A FEASIBILITY STUDY ON TURNING METHANE INTO LANDFILL GAS FOR ENERGY IN KETEREH

ROSIDAH BINTI MOHD SAAD

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2020

DEDICATION

I would like to dedicate this to my beloved mother and father, my lovely husband, children, family, friends and lecturers

Thanks for everything

ACKNOWLEDGEMENT

"In the name of Allah, the Most Gracious and Merciful"

Praise be to Allah, I am grateful to dear Allah for His Graciousness and blessings that I finally managed to complete this research and project report after going through the challenges and anticipations.

Deepest thanks to my supervisor, Dr. Shamila binti Azman for her assistance, guidance and all that she had taught me. Without her supervision, ideas, and support, this project would never have been completed on time. The knowledge she imparted to me is invaluable and I will be eternally grateful for that.

My appreciation to Mrs Zuhaida Binti Iberahim, Engineer from Ketereh City Council (MPIK) for the great cooperation and help given throughout this research.

My appreciation also to my dear husband and my family members, who have always stood by my side along the way. I also give my special thanks to my dearest colleagues and officemates who had been very helpful and understanding.

Finally, thank you for all that are involved in this research either directly or indirectly. I hope that all the effort put into this research by every one of you is blessed by Allah.

ABSTRACT

Methane, a gaseous natural by-product of organic solid waste degradation from landfills is proven to be an increasingly viable long-term form of renewable energy, albeit being the second highest greenhouse gas that contributes to global warming. The utilization of the methane released from landfills not only provide a sustainable energy production but also reduce the total emission of the gas to the environment. The quantification of the biogas emission, and the potential stored energy, from a landfill of a municipality or district will indicate whether that municipality is sustainable with the aforementioned form of energy. The objectives of this study were to determine total solid waste generation in Ketereh district, to calculate the methane emissions based on the total of solid waste generation at the landfill, and to propose a new methane-based power plant for the district. Municipal solid waste (MSW) data was obtained from the Ketereh City Council (MPIK). The methane emission was estimated using the Intergovernmental Panel on Climate Change (IPCC) methodology. The gas collection wells are designed based on the guidance from the Environment Protection Agency. The collected gas was purified using activated carbon before being fed into either an internal combustion engine or a gas turbine engine. Based on this study, the total methane emission per tons waste is estimated to be 79.98 m3, producing an average of 3.67 MW energy for 30 years.

ABSTRAK

Metana, sejenis gas yang terhasil secara semulajadi sebagai hasil sampingan melalui pelupusan sisa pepejal organik dari tapak-tapak pelupusan boleh menjadi sumber tenaga boleh diperbaharui walaupun ianya gas rumah hijau kedua terbanyak dalam pemanasan global. Penggunaan metana yang dibebaskan dari tapak pelupusan bukan sahaja menyediakan punca tenaga boleh diperbaharui, malah mengurangkan jumlah gas rumah hijau yang terbebas ke alam sekitar. Pengiraan jumlah pelepasan biogas, dan juga jumlah tenaga potensi yang terkumpul akan menunjukkan kesediaan sesuatu kawassan itu untuk bergantung kepada tenaga boleh diperbaharui. Objektif kajian ini adalah untuk mengenalpasti jumlah penghasilan sisa pepejal di daerah Ketereh, untuk menentukan nilai pembebasan metana, dan juga untuk mencadang pembinaan pusat penjanaan elektrik berteraskan metana di daerah tersebut. Jumlah sebenar diperoleh daripada Majlis Pembandaran Islam Ketereh (MPIK). Jumlah pembebasan metana dan dianggar menggunakan metodologi Intergovernmental Panel on Climate Change (IPCC). Telaga pengumpulan gas direka mengikut spesifikasi yang disyorkan oleh Agensi Pelindungan Alam Sekitar. Gas terkumpul menjalani penulenan menggunakan karbon aktif sebelum disalurkan ke enjin pembakaran dalaman atau enjin turbin gas. Berdasarkan kajian ini, 79.98m3 akan terhasil untuk setiap tan sisa yang terlupus, menghasilkan 3.67 MW tenaga secara purata untuk 30 tahun.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CO_2	-	Carbon dioxide
CH_4	-	Methane
N_2O	-	Nitrous oxide
MSW	-	Municipal solid waste
Tg	-	Teragram
IPCC	-	Intergovernmental panel on climate change
DOC	-	Degradable organic carbon
RICE	-	Reciprocating internal combustion engines
Kg	-	Kilogram
Cap	-	Capita
N_2	-	Nitrogen
O_2	-	Oxygen
m^3	-	Meter cube
kW	-	Kilowatt
MWh	-	Megawatt hour
EU	-	European Union
LFG	-	Landfill gas
LEL	-	Lower explosive limit
UEL	-	Upper explosive limit
LandGEM	-	Landfill Gas Emission Model
USEPA	-	United States Environmental Protection Agency
Yr	-	Year
Gg	-	Gigagram
DOC_f	-	Fraction of degradable organic carbon
SWDS	-	Solid waste disposal sites

pH	-	Potential of hydrogen
MCF	-	Methane correction factor
m	-	Meter
Btu	-	British thermal units
CNG	-	Compressed natural gas
LNG	-	Liquefied natural gas
FOD	-	First Order Decay
RM	-	Ringgit Malaysia
R	-	Recovered Methane
OX	-	Oxidation factor
CLB	-	Collected landfill biogas
mJ	-	Millijoule
Vs	-	Versus
Eq.	-	Equation
WHB	-	Worldwide Holdings Berhad
MW	-	Megawatt
TNB	-	Tenaga Nasional Berhad
GHG	-	Greenhouse gas
MSW	-	Municipal Solid Waste

LIST OF SYMBOLS

%	-	Percentage
Q	-	Volume
L_o	-	Methane potential
R	-	Solid waste rate
k	-	First order decay rate
c	-	Time period (closure to present year)
t	-	Time period (opening to present year)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Global warming poses a grave danger to human life. Greenhouse gas emissions (GHG) contribute to the bulk of the issue. Human-emitted GHGs include carbon dioxide (CO2), methane (CH4) , nitrous oxide (N2O), and many other halogenated substances containing fluorine (United States Environment Protection Agency, 2017). According to the Intergovernmental Panel on Climate Change (2013), these gasses exist naturally in the atmosphere although in a relatively much lower concentration as part of the ecosystem's natural order, however, their natural composition has been severely impacted by human activities, drastically increasing the heat-retaining gas particles in the atmosphere. CH4, although less concentrated compared to CO2, retains heat even better than its counterpart; with a capacity for global warming up to 21 times that. This is made worse when site emissions from municipal solid waste (MSW) are 50-75 per cent CH4 and only 25-50 per cent CO2 per volume, as stated by Kumar and Sammadder (2017). In addition, per capita waste generation rises along with population growth and area creation, eventually resulting in more CH4 emissions from landfill.

Research in the effort to tackle the methane problem were performed in several ways. One interesting idea is to turn the methane that has been released into electricity. There is a large amount of energy content contained in methane that can be a potential source of renewable energy, unfortunately, it is estimated that only 0.007 per cent of the overall national level of GHG has been reduced in the process of electricity production (Ahmed et. al, 2014). Methane is an important GHG and its effect on global warming is ranked second only to carbon dioxide (Chai *et al*., 2010). Table 1.1 shows the global estimation of methane sources and sink.

Table 1. 1 Global estimates of methane source and sink (Reay, 2010)

Natural sources	**Methane flux (Tg CH_4 yr^{-1})**	**Range**
Wetlands	174	100-231
Termites	22	20-29
Oceans	10	4-15
Hydrates	5	4-5
Geological	9	4-14
Wild Animals	15	15
Wild fire	3	2-5
Total (natural)	238	149-319
Anthropogenic sources		
Coal mining	36	30-36
Gas, oil, industry	61	52-68
Landfills and waste	54	35-69
Ruminant	84	76-92
Rice agriculture	54	31-83
Biomass burning	47	14-88
Total, anthropogenic	336	238-446
Total, all sources (AR4)	574 (582)	387-765
Sinks		
Soils	-30	26-34
Tropospheric OH	-467	428-507
Stratospheric loss	-39	30-45
Total sink (AR4)	-536 (581)	484-586
Imbalance (AR4)	38 (1)	-199-281

Anthropogenic methane gas emissions may be due to the oil , natural gas, and coal mining and transportation processes. Livestock farming, primarily livestock farming and other organic waste producing agricultural operations, and degradation of organic waste in urban solid waste landfills as reported by the United States Environmental Protection Agency (2016). The Intergovernmental Panel on Climate

Change (2014) also noted that the rise in atmospheric methane levels stems from agricultural activities, waste management, energy use, and burning of biomass. Figure 1.1 shows the global gas emissions in 2014 and methane is the second largest gas emissions after carbon dioxide.

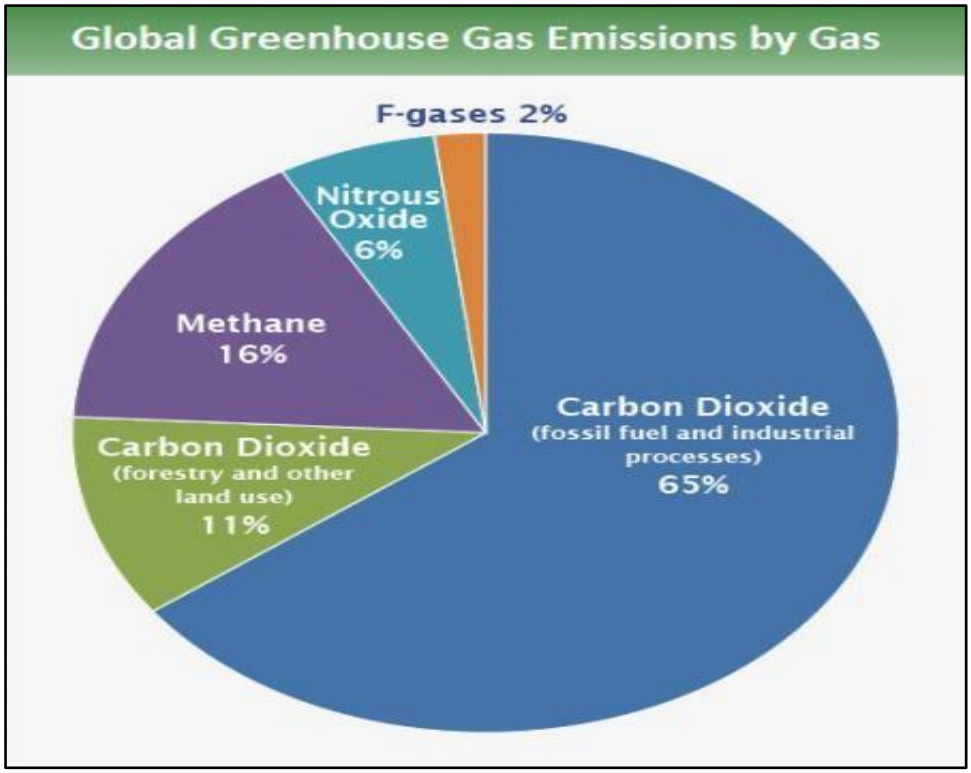

Figure 1. 1 Global greenhouse gas emissions in 2014 (Intergovernmental Panel Climate Change, 2014)

Malaysia is a developing country where increasing population and manufacturing sector growth have led to increased demand for energy supply (National Energy Efficiency Action Plan, 2014). Most landfills in developing countries minimize methane emissions by burning the expelled gas or flaring it out. A number of landfills are beginning to opt for the collection , treatment, and purification of the released gases to sell the methane. Many landfills, too, use methane gas directly to produce electricity.

It has also been stated that rapid growth, accredited to industrialization and high-density development over a 40-year period, has increased electricity demand and use nationwide (World Bank, 2016). Figure 1.2 shows that renewable energy potentially harvested from municipal wastes is much less in comparison to other industries in Malaysia.

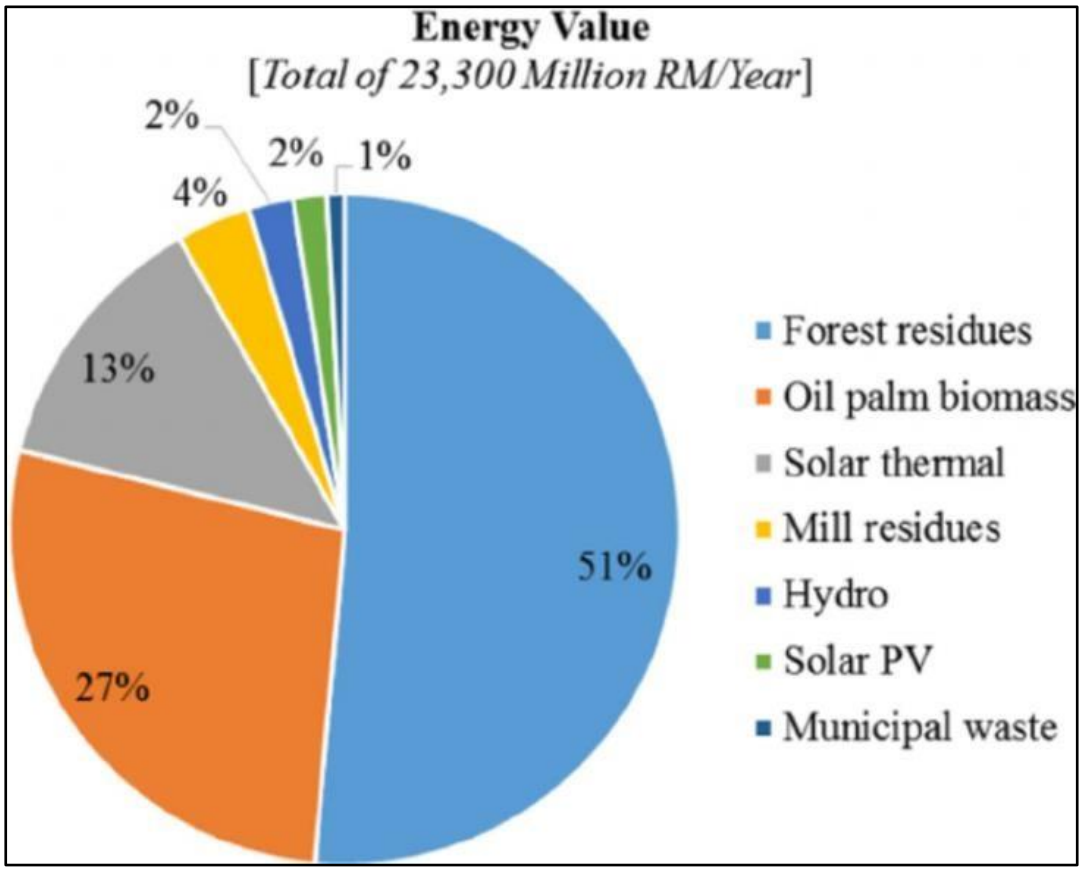

Figure 1. 2 Renewable energy sources potential in Malaysia (Alireza & Farzaneh, 2016)

Conversion of landfill biogas such as methane for energy production is an opportunity that not only decreases greenhouse gas emissions from landfills but also fulfills the need for a clean source of energy to heat residential areas near landfill sites (Broun and Sattler, 2015).

1.2 Problem Statement

The methane emissions in Asian countries were reported by many researchers (Du *et al*., 2017; Ghosh *et al*. , 2018; Abushammala *et al*., 2015). A research undertaken by Du *et al*. (2017) provides a ten-year review of rising methane emissions across several Chinese provinces using the 2006 Intergovernmental Panel on Climate Change due to residential and economic advances. Abushammala *et al*. (2015)'s study addresses the problem in Malaysia , in particular in the state of Selangor, also found that methane levels can be accurately estimated using the 2006 estimation method of the Intergovernmental Panel on Climate Change. Ghosh *et al*. (2018) conducted another study in India which yielded results supporting the idea of sustainable waste management along with energy generation using methane gas from landfill.

Developed nations, including the United States of America and the countries of the European Union, have long turned to transform their waste methane into either heat or electricity rather than flaring or burning it. Some of the developing nations are also catching up in this way, for example the Philippines' Payatas Landfill and South Africa's Marrianhill Landfill. Malaysia, too, is one of the developing countries that is beginning to embrace this relatively new waste management definition. Nevertheless, this waste management approach was only implemented by local government bodies, making it impossible to enforce it simultaneously nationally. The biogas plants, in Selangor and Negeri Sembilan for example, have the capacity to power residential areas around the landfill, reducing reliance on the main power provider, Tenaga Nasional Berhad.

The advantages of catching and turning methane in energy from landfill are developed across a lot of theoretical and practical bases. No such scheme has ever been implemented in Kelantan, even more so in Ketereh district, so quantification of methane needs to be done in order to suggest a biogas plant at the landfill. This research was therefore undertaken to measure the methane emissions from landfill and to suggest a new method for generating electricity.

1.3 Aim and Objectives of Study

The main aim of this study is to measure methane emissions from municipal solid waste in district Ketereh for a new method of generating electricity. The goals are defined as follows, in order to achieve the objectives of this study;

i. To determine the total municipal solid waste generation in the district of Ketereh.

ii. To calculate methane emissions based on the total volume of the solid waste production from the landfill.

iii. To propose a new methane processing plant for energy production.

1.4 Scope of Study

The following are scopes of study in order to achieve the objectives;

i. The study location is exclusively the Ketereh Landfill in Kelantan. The data for the monthly total municipal solid waste was obtained from Ketereh City Council.

ii. The methods implemented for the calculation of methane emissions is based on Intergovernmental Panel on Climate Change (IPCC) 2006.

1.5 Significant of Study

This research is significant as it can help provide the authorities with knowledge in addressing the environmental problems related to methane emissions. In addition, it can indirectly reduce the effect of landfill gas-induced diseases on wildlife. This work helps the authorities to consider using methane gas as part of a new generation.

REFERENCES

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.

Agency for Toxic Substances and Disease Registry. (2016). Landfill Gas Control Measures. Retrieved from Agency for Toxic Substances and Disease Registry website: https://www.atsdr.cdc.gov/HAC/landfill/html/ch5.html

Ahmed, S. I., Johari, A., Hashim, H., Mat, R., Lim, J.S., Ngadi, N., Ali, A., (2014) *Optimal landfill gas utilization for renewable energy production.* Retrieved from https://aiche.onlinelibrary.wiley.com

Ahmed, S. I., Johari. A., Hashim, H., Mat, R., and Alkali, H., (2013). *Landfill gas and its renewable energy potentials in Johor, Malaysia.* International journal of Emerging Trends in Engineering and Development.

Alireza Fazeli, Farzaneh Bakhtvar, Leila Jahanshaloo, Nor Azwadi Che Sidik and Ali Esfandyari Bayat (2016). *Malaysia's stand on municipal solid waste conversion to energy.*

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 Cumberland County Solid Waste Complex (2017). Retrieved from Cypark Resource Berhad (2017). Pajam Integrated Renewable Energy Park.

Du, M., Peng, C., Wang, X., Chen, H., Wang, M., Zhu, Q., (2017). *Quantification of methane emissions from municipal solid waste landfills in China during the past decade.* Renewable and Sustainable Energy Reviews. Retrieved from http://sciencedirect.com/science

Environmental Defense Fund (2016). *Climate and Energy*. Retrieved from Environmental Defense Fund website: https://www.edf.org/climate

Gas-to-Energy - Turning Waste into Energy (2016).Retrieved from Advanced Disposal Landfill website: http://www.advanceddisposal.com.

Ghosh, P., Shah, G., Chandra, R., Sahota, S., Kumar, H., Vijay, V.K., Thakur, I.S., (2018). *Assessment of methane emissions and energy recovery potential from the municipal solid waste landfills of Delhi, India.* Bioresource Technology. Retrieved from https://doi.org/10.1016/j.biortech.2018.10.069

Google Earth (2020). Retrieved from https://earth.google.com

Hammer, M., (2015). *Methane: How is Concentration Measured and What Levels are Cause for Concern?*. Retrieved from Hull Main Site website: http://www.hullinc.com.https://www.tandmassociates.com/projects/cumberland-county-solid-waste- complex-deerfield-township-nj/

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.

Intergovernmental Panel Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories Vol. 1-5. (2014). Climate Change 2014: Mitigation of Climate Change. Retrieved from Intergovernmental Panel on Climate Change website: https://www.ipcc.ch/report/ar5/wg3/

International Best Practices Guide for Landfill Gas Energy Project (2012). Retrieved from Global Methane Initiative website: https://www.globalmethane.org/

Iyamu, H.O., Anda, M., Ho, G., (2019). *A Review of Municipal Solid Waste Management in the BRIC and High-Income Countries: A Thematic Framework for Low-Income Countries.* Habitat International 95. Retrieved from http://www.sciencedirect.com/science.

Jagbir, S., and Ramanathan, A. L., (2010). *Solid Waste management: Present and Future Challenge*. I.K international Publishing House Pvt. Ltd.: New Delhi, India.

Johari, A., Ahmed. S.I, Hashim. H, Alkali. H and Ramli.M., (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

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

Kumar, A., Samadder, S.R., (2017). A review on technological options of waste to energy for effective management of municipal solid waste. Waste Management 69. Retrieved from https://www.sciencedirect.com/science

Landfill Gas (2017). Retrieved from http://www.carbtrol.com/industrial-applications/landfill-gas.html

Landfill Gas Composition. (2016). Retrieved from Clarke Energy website: https://www.clarke-energy.com/landfill-gas

Landfill Gas Power Plants (2017). Retrieved from Landfill Gas Power Plants - Waste to Energy (WTE) & Biomass in California website: http://www.energy.ca.gov/biomass/landfill_gas.html Municipality of Anchorage

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.

Menikpura, S.N.M., Janya, S.A., Bengtsson, M., (2015). Assessment of Environmental and Economic performance of Waste-to-Energy Facilities in Thai cities. Retrieved from http://www.sciencedirect.com/science.

Municipality of Anchorage (2017). Retrieved from The Municipality of Anchorage, Alaska website: https://www.muni.org/departments.

National Energy Education Department. (2016). Retrieved from National Energy Education Department website: http://www.need.org/

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/filedocuments/pdh_chapter3.pdf

Noor Asma Fazli Abdul Samad, Nur Ashikin Jamin, Suriyati Saleh, (2017). *Torrefaction of Municipal Solid Waste in Malaysia.* Retrieved from http://www.sciencedirect.com/science.

Reay, D., Smith, P., & Van Amstel, A. (2010). Methane and Climate Change. London: Earthscan Retrieved from http://crbenv.com/

Scarlat, N., Motola, V., Dallemand, J.F., Monforti-Ferrario, F., Mofor, L., (2015). *Evaluation of Energy Potential of Municipal solid Waste from African Urban Areas.* Renewable and Sustainable Energy Reviews, pp. 1269-1286.
Sciences. Retrieved from: http://www.academicjournals.org

Sharifah Norkhadijah Syed Ismail, and Latifah Abd. Manaf (2013). *The challenge of future landfill: A case study of Malaysia*. Journal of Toxicology and Environmental Health

Singh, S.K., Anunay, G., Shivangi, G., Vipul, V., (2016). *Greeenhouse Gas Emission from Landfills: A Case of NCT of Delhi, India.* Journal of Climatology and Weather Forecasting. Retrieved from http://www.academia.edu

Steffens, D., (2013). *Lifecycle Cost Considerations when Choosing a Power Generation System.* Retrieved from: http://www.catpowerplants.com

Tan, S.T., Ho, W.S., Hashim, H., Lee, C.T., Taib, M.R., Ho, C.S., (2015). *Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia.* Retrieved from http://www.sciencedirect.com/science.

Themelis, N.J., and Ulloa, P.A, (2007). *Capture and Utilisation of Landfill Gas*. Retrieved from: http://www.seas.columbia.edu/earth

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

United States Environmental Protection Agency (2007). *Overview of Greenhouse Gases***.** Retrieved from the Environmental Protection Agency website: http://www.epa.gov/ghgemissions/overview greenhouse-gases.

United States Environmental Protection Agency (2014). *Climate Change 2014: Mitigation of Climate Change*. Retrieved from: https://www.ipcc.ch/report/ar5/wg3/

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

Wang, S., (2015). *The Durban Municipal Solid Waste Project Alleviates Local Poverty*. Retrieved from Borgen Magazine website: http://www.borgenmagazine.com/durban-municipal-solid-waste/

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

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

Yusoff, M.S., Kamaruddin, M.A., Aziz, H.A., Adlan, M.N., Zaman, N.Q., Mahmood, N.Z., (2018). *Municipal Solid Waste Composition, Characterization and Recyclables Potential: A Case Study in Malaysia.* Retrieved from https://www.ingentaconnect.com/content