been shown through the graph in Figure 2. From the data shown by month for each year, it was found that there is a difference between the amounts of waste was generated. In the beginning of 2012, the rate of waste generated was a lower in July and continued to increase in the following months. While that for the other years, MSW generation was higher in the early, middle and end of each year. Among the factor that may contribute was because at the early, middle and end of the year is the time of the festive season in our countries such as the Chinese New Year, Hari Raya Aidilfitri and Christmas Day.

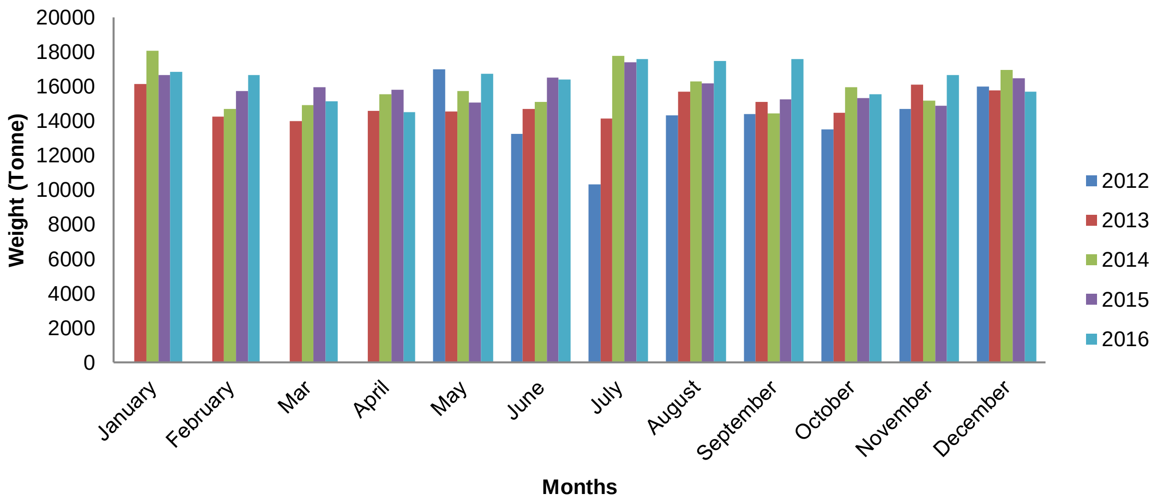

Figure 2: Actual Total of Municipal Solid Waste at Papan Landfill from 2012 to 2016

Figure 3 shows a difference weight of MSW based on actual and estimation determination. Results showed that the total of actual MSW generated starting May 2012 until 2016 was 871,513 tons; while the total estimate MSW was calculated is 939,226 tons. There is a difference of 67713 tons or 7.5%. This shows that the difference is not significant for both values. Therefore, the actual waste amount was used to quantify the total methane gas emissions in this study.

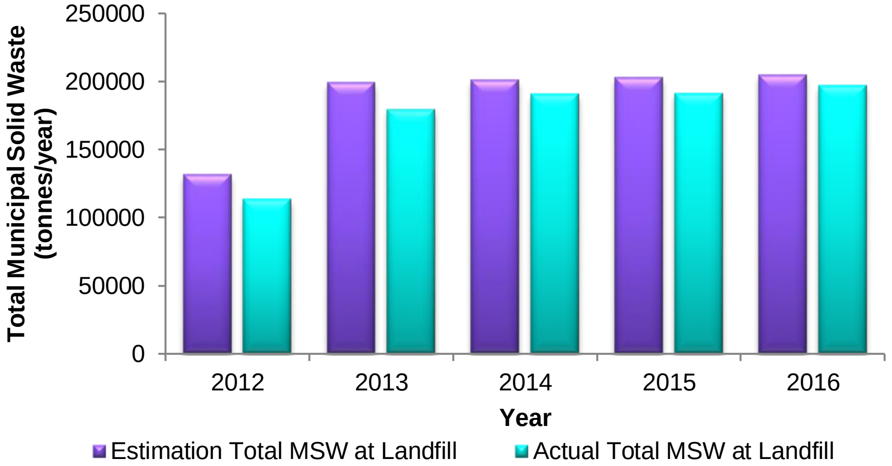

Figure 3: Difference between Actual and Estimated Total of MSW

3.2. Methane production from MSW

Table 4 shows the quantification amount of methane generated started on May 2012 to 2016 by year in Papan Landfill, Perak. The values in the table were generated by substituting values into Eq. (4). Total waste generated, MSW_T in were used for the estimation. MSW_F was taken as 1.0 because of actual total of MSW was used in this estimation. A total of 6534.28 tons of methane was generated in 2012 and an amount of methane gas production increased double in the next year as it fully operated. In 2013 methane amount reach to 10,337.33 tons/year and continued directly proportional to the change in the weight of the waste for subsequent years. Based on the estimation of different parameters needed, methane generation potential was found to be 0.0576 tonne methane/ tonne MSW which is equivalent to 80.4 m^3 methane/tonne MSW. This value is in close agreement with the experimental values presented by Themelis *et al.* (2007).

Table 4: Methane Production from Actual MSW

Year	MSW_T tons/yr[a]	MSW_F	MCF	DOC	DOC_F	F	OX	R	CH_4 tons/yr[b]
2012	113450	1.0	0.6	0.17	0.77	0.55	0	0	6534.28
2013	179480	1.0	0.6	0.17	0.77	0.55	0	0	10337.33
2014	190627	1.0	0.6	0.17	0.77	0.55	0	0	10979.37
2015	191157	1.0	0.6	0.17	0.77	0.55	0	0	11009.90
2016	196798	1.0	0.6	0.17	0.77	0.55	0	0	11334.77

[a] Table 2
[b] Calculated from Eq. (4)

3.3. Electricity recovery from methane emissions

Based on actual total emissions of methane, the annual electricity was estimated using Eq. 5 and shown in Table 5. The amount of CH_4 tons/yr. was converted to m^3/yr and used as landfill biogas collected value. It because biogenic carbon dioxide content is in combustible fuel and has zero value (Broun *et al.* 2015). In 2012, the electricity generated was 6.0 MW for 8 months, while the rate of generation increased nearly 50% to 9.5~10.4 MW for the year 2013 to 2016. So, the average annual electricity generated about 10.1 MW. For four years, the value is the same due to the different amount of methane generated is insignificant. Results showed that the amount of methane be produced can be enough to generate new energy. It is based on among projects of energy generation in landfills that are running such as at Air Hitam Landfill in Selangor is 2.0MW (WHB Environment, 2017), Bukit Tagar Landfill in Selangor is 1.0MW (KUB-Berjaya, 2017), Pajam Landfill in Negeri Sembilan is 1.0MW (Sustainable Energy Development Authority Malaysia, 2017), Payatas Landfill in Manila is 1.0 MW (Serrona, 2006), Mariannhill Landfill in Durban is 3MW (World Bank, 2015) and Mahoning Landfill in Ohio is 4.2 MW (Waste Management World, 2012).

Table 5: Electricity Recovery from Methane Emissions

Year	CLB[a]	LHV	HR	1/HR	PL	(1-PL)	AF	Annual Electricity (AE)	
	m^3/yr	MJ/m^3	kWh/MJ					MWh[b]	MW
2012	9123623	18.00	11.00	0.09	0.06	0.94	0.94	13192	6.0
2013	14433706	18.00	11.00	0.09	0.06	0.94	0.94	20870	9.5
2014	15330171	18.00	11.00	0.09	0.06	0.94	0.94	22166	10.1
2015	15372798	18.00	11.00	0.09	0.06	0.94	0.94	22227	10.1
2016	15826397	18.00	11.00	0.09	0.06	0.94	0.94	22883	10.4

[a] Table 4 (CH_4 tons/yr convert to m^3/yr)
[b] Calculated from Eq. (5)

4. Conclusion

The results obtained in this study draw some conclusions where the total production of waste increased from year to year. This shows the level of production of methane gas also increased. The average difference in estimation and actual volume of municipal solid waste is 7.5%. The difference was not significant; therefore the actual MSW can be used to estimate emissions of methane. The total of methane gases produced equivalent to 80.4 m^3 methane/tons MSW and it suitable for use as a new energy source because of the implications that affect the environment if it were released. The average total of electricity recovery is 10.1 MW based on methane emissions at Papan Landfill. The estimated finding is greater than the value that was generated by the existing landfill. So, landfill gas is a good source for power generation and it can be used to displace other energy sources. Suggested that the biogas treatment plant to generate energy and developed in a landfill because of estimation energy to be generated is high. Some suggestions were construct Biogas Plant near to the landfill area, propose biogas treatment plant schematic for Papan Landfill and propose electricity power supply to Taman Lahat Indah.

References

Abushammala M.F.M., Noor Ezlin Ahmad Basri, Hassan Basri and Abdul Amir H Kadhum (2011). Regional landfills methane emission inventory in Malaysia. Retrieved from: http://www.journals.sagepub.com/doi/pdf.

Abushammala, M.F.M, Noor Ezlin Ahmad Basri and Mohammad K.Younes. (2015). Methane Generation from Landfills: Malaysia Specific Parameters. *5th International Conference on Environment Science and Engineering, 83*. Retrieved from: http://www.ipcbee.com/vol83/003-ICESE2015-W0009.pdf.

Anwar Johari, Saeed Isa Ahmed, Haslenda Hashim, Habib Alkali and Mat Ramli (2012). Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. *Renewable and Sustainable Energy Reviews, 16.* Retrieved from: https://www.agro.uba.ar/users/semmarti/RSU

Bo-Feng, C., Jian-Guo, L., Qing-Xian, G., Xiao-Qin, N., Dong, C., Lan-Cui, L., Ying, Z., and Zhan Sheng, Z. (2014). Estimation of Methane Emissions from Municipal Solid Waste Landfills in China Based on Point Emission Sources. *Advances in Climate Change Research, 5*. Retrieved from: http://www.sciencedirect.com/science.

Broun, R., and Sattler, M. (2015). A Comparison of Greenhouse Gas Emissions and Potential Electricity Recovery from Conventional and Bioreactor Landfills. *Journal of Cleaner Production, 112*. Retrieved from: http://www.sciencedirect.com

Chai, X.L., Lou, Z.Y., Shimaoka, T., Nakayama, H., Ying, Z., Cao, X.Y., Komiya, T., Ishizaki, T. and Zhao, Y.C. (2010). *Characteristics of environmental factor their effects on CH and CO emissions from a 4 2 closed landfill: An ecological case study of Shanghai*, 30(3), 446-450.

Chua, K.H., Sahid E.J.M. and Leong Y.P. (2011). *Sustainable municipal solid waste management and GHG abatement in Malaysia*. Green & Energy Management, Malaysia, pp. 3-4.

Clarke Energy (2016). Retrieved from: https://www.clarke-nergy.com/landfill-gas

Hoornweg D. and Bhada-Tata P. (2012). What a waste: *A Global Review of Solid Waste Management*. Urban development and local government unit, World Bank, Washington DC, USA

Intergovernmental Panel Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories Vol. 1-5. (2006). *Intergovernmental Panel on Climate Change*. Retrieved from Intergovernmental Panel on Climate Change website: http://www.ipcc-nggip.iges.or.jp.

Intergovernmental Panel Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories Vol. 1-5. (2013). Climate Change 2013: The Physical Science Basis. Retrieved from Intergovernmental Panel on Climate Change website: http://www.ipcc-nggip.iges.or.jp.

Kathirvale, S., Muhd Noor Muhd Yunus, Kamaruzzaman Sopian and Abdul Halim Samsuddin (2004). Renewable Energy. *Energy potential from municipal solidwaste in Malaysia*. Retrieved from: https://www.researchgate.net/publication

KUB-Berjaya Enviro Sdn Bhd (2017). *Sanitary Landfill & Waste Management Solution.* Retrieved from: http://www.kbenviro.com.my/generating-renewable energy.php

Larsson J. (2014). A case study of landfill gas potential at Kikas landfill: *Assessment of environmental impacts and alternatives for mitigation*. Sweden: Chalmers University of Technology.

National Energy Efficiency Action Plan. (2014). Retrieved from Department of communication energy and natural resource website: https://ec.europa.eu/energy.

National Fire Protection Association (2016). NFPA 59A: *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG).* Retrieved from website: http://www.nfpa.org/ codes-and-standards.

Nelson, V. (2011). Introduction to Renewable Energy. United States: CRC press Taylor &Francis Group. Project Technology Option. Retrieved from: https://www.epa.gov/sites/production/files/2016- documents/pdh_chapter3.pdf

Rajaram V., Faisal Zia Siddiqui and Mohd Emran Khan (2012). From Landfill Gas to Energy: *Technologies and Challenges*. United States: CRC press Taylor & Francais Group.

Saeed Isa Ahmed, Anwar Johari, Haslenda Hashim, Ramli Mat and Habib Alkali (2013). *Landfill gas and its renewable energy potentials in Johor, Malaysia.* International journal of Emerging Trends in Engineering and Development.

Serrona, K.R.B., & Yu, J.Y. (2006). Waste-to-Energy Development in Metro Manila, Philippines: The Case of Payatas Landfill Gas Recovery Project. Retrieved from: https://www.jstage.jst.go.jp/article/jswmepac/17/0/17_0_429/_pdf

Steffens, D. (2013). *Lifecycle Cost Considerations when Choosing a Power Generation System.* Retrieved from: http://www.catpowerplants.com/Media/Downloads/Lifecycle%20Costs%20Article.pdf

Surroop, D., and Mohee, M. (2011). Power Generation from Landfill Gas. *2011 2nd International conference on Environmental Engineering and Applications, 17*. Retrieved from: http://ipcbee.com/vol17/45-L30010.pdf.

Sustainable Energy Development Authority Malaysia (2017). *Negeri Sembilan Guna Tenaga Tapak Sampah.* Retrieved from: http://seda.gov.my

Themelis, N.J. and Ulloa, P.A, (2007). Capture and Utilisation of Landfill Gas. Retrieved from: http://www.seas.columbia.edu/earth/wtert/sofos/Themelis_Capture%20and%20Utilisation%20of%20Landfill%20Gas.pdf

Themelis, N.J. and Ulloa, P.A, (2007) Methane generation in landfills, Renewable Energy 32. United States Environmental Protection Agency (2008). Background Information Document for Updating AP-42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills. Washington, DC.

United States Environmental Protection Agency (2015). *Complete LFG Energy Project Development Handbook*. Retrieved from: http://www.epa.gov/lmop/documents/pdfs/pdf_full.pdf

United States Environmental Protection Agency (2016). *Overview of Greenhouse Gases*. Retrieved from the Environmental Protection Agency website: http://www.epa.gov/ghgemissions/overview greenhouse-gases.

United States Energy Information Administration (2016). *Electricity in the United States.* Retrieved from: https://www.eia.gov/energyexplained

United States Environmental Protection Agency (2017). *Overview of Greenhouse Gases*. Retrieved from the Environmental Protection Agency website: http://www.epa.gov/ghgemissions/overview greenhouse-gases.

Waste Management World (2012). *4.2 MW Landfill gas to Energy Project in Ohio*. Retrieved from: https://waste-management-world.com/a/4-2-mw-landfill-gas-to-energy-project-in-Ohio

WHB Environment (2017). *Air Hitam Sanitary landfill*. Retrieved from Worldwide Environment website: http://www.whbenvironment.com.my.

World Bank. (2016, November 10). *World Development Indicators*. Retrieved from the World Bank website: http://data.worldbank.org/datacatalog/world- development-indicators.

World Bank (2017, April 8). *Waste Generation*. Retrieved from the World Bank website: http://siteresources.worldbank.org/inturbandevelopment.