CHEMICAL ENGINEERING TRANSACTIONS
VOL. 78, 2020
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-76-1; **ISSN** 2283-9216
DOI: 10.3303/CET2078070

Development of Electricity and Heat Generation Assessment Index for Waste to Energy Technology Selection

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Developing nations are still in search for practical solutions to improve the current waste management system through the application and development of Waste-to-Energy (WtE) technologies. WtE is important in solving major issues regarding ineffective waste management. Different WtE technologies have different ways of operation and different amount of energy production. Therefore, it is very important to identify the type of WtE technology that is suitable for implementation according to their energy aspect. The aim of this work is to introduce the Electricity and Heat Generation Assessment Index (EHGAI) developed with the purpose of assisting the selection of suitable WtE technologies for implementation in terms of energy aspect. There are three energy parameters involved in the development of this technique which are heat energy generation, net electrical output and MSW mass reduction. Scores for this index were developed based on the parametric values obtained from the literatures while suitability of WtE technology on waste composition is used as weightage. This index was implemented on Taman Beringin Landfill case study. Results produced show that incineration is the best WtE technology in terms of energy production and MSW reduction aspects however, additional pre-processing of waste prior to incineration is needed for incineration to efficiently transform waste to energy. This results in incineration and anaerobic digestion as having the same EHGAI Total Score of 9 indicating both WtE technologies as suitable for energy production.

1. Introduction

Rapid economic and industrial development and urbanisation throughout the world results in a drastic increase of municipal solid waste (MSW). The most common approach of handling MSW in Malaysia is by dumping them in landfills with minimal energy recovery. According to Khairuddin et. al. (2015), simple and economical management of landfill makes it the best disposal method in the developing countries. Ineffective waste management can cause a major impact to the environment, for example the release of methane (CH_4) and carbon dioxide (CO_2) gas due to improper disposal of wastes at landfills contributes to phenomenon such as global warming. Noted that CH_4 is a stronger greenhouse gas than CO_2. In order to overcome these issues, waste to energy (WtE) technologies are being considered for further development of a proper waste management system (Tan et al., 2015). In addition, WtE technologies produces value added product that can benefit the society.
WtE technology converts waste to gaseous, liquids or solid fuels that can be utilized in generating energy (Maisarah et. al., 2018). The primary products of WtE technologies are fuel gases, electricity, heat, solid and liquids. WtE technology possess various advantages, for instance cheaper and environmental friendlier alternative to fossil fuels. MSW can be treated using three types of WtE technologies namely biological treatment, thermal treatment and landfill gas recovery system (LFGRS). Biological treatment involves a secondary treatment where microorganisms are introduced, primarily, bacteria to convert waste in the form of organic matter into simpler element. The microbes decompose the organic matter using enzymes to produce methane and alcohol. Biological treatment can be divided into anaerobic and aerobic digestion. Biological treatment of WtE of anaerobic production produces energy in the form of biogas. This treatment ranks the third most favourable method based on the hierarchy of waste management.

Paper Received: 05/05/2019; Revised: 29/08/2019; Accepted: 16/10/2019
Please cite this article as: Ahmad S.I., Ho W.S., Thamotharan V., Abdul Kohar R.A., Bong C.P.C., Hashim H., Rashid R., 2020, Development of Electricity and Heat Generation Assessment Index for Waste to Energy Technology Selection, Chemical Engineering Transactions, 78, 415-420 DOI:10.3303/CET2078070

Thermal treatment is divided into thermal treatment with and without energy recovery. The technologies that involve thermal treatment to recover energy are gasification, incineration, pyrolysis and treatment by plasma torch. Each of this WtE technologies have different ways of operating and processing. Thermal treatment reduces the quantity of waste through heat energy and produces syngas, char and bio-oil and is an efficient and effective way for MSW recycling. Thermal treatment can be further categorised into incineration, gasification and pyrolysis while biological treatment can be divided into aerobic and anaerobic digestion. Land disposal is the last step in the hierarchy of waste management. It is the least favourable method as it has a lot of disadvantages, socially, economically and environmentally. All and any type of MSW can be disposed in a dumpsite as there are no specifications on the type of MSW that should be disposed at a certain dumpsite. The release of harmful gases like SO_X, NO_X and CO_2 from land disposal can be a major leading factor to other phenomenon like global warming.

On economy aspect of waste management, "tipping fees" is commonly imposed to handle MSW from it location of generation to disposal. These fees are increasing in order to fulfill the requirements of landfill operations as a measure to help in reducing pollution (Wright, 2012).

Many countries are still searching for a practical solution to improve their waste management system into a more systematic system. It is crucial for a country to assess whether the chosen technology will be able to reach their desired goal and demand in the future. A study done on MSW management in India found that the development of a landfill system for energy recovery had a tremendous energy potential of 219 PJ in the year 2010 (Tan et al., 2014). Currently, there are various countries already implementing WtE technology with different operation and amount of energy produced. Before a WtE technology can be implemented, it is important to identify which WtE technology is more suitable. A theoretical model for energy recovery from MSW was developed in Turkey (Yilmaz and Abdulvahitoglu, 2019). This model considers energy, economy and ecology nexus based on the characteristics of the solid waste system. Although there are various studies on waste management and WtE technologies, specific technique or score indicator to select the best WtE technology in terms of energy aspect is currently in non-existence.

Therefore, the objective of this work is to develop an Electricity and Heat Generation Assessment Index (EHGAI) suitable to be used in selecting the best WtE technology in term of energy aspect particularly in terms of heat and electricity production. Three parameters namely heat energy, net electrical generation and percentage of MSW mass reduction are included in this index. Suitability of WtE technology on waste composition is taken as the weightage in this index. This work is also a continuation to the work by Ahmad et. al. (2019) who developed a quantitative index in order to select the best WtE technology in terms of safety and health aspects.

2. Development of electricity and heat generation assessment index (EHGAI) for waste to energy technology

There are three main steps involved in developing the EHGAI as illustrated in Figure 1. The first step is to study and review the available works related to electricity and heat generation in WtE technologies. The purpose of this steps is to acquire the electricity and heat generation values produced by WtE technologies. In the second step, data is collected for analysis. Electricity, heat generation values and percentage of MSW mass reduction were gathered from the previous works and other resources. The third step is the development of scoring technique. In this index, scoring tables based on the electricity, heat generation and percentage of MSW mass reduction values gathered in the previous step were developed. These scores will be used in determining which WtE is the best in terms of electricity, heat generation and MSW reduction aspects.

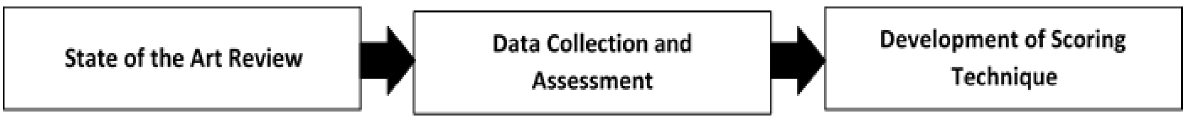

Figure 1: Electricity and Heat Generation Assessment Index (EHGAI) Development Steps

2.1 Electricity and heat generation data collection

As currently there is no available assessment index focused on assessing the energy parameters for WtE technologies, past works related to WtE technologies are studied in order to extract the electricity and heat generation values. Among the works studied are, Energy, economic and environmental (3E) analysis of WtE strategies (Tan et al. 2015), life cycle assessment of waste-to-energy (WtE) technologies for electricity generation using municipal solid waste in Nigeria (Ayodele et al. 2017), energy and emissions benefits of renewable energy derived from municipal solid waste (Tan et al. 2014), optimal process network for municipal solid waste management (Tan et al., 2013) and many more. In this work, only readily available information on electricity and heat generation values by WtE is considered for evaluation.

2.2 Development of scoring system

Scoring and ranking system is developed with the purpose to assist users in selecting the best WtE technology in terms of energy and MSW mass reduction aspect. Development of scoring technique for this index can be divided into two main steps which are scores development and weightage determination.

2.4.1 Score development

The scoring system is developed by setting a range of score from 1 to 10 for each parameter values. Values for each parameter were gathered from literatures as mentioned previously. Scores for each parameter will be added together to produce one unique score for each WtE technology. Higher scores indicate that the option of WtE technology as more substantial. The three parameter considered in this study are net electricity output, heat energy output, and MSW mass reduction.
Net Electricity output determines the amount of electrical energy generated for a particular WtE technology. Heat energy is also produced or generated in WtE technologies. Different type of WtE technologies produces different ranges of heat corresponding to many factors and parameters to be used as steam in powerplants. In this method, evaluation of heat energy refers to the Heat Energy Output (HEO). Scoring table for NEO and HEO parameter are shown in Table 1.

Table 1: Scoring range development for Net electrical Output

Score	NEO Score Range (MWh/tMSW)	HEO Score Range (MWh/t MSW) 10^8
1	0-50	0-1.0
2	51-100	1.1-2.0
3	101-150	2.1-3.0
4	151-200	3.1-4.0
5	201-250	4.1-5.0
6	251-300	5.1-6.0
7	301-350	6.1-7.0
8	351-400	7.1-8.0
9	401-450	8.1-9.0
10	451-500	9.1-10.0

MSW mass reduction (MSWReduc) is also included as one of the parameter for energy aspects. The MSW mass reduction values used in the assessment are in percentage. Aside from evaluating the heat and electricity generation of the WtE technologies, it is also important to know whether the WtE technologies are efficient in waste mass reduction.
WtE technologies that produce high heat and electricity amount with high reduction in waste mass are highly preferable. This is in line with the original purpose of WtE technologies which is to overcome waste generation problem while possess high potential as renewable energy source. Scoring table MSW mass reduction parameter are shown in Table 2.

Table 2: Scoring range development for MSW Reduction

Range (%)	MSWReduc Score
0-10	1
11-20	2
21-30	3
31-40	4
41-50	5
51-60	6
61-70	7
71-80	8
81-90	9
91-100	10

2.4.2 Calculation of weightage and total score

In this technique, suitability of WtE technology on waste composition is used as weightage. According to Tan et. al. (2015), waste having high percentage of biodegradable substance with high moisture content is highly suitable to be processed in the LFGRS. High moisture content is also favourable for anaerobic digestion (Kumar and Samadder, 2017). However, incineration prefers waste with low moisture content (Tan et. al. 2015). The weightage assignment is given to each WtE technology according to these assumptions. The value of 1.0 is given to WtE technology with high suitability of processing MSW with high moisture content, in this case LFGRS and anaerobic digestion. Meanwhile, the value of 0.5 is given to WtE technology with low suitability to process MSW with high moisture content such as incineration. However, this does not indicate that incineration cannot be used to process MSW with high moisture content. The weightage value of 0.5 is given to incineration due to the requirement of additional prior pre-processing step as waste with high moisture content needs to be pre-dried to lower its moisture content before it enters the incinerator (Tan et al., 2015). This also indicates that incineration utilizes more energy than LFGRS and anaerobic digestion. Table 4 shows the weightage value assigned for incineration, LFGRS and anaerobic digestion according to their suitability on waste composition.

Table 3: Weightage Assignment for Each WtE Technology

Characteristic of Waste	LFGRS	Incineration	Anaerobic Digestion
High Moisture Content	1.0	0.5	1.0
Low Moisture Content	0.5	1.0	0.5

Moisture content is included as weightage in the calculation of EHGAI Total Score as shown in Eq(1) and Eq(2) where “Weightage” refers to weightage value as shown in Table 3, NEO Score refers to the Net Electricity Output, HEO Score refers to the Heat Energy Output while MSWReduc Score refers to MSW Reduction scores.

$$EHGAI\ Total\ Score = Weightage\ (Parameters\ Total\ Score) \tag{1}$$

$$Parameters\ Total\ Score = (NEO\ Score + HEO\ Score + MSWReduc\ Score) \tag{2}$$

3. Application to case study

In this work, data from Taman Beringin Landfill case study as shown in Table 4 are used to illustrate the usage of EHGAI developed. Taman Beringin Landfill is located 10 km North West of the capital of Malaysia, Kuala Lumpur and is originally used for the disposal of residential and commercial waste collected from the city. Currently, Taman Beringin landfill is filled and is no longer used as a landfill. Taman Beringin landfill currently serves as a waste transfer station to transfer to another sanitary landfill located in the northern part of Selangor state, 60 km from Kuala Lumpur.

The current Malaysian government are still considering further upgrades for the implementation for WtE technologies such as incineration, anaerobic digestion and landfill gas recovery system at the Taman Beringin landfill. The main purpose of implementing the best WtE technology would be to gain profit from selling of value added products generated from the WtE technology in the form of electricity generation and to provide electricity around the Selangor and Kuala Lumpur areas (Tan et al., 2015).

Data in Table 4 are collected from the existing literatures and previous case studies. Data on three WtE technologies which are anaerobic digestion, incineration and LFGRS focusing on energy based parameters such as energy content, MSW reduction, net electrical output and heat energy were gathered.

Table 4: Data collected at Taman Beringin Landfill

Parameters	LFGRS	Incineration	Anaerobic Digestion
Net Electrical Output (MWh/t MSW)	215	251	244
MSW Reduction (%)	20	75	20
Heat Energy Output (MWh/t MSW)	0.48×10^8	4.05×10^8	2.04×10^8

The developed EHGAI is implemented on the Taman Beringin Landfill case study. Table 5 shows the score produced for each parameter for each WtE technology assessed. In EHGAI, higher score indicates that the WtE technology option is a more substantial.

Table 5: Scoring range for energy parameters

Parameters/WtE technology	LFGRS	Incineration	Anaerobic Digestion
NEO Score	5	6	5
HEO Score	1	4	2
MSWReduc Score	2	8	2
Parameters Total Score	8	18	9
Weightage	1	0.5	1
EHGAI Total Score	8	9	9

According to Table 5, incineration has the highest Parameter Total Score of 18 followed by anaerobic digestion and LFGRS with Parameters Total Score of 9 and 8. This indicates that incineration is the most suitable WtE technology in terms of electricity and heat generation as well as mass reduction compared to anaerobic digestion and LFGRS highlighting its benefits in terms of energy producer and efficiency in managing MSW.

According to Tan et. al. (2014), Malaysia's MSW composition is consisted of mainly organic waste followed by plastics, paper, textile, glass, garden waste and metal with percentage of 41.1 %, 22.2 %, 20.9 %, 7.7 %, 3.6 %, 2.2 % and 2.0 %. Therefore, it can be considered that the MSW to be processed in the WtE technologies possesses high moisture content. The weightage value assigned to each WtE technology is 1, 0.5 and 1 for LFGRS, incineration and anaerobic digestion.

Further evaluation was conducted by applying the weightage values into the equation as shown in Equation 1. According to the EHGAI Total Score, both incineration and anaerobic digestion have the same score of 9 while LFGRS has the EHGAI Total Score of 8. Although incineration is able to produce more electricity and heat compared to anaerobic digestion, additional pre-processing of waste prior to incineration is needed for incineration to efficiently transform waste to energy, hence consuming more energy. This indicates that both incineration and anaerobic digestion are suitable for energy production as both have their own advantages and limitations.

As EHGAI is currently on the preliminary stage of development, there are a few recommendations that can be applied for the improvement of EHGAI. Firstly, incorporation of more energy parameters is suggested for the improvement of EHGAI. Currently, EHGAI only considers the energy production parameters but not the energy used to convert MSW to energy. Detailed information in the energy used can also be evaluated for comprehensive energy assessment. Secondly, improvement on the scores assigned on each parameter is also proposed. The current scores assignment only considers moisture content as the weightage, other aspects for example economical factor can also be considered in choosing the suitable energy producer. Thirdly, it is also recommended for the work to also consider the dilemma in WtE purposes as argued by Malinauskaite and Jouhara (2019).

According to Malinauskaite and Jouhara (2019), the benefits of WtE for example elimination of waste or clean energy production should not outweigh the social environmental costs. Energy production method as well as methane and carbon dioxide minimization should also be considered. The concept of energy justice can be applied in order to achieve this purpose. Energy justice utilizes the concepts of social and moral in the decision-making of energy production, distribution and consumption (Fetanat et al., 2019). According to Heffron et al. (2015), energy justice also calls for critical evaluation on energy policies implications which will balance the dilemmas in order to deliver the best result to the society.

While both electricity and heat are useful source of energy, however the demand for heat is not the same for different location in the globe. This study uses Taman Beringin as a case study however, Taman Beringin is in Malaysia and usually heat energy is not in high demand. As recommendation, this work can also be expended to assess location where heat energy is in demand and location where it is not. Possibility of using the heat for producing cooling demand can also be considered.

4. Conclusions

This research introduces the development of the Electricity and Heat Generation Assessment Index (EHGAI) for the selection of the best WtE technologies in terms of energy aspects. There are three energy parameters involved in this technique which are heat energy generation, net electrical output and MSW reduction. Scores for this index were developed based on the parameters values obtained from the literatures while suitability of WtE technology on waste composition is used as weightage.

This index was implemented on the Taman Beringin Landfill case study. Results produced show that incineration is the best WtE technology in term of energy production and MSW mass reduction aspects however, additional pre-processing of waste prior to incineration is needed for incineration to efficiently

transform waste to energy. This results in incineration and anaerobic digestion as having the same EHGAI Total Score of 9 indicating both WtE technologies as suitable for energy production.
EHGAI is a simple index-based energy assessment technique that is easy to use even for those who are not familiar with the technicality of energy evaluation. EHGAI is therefore beneficial for governments to have a quick analysis on the solid waste in their region and identify suitable WtE technologies that can be implemented in their region. However, improvements on the parameters included for assessment and scores assignment is recommended for comprehensive energy assessment, especially in the aspect of economy, environment, and health.

Acknowledgments

Special thanks to Universiti Teknologi Malaysia (UTM) and the Ministry of Higher Education of Malaysia for the financial support received to conduct this research under the Post-Doctoral Fellowship Scheme (Q.J130000.21A2.04E26).

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