STRUCTURAL OPTIMISATION APPROACH AND INDICATORS FOR INTEGRATED MUNICIPAL SOLID WASTE MANAGEMENT

TAN SIE TING

UNIVERSITI TEKNOLOGI MALAYSIA

STRUCTURAL OPTIMISATION APPROACH AND INDICATORS FOR INTEGRATED MUNICIPAL SOLID WASTE MANAGEMENT

TAN SIE TING

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Environmental Engineering)

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

OCTOBER 2015

To my dearest husband, parents and family:

Whose love have nourished and sustained me always.

ACKNOWLE

ABSTRACT

Rapid urbanization, population growth, and industrialization are contributing to the large-scale increase of total waste generation in Malaysia and changing the characteristics and composition of the municipal solid waste (MSW). The present practice of municipal solid waste management (MSWM) in Malaysia is depends very much on landfill disposal. To date, Malaysia is at the transition and planning stage towards sustainable MSWM with more efficient approaches. The main aim of this thesis is to develop a sustainable MSMW system based on a structural and comprehensive framework through optimisation modeling and indicator approaches. A case study of Iskandar Malaysia (IM) was employed in this research. In order to achieve the goal, three objectives were identified: the first objective is to evaluate and benchmark the performance of the MSWM system through a new developed indicator system known as Sustainable Waste Management Performance Indicator (SWMPI). The second objective is to assess the energy and carbon reduction potential of waste-to-energy (WTE) strategies for MSW in IM. The results in the second objective were used as the input data for the third objective. The third objective is to establish a sustainable and cost effective solution for the processing network of MSWM, through the model of Optimal Waste Processing Network (OWPN). At the end of the study, improvement of MSMW system through the third objective had been evaluated by the model of SWMPI from first objective. The analysis has proven that the optimal results from the OWPN model of MSWM system has successfully improved the waste management in terms of waste basic data, economic, waste management, and environmental criteria in SWMPI, where significant improvement was found in waste management and environment criteria of the indicator system. Both SWMPI and OWPN had been proven as powerful tools that assist the benchmarking of MSWM system in IM against other cities.

ABSTRAK

Proses pembandaran yang pesat, pertumbuhan penduduk, dan perindustrian telah menyumbang kepada peningkatan jumlah penjanaan sisa pepejal pada skala yang besar di Malaysia dan turut mengubah ciri-ciri dan komposisi sisa pepejal perbandaran yang dihasilkan. Pada masa kini, pengurusan sisa pepejal (MSWM), di Malaysia amat bergantung kepada tapak pelupusan sampah. Setakat ini, Malaysia berada pada peringkat peralihan dan perancangan ke arah MSWM yang mampan dengan pendekatan yang lebih berkesan. Tujuan utama tesis ini adalah untuk membangunkan satu sistem MSMW yang mampan dengan rangka kerja yang sistematik dan komprehensif melalui model pengoptimuman dan pendekatan indikator. Dalam penyelidikan ini, kajian kes Iskandar Malaysia (IM) telah digunakan. Untuk mencapai tujuan utama tesis ini, tiga objektif telah dikenal pasti: Objektif pertama adalah untuk menilai aras prestasi sistem MSWM melalui sistem petunjuk baru yang dikenali sebagai Petunjuk Prestasi Pengurusan Sisa Pepejal Mampan (SWMPI). Objektif kedua adalah menilai potensi tenaga dan pengurangan karbon daripada sisa pepejal melalui strategi Sisa ke Tenaga (WTE) dalam IM. Keputusan daripada objektif kedua telah digunakan sebagai input untuk objektif ketiga. Objektif ketiga adalah untuk memberikan satu penyelesaian jangka panjang dan kos efektif untuk rangkaian pemprosesan MSWM, melalui model Rangkaian Pemprosesan Sisa Optimum (OWPN). Pada akhir kajian ini, peningkatan MSMW melalui objektif ketiga akan dinilai melalui model SWMPI daripada objektif pertama. Analisis ini membuktikan bahawa hasil yang optimum daripada model OWPN sistem MSWM telah berjaya memperbaiki pengurusan sisa dari segi data asas, ekonomi, pengurusan sisa dan kriteria alam sekitar di SWMPI, di mana peningkatan yang mendadak telah dilihat dalam pengurusan dan persekitaran sistem petunjuk. Kedua-dua model SWMPI dan OWPN telah dibuktikan sebagai alat yang berkuasa memberikan penanda aras untuk sistem MSWM di IM berbanding dengan bandar yang lain.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABC	-	Action Plan for Beautiful and Clean Malaysia
Act 672	-	Solid Waste and Public Cleansing Management Act of 2007
AHP	-	Analytic Hierarchy Process
BAU	-	Business as Usual
EQA	-	Environmental Quality
GAMS	-	Generalised Algebraic Modelling System
GDP	-	Gross Domestic Product
GHG	-	Greenhouse gases
IPCC	-	Intergovernmental Panel on Climate Change
ISWM	-	Integrated sustainable waste management
LA	-	Local Authority
LCA	-	Life-cycle assessment
LFG	-	Landfill gases
LFGRS	-	Landfill gases recovery system
LP	-	Linear programming
MBT	-	Mechanical-biological treatment
MCDM	-	Multi-criteria decision models
MHLG	-	Ministry of Housing and Local Government
MILP	-	Mixed integer linear programming
MINLP	-	Mixed integer nonlinear programming
MIXTECH		Mixed technologies scenario
MRF	-	Material recycling facilities
MSW	-	Municipal solid waste
MSWM	-	Municipal solid waste management
NLP	-	Nonlinear programming

NSP	-	National Strategic Plan
NSWMD	-	National Solid Waste Management Department
OR	-	Operation Research
OWPN	-	Optimal Waste Processing Network
PSE	-	Process systems engineering
RE	-	Renewable energy
RM	-	Ringgit Malaysia
SA	-	System Analysis
SE	-	System Engineering
SWMPI	-	Sustainable Waste Management Performance Indicator
SWMPCC	-	Solid Waste Management and Public Cleansing Corporation
WPNWM	-	Master Plan on National Waste Minimization
WTE	-	Waste-to-energy
WTEA	-	WTE assessment
WTR	-	Waste-to-recycling

LIST OF SYMBOLS

Chapter 4

r_{ij}	-	Normalized value of the *j*th city, *i*th indicator
x_{ij}	-	Original value of the *j*th city, ith indicator
H_i	-	Entropy number of the *i*th indicator
n	-	Number evaluating object
w_i	-	Weight of indicators
m	-	Total number of indicators in the indicator layer
S_k	-	Score of sustainable waste management of the kth criteria

Chapter 5

X	Weight fraction (in wet basis) of different element in MSW
MC	moisture content
W	total waste generation (t)
WF_j	waste fraction for *jth* type of waste disposed to landfills
Y	a conversion factor for converting C to CH_4, which is 16/12.
MCF	*Methane correction factor*
DOC_j:	*Degradable value organic carbon*
DOCF	*Dissimilatabledegradable organic carbon under anaerobic conditions*
F	*Fraction of CH_4 in LFG*
C_{iorgj}	Fraction of anthropogenic carbon in terms of dry mass of component j
OF_j	Oxidation factor of component j

Z		Conversion factor for converting from C to CO_2, which is 44/12
EF_{elec}		Total electricity generation through WTE technology (kWh/t MSW)
$Elec$		Carbon emission avoided factor for every unit of power generation

Chapter 6

$ACPCOST_{pzt}$	-	Annualised capital cost of technology p with capacity z at period t (USD/t)
CAP_{pz}	-	Capacity of the process with size *z*
CEP_{pt}	-	Carbon emission from process *p* in period *t* (t/y)
EF_p	-	Emission factor for process *p*.
$EXREC_{it}$	-	Input rate of external resource *i* during period *t* (t/y)
MAT_{ipt}	-	Input rate for material *i* into process o during period t (units/y)
$MPSM_{ip}$	-	Material process selection matrix
$PRCM_{pi}$	-	Process resource conversion matrix
$PRES_{pt}$	-	Quantity of the resource being processed by process *p* at period *t* (units /y)
$PRICE_{it}$	-	Unit price of product *i* in period *t* (USD/ unit)
$PRODEM_{it}$	-	Product demand for product *i* at time *t* (units/ y)
PRO_{it}	-	Production rate of product *i*during period *t* (units/y)
RES_{it}	-	Amount of resource *i* in the system during time period *t* (t/y)
$SGRES_{ipt}$	-	Quantity of resource *i* generated within the system under process *p* through period *t* (t/y)
$UPCOST_{pt}$	-	Unit processing cost of process *p* in period *t* (USD/unit)
$UVCost_{pt}$	-	Variable cost of the corresponding process *p* in time *t* (USD/unit)
YOP_{pzt}	-	Binary variable of deciding whether the process *p* should be operated at size *z* during period *t*

YP_{pz}	-	Binary decision variable for purchasing technology *p* with capacity *z*
$PROFIT$	-	Overall profit (USD)
REV	-	Product revenues of the MSWM system (USD)
$CCOST$	-	Capital cost (USD)
$CERT$	-	Carbon emission reduction target for the system
$PCOST$	-	Total processing cost the resource (USD)
$VCOST$	-	Total variable operating and maintenance cost of the system (USD)

Greek Letters

$\sum$	-	Summation
$\forall$	-	All belong to

Subscripts

Chapter 4

i	indicator
j	city
k	criteria

Chapter 5

j	component of MSW

Chapter 6

i	-	Resource/product
p	-	Process/technology
t	-	Period
z	-	Capacity of plant

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Municipal solid waste (MSW) commonly known as refuse or rubbish, discarded from residential, commercial, and institutional areas, is a striking by-product of civilization. MSW management (MSWM) is always recognised as a complex system, which involves many technologies associated with controlling waste generation, handling and storage, transportation, processing and final disposal. This chapter introduces the research backgrounds that include the outlook of Malaysia's waste generation and management, and Malaysia's focal development for sustainability, followed by the problem statement and research questions drawn from the study. Next, the research objectives and the scopes of this study focus on the development of a novel structural framework for integrated MSWM system. Finally, this chapter highlights the contributions of this thesis towards the integrated and sustainable waste management for Iskandar Malaysia region and other cities as a whole.

1.2 Research Background

1.2.1 Current Situation and Problem of MSWM in Malaysia

Malaysia's Solid Waste and Public Cleansing Management Act of 2007 (Act 672) define municipal solid waste (MSW) as controlled solid wastes that include commercial, household, institutional and public solid wastes. Waste management is one of the critical environment issues in Malaysia. MSW in Malaysia is typically disposed off in a bin or container within the house premises and collected by regional private concessionaires. The waste is first sent to the transfer stations for compaction, with a minimal sorting, before being sent to the waste disposal sites. In year 2009, 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 (Agamuthu *et al.*, 2009). In year 2012, the government starts to enforce the regulation of waste recycling by increasing the household recyclable waste collection rate through the program 3+1 waste collection (3 days in a week for mixed MSW collection and one day for recyclable waste collection); however, the program is considered as unsuccessful with the recycling rate remained low. The practice of waste segregation is random and unofficial in Malaysia, while waste recycling is mainly performed by garbage scavengers at the landfill sites. Landfilling 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. Over dependence on landfilling and inappropriate waste disposal has continuously pressing the government's financial, as well as the nation's environmental, health and safety issues. It also amplifies 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 primary release of GHG comes from waste landfill sites, which contributed up to 90% of the total emission from the waste sector in Malaysia (Malaysia Second National Communication to the UNFCCC, 2007).

The substantial growth of the waste generation and the complexity of the waste composition make the waste management system more challenging. In addition, inadequate storage, collection and disposal practices with lack of legislation and policies for long-term waste management planning had increased the worries of municipal authorities (Daiz, 2011).The situation is more severe in the developing countries such as Malaysia. The government of Malaysia had spent millions of Ringgit on waste management. About RM 662 M was spent in year 2005 on solid waste management (SWM) and it is estimated to rise to RM 1.043 B by year 2020 (Ministry of Housing and Local Government (MHLG), 2006). The increase of management cost is due to the investment cost of technologies and programs for the SWM mainly through sanitary landfill and partly through incineration. Approximately half of the Malaysia capital investment of MSWM has been spent on the waste treatment and disposal technologies. Such expenditure transpires the need to find alternative solutions to achieve efficient and sustainable MSWM at minimal cost.

1.2.2 System Approach to Waste Management

System analyses such as engineering models, analysis platforms, and assessment tools are predominantly used as decision-support tools for planning process, as well as monitoring and optimizing existing waste management system since the 1960s (Chang *et al.,* 2011). Most of the models presented in the literature aim to guide the decision maker towards the choice of the best strategy in MSWM, with a simple goal of one objective (e.g. optimal waste collection routes for transportation, maximize energy production from waste recovery, minimal waste-to-landfill capacity) or complex goal (e.g. evaluating the alternative waste management strategies with maximum cost and maximum energy recovery). Apart from that, most of the models for waste management and the corresponding tools have so many variables and constraints as well as requiring large quantity of data and complex equation, solving them through general – purpose solvers can be very hard and time-consuming.

1.3 Problem Statement

The MSMW in Malaysia to date are not well managed towards sustainable development. There is a definite need to have a systematic and comprehensive MSWM framework and models to address the MSWM issues, modeling the full potential of waste as a resource, and integrating different types of waste processes in a MSWM system towards sustainable and integrated management. Following are the problems identified for the current MSMW framework:

(1) There is a great diversity in the nature and standards of a waste management system within and between countries and different urban areas. Various MSWM system claims to be a sustainable development framework, but there are different standards of defining a sustainable and integrated waste management system. Computerized model of MSWM system could be more challenging with diverse elements and standards. Apart from that, the current waste management indicators are not covering economic aspect. A comprehensive indicator system for sustainable waste management is essential to provide a guideline for decision-makers to benchmark the system with the best practice and keep track on the performances.

(2) Current MSWM strategies are highly dependent on landfill while the waste recycling program in Malaysia faced a failure due to the behaviour issues of the community. Therefore, another alternative for waste management, the waste-to-energy (WTE) rose as a promising strategy as MSW is a potential energy source. Nevertheless, the possibility of WTE in Malaysia had not been examined thoroughly. Understanding the full potential of WTE in Malaysia is essential for the planning of MSWM system.

(3) The current MSWM in Malaysia can be improved through system analyses in optimisation. Although there are various models designed to address the MSW issues, the literature indicates the lack of proposal for sustainable waste management in Malaysia that integrated technology selection for solid waste treatment and WTE treatment, mitigation of GHG emission and optimisation of economic impact for a long term planning.

The problem statement for this research is stated as follows:

Given a case study of the current MSWM system, it is desirable to determine the level of sustainable waste management, forecast the WTE potential energy, and finally analyse the optimal waste processing network towards integrated waste management system by using three comprehensive methodologies.

1.4 Research Questions

Several key research questions are raised from the problem statement:

Q1. How sustainable is the current MSWM system in Malaysia as compared to other countries?

Q2. What is the potential of energy production and carbon reduction with various WTE strategies for MSW?

Q3. What are the best available technologies for MSW in Malaysia to be utilised in order to achieve optimal profit and energy production from waste with minimal GHG emission?

1.5 Research Objectives

In order to address the research questions, the main aim of this research is to develop a sustainable MSMW system with a systematic and comprehensive framework based on structural optimization modelling approach and indicator system.

In order to achieve the ultimate goal, three specific objectives bounded on the relevant research questions are listed as follow:

1) Development of an indicator system for MSWM to evaluate the degree of sustainability of MSWM system and to understand Malaysian' MSWM performance (Q1)
2) Development of a modeling system to forecast and assess the energy and carbon reduction potential for WTE strategies of MSWM in Malaysia (Q2)
3) Development of a holistic optimisation model of MSWM system with optimal resource allocation, profit targeting, capacity planning, and environmental evaluation to fulfil the co-benefits of long term planning (Q3)

1.6 Scope of Work

In order to achieve the intended research objectives, several scopes of the study have been identified as follow:

1) Literature review and analyses on the current scenario and state-of-art on:
   i. The current scenario of MSWM in Malaysia.
   ii. The state-of-the-art research on MSWM in the aspect of indicators development, process network and process optimisation.

2) Developing a waste management indicator system, namely Solid Waste Management Performance Indicator (SWMPI). The specific scopes include:
   i. Investigating the potential factors and indicators for MSWM based on the availability of data resources as well as key parameters in the development of sustainable MSWM.
   ii. Developing a calculation model to determine the weighting factors of the waste management indicators after the essential data has been collected.
   iii. Ranking and evaluating the status of Malaysia waste management from the indicator system.

3) Developing a forecasting model, namely Waste-to-energy Assessment (WTEA) Model. The specific scopes include:
   i. Assessing the potential of WTE for RE production and carbon reduction in Malaysia by considering the chemical compositions and biogenic carbon fractions of the waste.
   ii. Performing sensitivity analysis on case studies to analyse and evaluates the economic and technical performances of the designed MSWM system.

4) Developing an optimisation model, namely the Optimal Waste Processing Network (OWPN). The specific scopes include:
   i. Developing an optimisation model to aim for the maximum profit and resource utilisation planning of MSWM system. It also takes into account for waste treatment technologies, forecasts the production of by-product from the waste treatment process, estimates the facility capacity, and forecast the GHG emission of the system.
   ii. Performing sensitivity analysis on case studies to analyse and evaluate the economic and technical performances of the designed MSWM system.

1.7 Research Contributions

The main contribution of this research is produce a structural and comprehensive framework based on optimization modelling approach and indicator as tools to evaluate the economic and environmental impacts for the development of a sustainable waste management system. The specific research contributions are described as follows:

i. A new indicator system known as Sustainable Waste Management Performance Indicator (SWMPI) for evaluating the status of MSWM system (Contribution 1).

ii. A new simulation model known as WTE Assessment (WTEA) model for the prediction and assessment of potential energy production and GHG emission reduction for WTE system (Contribution 2)

iii. A new optimisation model known as Optimal Waste Processing Network (OWPN) model is capable to determine the optimal design and operational of waste management processing network. The short computational running time of MILP model enable a quick analysis thus making the constructive economic and technical evaluation become possible. Since the models are time dependent, the models would be able to generate periodical results that are essential to study the pattern of waste utilisation and thus, it would be beneficial especially for the policy makers. (Contribution 3)

iv. Contribution towards achieving Malaysia's goals and targets in MSMW. Case studies implemented in this research works are based on data collected within the region of Malaysia. The results therefore reflect the evaluation of MSWM system in Malaysia. These results will be analysed and evaluated as a mean to promote the implementation of integrated and sustainable MSWM system (Contribution 4).

Publications spawned as parts of this research work are listed in Appendix 1 with associated key contributions of this thesis.

1.8 Thesis Outline

Overall, this thesis comprises of seven chapters, a graphical presentation of the entire studies performed in this thesis work is presented in Figure 1.2, showing the inter-relationship between research objectives. The solid line arrows shows the flow of the thesis presentation and the dotted arrows show the linkage of the outcome of each individual study to the input of the different studies.

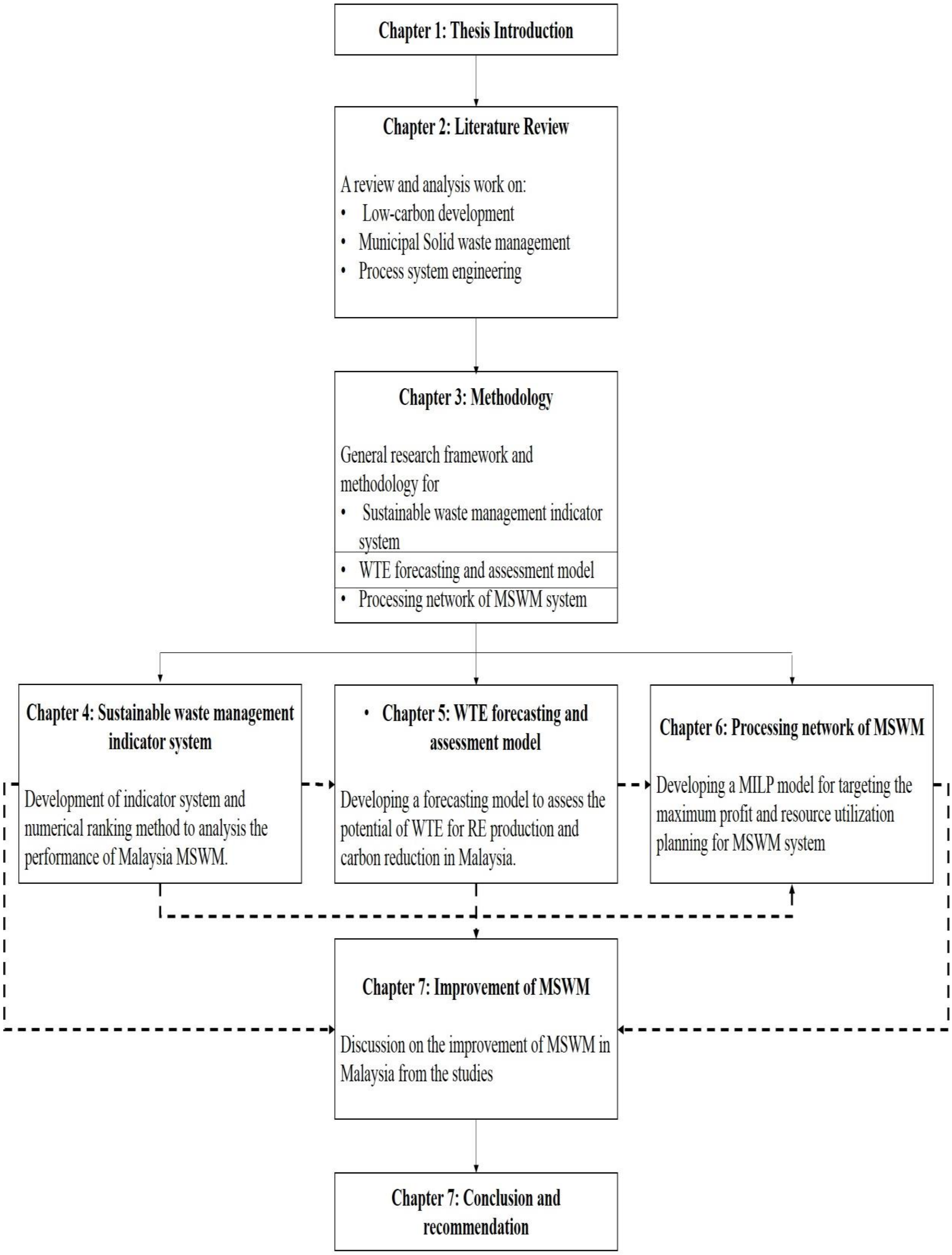

Figure 1.1: The conceptual link among the chapters and thesis work

REFERENCES

Agamuthu, P., Fauziah, S. H., and Kahlil, K. (2009). Evolution of solid waste management in malaysia: Impacts and implications of the solid waste bill. *Journal of Material Cycles and Waste Management*. 11(2), 96–103.

Aishah, S. A. K. S., Hanafi, A. Z. A., Mohamad, R.S., Kheng, H. K., and Hairi, A. (2008). Combustion characteristics of Malaysian municipal solid waste and predictions of air flow in a rotary kiln incinerator. *Journal of Mater Cycles Waste Management*. 10, 116–123.

Arena, U. (2012). Process and technological aspects of municipal solid waste gasification: A review. *Waste Management*. 32(4), 625-639.

Arendse, L., and Godfrey, L. (2010). Waste Management Indicators for National State of Environment Reporting. United Nations Environment Programme (UNEP).

Ayhan, D. (2011). Waste Management, Waste Resource Facilities and Waste Conversion Processes. *Energy Conversion and Management*. 52(2), 1280-1287.

Badran, M. F. and El-Haggar, S. M. (2006). Optimisation of municipal solid waste management in Port Said - Egypt. *Waste Management.* 26, 534-545.

Barcelona City Council. (2013). Waste Prevention Plan for Barcelona 2012-2020. Barcelona: Department of the Environment and Urban Services. (Accesed 20 July 2014). http://w110.bcn.cat/MediAmbient/Continguts/Vectors_Ambientals/Neteja_i_Gestio_de_Residus/Documents/Fitxe

Beijing Municipal Bureau of Statistics. (2013). *Beijing Statistics Year book 2013. Chapter 4-19: Wastewater and waste management*.

Brisson, I. E. (1997). Assessing the Waste Hierarchy – a Social Cost-Benefit Analysis of Municipal Solid Waste Management in the European Union.

Chang, N. B., Chen, Y. L., and Wang, S. F. (1997). A fuzzy interval multi-objective mixed integer programming approach for the optimal planning of solid waste management systems. *Fuzzy Sets and Systems*. 89(1), 35-60.

Chang, N.B., Qi, C., Islam, K., and Hossain, F. (2012). Comparisons between global warming potential and cost–benefit criteria for optimal planning of a municipal solid waste management system. *Journal of Cleaner Production*. 20(1), 1-13.

Chen, Y.T., and Chang, D. S. (2010). Diffusion effect and learning effect: an examination on MSW recycling. *Journal of Cleaner Production*. 18(5), 496-503.

Chua, K. H., Endang, J. M. S., and Leong, Y. P. (2011). Sustainable municipal solid waste management and GHG abatement in Malaysia. *In: 15th International Conference on ISO & TQM*. 4(2), 1-8.

Cifrian, E., Coz, A., Viguri, J., and Andrés, A. (2010). Indicators for Valorisation of Municipal Solid Waste and Special Waste. *Waste and Biomass Valorization*. 1(4), 479-486.

City of London. (2014). Planning a sustainable future for the City of London: Waste Strategy 2013-2020. (Accesed 20 July 2014). https://www.cityoflondon.gov.uk/services/environment-and-planning/waste-and-recycling/Documents/city-of-london-waste-strategy.pdf

Clean Authority of Tokyo 32 Cities. Quantity and contents of waste.http://www.union.tokyo23-seisou.lg.jp.e.de.hp.transer.com/somu/koho/toke/nakami/index.html

Dai, C., Li, Y. P., and Huang, G. H. (2011). A two-stage support-vector-regression optimisation model for municipal solid waste management – A case study of Beijing, China. *Journal of Environmental Management*. 92(12), 3023-3037.

Daiz, L. F. (2011). *Solid waste management in developing countries: Status, perspectives and capacity building*. CalRecovery, Inc.

Demirbas, A. (2011). Waste management, waste resource facilities and waste conversion processes. *Energy Conversion and Management*. 52(2), 1280-1287.

Deng, H., Yeh, C. H., and Willis, R. J. (2000). Inter-company comparison using modified TOPSIS with objective weights. *Computers and Operations Research*. 27, 963–973.

Department of the Environment (DOE). (1995). Making Waste Work: a Strategy for Sustainable Waste Management in England and Wales. HMSO, London.

Department of the Environment, United Kingdom. (1995). *Making Waste Work: A strategy for Sustainable Waste Management in England and Wales*. London: HMSO.

Dickinson, J., Khan, J., and Amar, M. (2013). Inventory of New York City Greenhouse Gas Emissions. Mayor's Office of Long-Term Planning and Sustainability. New York. (Accesed 16 October 2014). http://www.nyc.gov/html/planyc/downloads/pdf/publications/NYC_GHG_Inventory_2013.pdf

Economic Planning Unit (EPU). (2010). *Tenth Malaysian Plan*. Malaysia: EPU, Kuala Lumpur

Economist Intelligence Unit. (2011).*Asian Green City Index: Assessing the environmental performance of Asia's major cities*. Siemens AG. (Accesed 20 July 2014). http://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/report_asia.pdf

Edgar, T. F., Himmelblau, D. M. and Lasdon, L. S. (2001). *Optimisation of Chemical Processes*. McGraw-Hill.

Energy Information Administration (EIA). (2010). Updated capacity cost estimates for electricity generation plants, Office of Energy Analysis, Washington: U. S. Department of Energy., Washington, USA.

Engku Azman Tuan Mat. (2001). Partnership between Government, Waste Management Companies, Recyclers, and Communities in the Context of the 3Rs in Waste Management.

Environmental Quality (EQA) Act 1974 (Act 127). (2006). The Commissioner Of Law Revision, Malaysia

European Environmental Agency (EEA). (2007). Indicators. (Accesed 13 November 2014). http://www.eea.europa.eu/themes/waste/indicators.

Fragkou, M. C., Vicent T., and Gabarrell X. (2010). A general methodology for calculating the MSW management self-sufficiency indicator: Application to the wider Barcelona area. *Resources, Conservation and Recycling***.** 54(6), 390-399.

GAMS Development Corporation. (2013). GAMS: General Algebraic Modeling System (version 22. 9) [Computer software]. Washington, United States. (Accesed: 11 November 2013). www.gams.com

Government of Malaysia (GOM). (2007). *Solid Waste & Public Cleansing Management Act*. Government Reports 2002. Kuala Lumpur: Government Printers.

Greene, K. L. and Tonjes D. J. (2014). Quantitative assessments of municipal waste management systems: Using different indicators to compare and rank programs in New York State. *Waste Management.* 34(4), 825-836.

Guimaraes, B., Simoes, P., and Marques, R.C. (2010). Does performance evaluation help public managers? A balanced scorecard approach in urban waste services. *J. Environ. Manage*. 91 (12), 2632–2638.

Guo, P., and Huang, G. H. (2009). Inexact fuzzy-stochastic mixed-integer programming approach for long-term planning of waste management – Part A: Methodology. *Journal of Environmental Management*. 91(2), 461-470.

Haslenda, H., and Ho, W. S. (2011). Renewable energy policies and initiatives for a sustainable energy future in Malaysia. *Renewable and Sustainable Energy Review*. 15, 4780-4787.

Hassan, M. A., Idris, A., Ariff, A., Abdul Karim, M. I., Abdul Razak, A. R., and Baharum, Z. (2001). Co-composting of sewage sludges and municipal solid wastes. Research on sludge. Final report. Indah Water Konsortium and Universiti Putra Malaysia.

Health & Environmental Services, City of London. (2012). Planning a sustainable future for the City of London. City of London. (Accesed 16 October 2014). http://www.cityoflondon.gov.uk/services/environment-and-planning/waste-and-recycling/Documents/city-of-london-waste-strategy.pdf

Helmy, M., Laksono, T. B., Gardera, D. (2006): 3R Implementation in Indonesia. Proc. of Senior Official Meeting on the 3R Initiative. J1CA. Tokyo. Japan

Hoornweg, D. and Bhada-Tata, P. (2012). What a Watse: A Global Review of Solid Waste Management. World Bank. Washington.

Huszain Huzin. (2004). *National Waste Recycling Program*. Power-Point presentation, Seminar for the Study on National Waste Minimization in Malaysia, Ministry of Housing and Local Government, 16 September 2004, Kuala Lumpur.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme. Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan.

Iskandar Regional Development Authority. (2010a). Integrated Solid Waste Management Blueprint of Iskandar Malaysia.. Johor Bahru, Malaysia: Maunsell., Malaysia.

Iskandar Regional Development Authority. (2010b). Renewable Energy and Energy Efficiency Blueprint for Iskandar Malaysia. Johor Bahru, Malaysia.

Jabatan Pengurusan Sisa Pepejal Negara (JPSPN). (2015). Laman Web Rasmi Jabatan Pengurusan Sisa Pepejal Negara - JPSPN. (Accesed 13 April 2013). http://www.kpkt.gov.my/jpspn_en_2013/main.php?Content=vertsections&SubVertSectionID=137&VertSectionID=1&CurLocation=51&IID=&Page=1

Johari, A., Saeed, I. A., Hashim, H., Alkali, H., and Ramli, M. (2012a), Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. *Renewable and Sustainable Energy Reviews*. 16(5), 2907-2912.

Johari, A., Mat, R., Alias, H., Hashim, H., Hassim, H. M. H., and Rozainee. M. (2012b) Formulation and Heat Contents of Simulated MSW with High Moisture Content. *Journal of Engineering Science and Technology*. 7,6701 – 710.

Juul, N., Münster, M., Ravn, H., and Söderman, M. L. (2013). Challenges when performing economic optimisation of waste treatment: A review. *Waste Management.* 33(9), 1918-1925.

Kalantarifard, A. and Go, S. Y. (2011). Energy potential from municipal solid waste in Tanjung Langsat landfill, Johor, Malaysia. *International Journal of Engineering Science and Technology*. 3(12), 8560-8568.

Kankyo Metro Tokyo. (2015).*Waste Management ｜Environment of Tokyo*. (Accesed 12 April 2014). http://www.kankyo.metro.tokyo.jp/en/waste/

Kathirvale, S., Muhd, Y. M. N., Sopian, K., and Samsuddin, A. H. (2004). Energy potential from municipal solid waste in Malaysia. *Renewable Energy*. 29(4), 559-567.

Klundert, A. V. D. and Anschütz, J. (2001). ntegrated Sustainable WasteManagement - the Concept. *Tools for Decision-makers.* WASTE

Krishnan, G. (1999). Solid waste separation at source pilot project initiated in Putrajaya. The Star, 19th November 2009.

Lastella, G., Testa, C., Cornacchia, G., Notornicola, M., Voltasio, F., and Sharma, V. K. (2002). Anaerobic digestion of semi-solid organic waste: biogas production and its purification. *Energy Conversion and Management*. 43(1), 63-75.

Li, P., and Chen, B. (2011). FSILP: Fuzzy-stochastic-interval linear programming for supporting municipal solid waste management. *Journal of Environmental Management.* 92(4), 1198-1209.

Liamsanguan, C., and Gheewala, S. H. (2008). The holistic impact of integrated solid waste management on greenhouse gas emissions in Phuket. *Journal of Cleaner Production*.16(17), 1865-1871.

Lim, J. S. (2013). Optimal Design and Synthesis of Rice Supply Chain. Universiti Teknologi Malaysia. PhD Thesis.

Liu, C., Guo, Z., Han, B., Yuan, H., and Zhu, S. (2013). The Construction and Empirical Study of Low-Carbon City Comprehensive Evaluation. LTLGB 2012. F. Chen, Y. Liu and G. Hua, Springer Berlin Heidelberg**:** 1049-1059.

Liu, L., Zhou, J. Z., An, X. L., Zhang, Y. C., and Yang, L. (2010). Using fuzzy theory and information entropy for water quality assessment in Three Gorges region, China. *Expert Systems with Applications*. 37(3), 2517–2521.

Low Carbon Society Blueprint for Iskandar Malaysia 2025. 2012. Johor Bahru, Malaysia. (Accessed 1 December 2013). 2050.nies.go.jp/cop/cop18/SPM_LCS%20Blueprint_Iskandar%20Malaysia.pdf

Malaysia Second National Communication to the UNFCCC. (2007). ISBN 978-983-44294-9-2.

Manaf, L. A., Samah, M. A. A., and Zukki, N. I. M. (2009). Municipal solid waste management in Malaysia: Practices and challenges. *Waste Management, 29*(11), 2902-2906

McDougall, F., White, P., Franke, M., and Hindle, P. (2001). *Integrated Solid Waste Management: A Life Cycle Inventory*. 2nd Edition. United Kingdom: Blackwell Science, Oxford.

Mendes, P., Santos, A.C., Perna, F., and Teixeira, M. R. (2012). The balanced scorecard as an integrated model applied to the Portuguese public service: a case study in the waste sector. *J. Clean. Prod*. 24, 20–29.

Merrild Hanna. (2009). *Indicators for waste management: How representative is global warming as an indicator for environmental performance of waste management?* Technical University of Denmark. PhD Thesis.

Milutinović, B., Stefanović, G., Dassisti, M., Marković, D., and Vučković, G. (2014). Multi-criteria analysis as a tool for sustainability assessment of a waste management model. *Energy*.74(0), 190-201.

Ministry of Housing and Local Government (MHLG). (1998). Action Plan for a Beautiful and Clean Malaysia, Kuala Lumpur: Government Printers.

Ministry of Housing and Local Government (MHLG). (2005). National Strategic Plan for Solid Waste Management in Malaysia, Ministry of Housing & Local Government Malaysia.

Ministry of Housing and Local Government (MHLG). (2006a). The Study of National Waste Minimization in Malaysia, Ministry of Housing and Local Government and the Japanese International Cooperation Agency

Ministry of Housing and Local Government (MHLG). (2006b). The National Solid Waste Management Policy Ministry of Housing and Local Government.

Ministry of Housing and Local Government (MHLG). (2012). Laboratory of solid waste management. www.kpkt.gov.my/kpkt/fileupload/hebahan/lab_sisa_pepejal.pdf. (Accessed: 7 July 2013)

Münster, M., and Meibom, P. (2010). Long-term affected energy production of waste to energy technologies identified by use of energy system analysis. *Waste Management.* 30(12), 2510-2519

Münster, M., and Meibom, P. (2011). Optimisation of use of waste in the future energy system. *Energy*. 36(3), 1612-1622.

Nadzri, Y., and Larsen, B. (2007). Federalising Solid Waste Management in Peninsular Malaysia. *Waste Management*. 1-13.

New York State Department of Environmental Conservation. (2010). Beyond Waste: A sustainable materials management strategy for New York State. New York.(Accessed 25 March 2013). http://www.dec.ny.gov/docs/materials_minerals_pdf/frptbeyondwaste.pdf

Ng W. P. Q., Varbanov P. S., Klemes J. J., Hegyhati M., Bertok B., Heckl I., and Lam H. L. (2013). Waste to energy for small cities: economics versus carbon footprint. *Chemical Engineering Transactions*. 35, 889-894

Noor, Z. Z., Yusuf, R. O., Abba, A. H., Abu Hassan, M. A., and Mohd Din, M. F. (2013). An overview for energy recovery from municipal solid wastes (MSW) in Malaysia scenario. *Renewable and Sustainable Energy Reviews*. 20(0), 378-384.

OECD. (2004). OECD key environmental indicators. OECD Environment Directorate, Paris.

Oh, T. H., Pang, S. Y., Chua, S. C. (2010). Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth. *Renewable and Sustainable Energy Reviews*. 14: 1241–1252

Omar, I., Mncwango, S. (2005). Sanitary landfill energy harnessing and applications. *Journal of Engineering, Design and Technology.* 3:127–39

Pires, A., Martinho, G., and Chang, N.-B. (2011). Solid waste management in European countries: A review of systems analysis techniques. *Journal of Environmental Management.* 92(4), 1033-1050.

Poeschl, M., Ward, S., and Owende, P. (2012). Environmental impacts of biogas deployment – Part II: life cycle assessment of multiple production and utilisation pathways. *Journal of Cleaner Production.* 24(0), 184-201.

Poeschl, M., Ward, S., and Owende, P. (2012). Environmental impacts of biogas deployment – Part I: life cycle inventory for evaluation of production process emissions to air. *Journal of Cleaner Production*. 24(0), 168-183.

Pusat Tenaga Malaysia. (2010). Malaysia's 2011 Proposed Solar, Biomass, Biogas and Hydro Tariffs (Seri Kembangan, Malaysia).

Rardin, R. L. (1997). *Problem Solving with Matheamtical Models*.

Rathi, S. (2007). Optimisation model for integrated municipal solid waste management in Mumbai, India. *Environment and Development Economic.* 12: 105-121.

Rhyner, C. R. (1998). The effects on waste reduction and recycling rates when different components of the waste stream are counted. *Resour. Conserv. Recycl*. 24, 349–361.

Rimaitytė, I., Denafas, G., Martuzeviciusl, D., Kavaliauskas, A. (2010). Energy and Environmental Indicators of Municipal Solid Waste Incineration: toward Selection of an Optimal Waste Management System. *Polish J. of Environ. Stud*. 19(5), 989-998

Rodionov, M., and Nakata, T. (2011). Design of an optimal waste utilisation system: a case study in St. Petersburg, Russia. *Sustainability*. 3, 1486-1509.

Ryu, C. (2010). Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emission in South Korea. *Journal of Air & Waste Management*. 60, 176–183.

Sakawi, Z. (2011). Municipal solid waste management in Malaysia: solution to sustainable waste management in Malaysia. *J Appl Sci Environ Sanitation*. 6, 29–38.

Salvia, M., Cosmi, C., Macchiato, M., and Mangiamele, L. (2002). Waste management system optimisation for Southern Italy with MARKAL model. *Resources, Conservation and Recycling*. 34(2), 91-106.

Santibañez-Aguilar, J. E., Ponce-Ortega, J. M., Betzabe González-Campos, J., Serna-González, M., and El-Halwagi, M. M. (2013). Optimal planning for the sustainable utilisation of municipal solid waste. *Waste Management*. 33(12), 2607-2622.

Sevigné Itoiz, E. (2013).*Greenhouse Gases (GHG) emissions from Municipal Solid Waste of Barcelona*. Presentation, Toulouse.

Shadiya, O. O., Satish, V., and High, K. A. (2012). Process enhancement through waste minimization and multi-objective optimisation. *Journal of Cleaner Production*. 31(0), 137-149.

Shannon, C. E. (1948). A mathematical theory of communications. *Bell Systems Technical Journal*. 27(3), 379-423.

Statistical office of the European Union (Eurostat). (2003). Municipal waste generation and treatment, by type of treatment method (tsdpc240): Indicator Profile (ESMS). (Accessed 20 August 2014). http://ec.europa.eu/eurostat/cache/metadata/EN/tsdpc240_esmsip.htm

Statistics Division of Bureau of General Affairs, Tokyo. (2008). (Accesed 20 April 2014). http://www.toukei.metro.tokyo.jp/homepage/ENGLISH.htm

Sundana. E. J. (2004). Solid waste management services in Bandung Municipality: Status of financial and cost recovery. Proc. of Financing and Cost Financing and Cost Recovery for the Provision of Urban Environmental Infrastructure Services. AlT Center, Bangkok, Thailand.

Surabaya City (2011). *Community-Based Solid Waste Management as Best Practice in Surabaya City*. Presentation at the 2nd High Level Seminar on Environmentally Sustainable Cities, 15-16 March 2011, Kitakyushu, Japan

Swedish Environmental Protection Agency. (2005). A Strategy for Sustainable Waste Management: Sweden's Waste Plan. ISBN: 91-620-1249-5

Swedish Environmental Protection Agency. (2012). From waste management to resource efficiency: Sweden's Waste Plan 2012–2017. Stockholm.

Swedish Waste Management Association. Towards a greener future with Swedish. Waste-to-energy. Malmo. (Accessed 16 October 2014). http://www.avfallsverige.se/fileadmin/uploads/forbranning_eng.pdf

Tan, S. T, Hashim, H., Lim, J. S., Ho, W.S., and Lee, C. T. (2014b). Energy and Emission Benefits of Renewable Energy Derived from Municipal Solid Waste: Analysis of a Low Carbon Scenario in Malaysia. *Applied Energy*. 136, 797-804. (DOI: 10.1016/j.apenergy.2014.06.003)

Tan, S. T,Lee, C. T, Hashim, H., Ho, W.S., and Lim, J. S. (2014a). Optimal Process Network for Municipal Solid Waste Management in Iskandar Malaysia. *Journal of Cleaner Production*. 48-58.

Tan, S. T., Hashim, H., Ho, W. S., and Lee, C. T. (2013). Optimal Planning of Waste-to-Energy through Mixed Integer Linear Programming. *World Academy of Science, Engineering and Technology*.78:1832-1839 .

Taparugssanagorn, K., Yamamoto, K., Nakajima, and F., Fukushi, K. (2007). Evaluation of waste-to-energy technology: Economic feasibility in incorporating into the integrated solid waste management system in Thailand. *The IE Network Conference*. 91-96.

Tchnobanoglous, G., Theisen, H., and Vigil, S. A. (1993). *Integrated solid waste management: Engineering principles and management issues*. McGrow-Hill.

The Greater London Authority. (2013). The Greenhouse Gas Emissions Performance Standard for London's Municipal Waste – 2011/12 Update. London.

The Japan Institute of Enegry. (2008). The Asian Biomass Handbook: A guidbook for biomas production and utilisation.

UNCSD. (2011). Indicators of Sustainable Development: Guidelines and Methodologies. (Accessed 24 January 2015). http://www.un.org/esa/sustdev/publications/publications.htm

United Nations Population Division. (2015). United Nations Department of Economic and Social Affairs. (Accessed 2 January 2015). http://www.un.org/en/development/desa/population/

United Stae Environmental Protection Agency. (2013). Non-hazadous Waste Management Hierachy. (Accessed 2 January 2015) http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm

US Environmental Protection Agency. (2013, June 17). Municipal Solid Waste. (Accesed 15 January 2013). http://www.epa.gov/epawaste/nonhaz/municipal/index.htm

UTM-Low Carbon Asia Research Center. (2013). Low Carbon Society Blueprint for Iskandar Malaysia 2025 Full Report. Publisher: Universiti Teknologi Malaysia. Malaysia.

Vergara, S., and Tchobanoglous, G. (2012). Municipal solid waste and the environment: A global perspective. *Annual Review of Environment and Resources*. 37, 277-309.

Wang, H. and Wang, C. (2013). Municipal solid waste management in Beijing: characteristics and challenges. *Waste Management & Research*. 31(1), 67-72.

Wang, T. C., and Lee, H. D. (2009). Developing a fuzzy TOPSIS approach based on subjective weights and objective weights. *Expert Systems with Applications*. 36 (5), 8980-8985.

Wanichpongpan, W., and Gheewala, S. H. (2007). Life cycle assessment as a decision support tool for landfill gas-to energy projects. *Journal of Cleaner Production*. 15(18), 1819-1826.

Wenger, R. B., Rhyner, C. R., and Wagoner, E. E. (1997). Relating disposal-based solid waste reduction rates to recycling rates. *Resour. Conserv. Recycl*. 20, 267–276.

Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G. (2012). Comparative analysis of solid waste management in 20 cities. *Waste Management*. 30, 237–254.

Xu, X. Z. (2004). A note on the subjective and objective integrated approach to determine attribute weights. *European Journal of Operational Research*. 156 (2), 530–532.

Xu, Y., Huang, G. H., Qin, X. S., Cao, M. F., and Sun, Y. (2010). An interval-parameter stochastic robust optimisation model for supporting municipal solid waste management under uncertainty. *Waste Management*. 30(2), 316-327.

Yabar, H., Hara, K., and Uwasu, M. (2012). Comparative assessment of the co-evolution of environmental indicator systems in Japan and China. *Resources, Conservation and Recycling*. 61(0), 43-51.

Yeh, C.H., and Xu, Y. (2013). Sustainable planning of e-waste recycling activities using fuzzy multi-criteria decision making. *Journal of Cleaner Production*. 52(0), 194-204

Yip, C. H., and Chua, K.H. (2008). An overview on the feasibility of harvesting landfill gas from MSW to recover energy. *ICCBT*. F(28), 303–10.

Young, G. C. (2010). *Municipal solid waste to energy conversion process: Economic, technical, and renewable comparisons*. United States of America: John Wiley & Sons, Inc.

Zabaleta Amaia. (2008). Sustainability Indicators for Municipal Solid Waste Treatment Case study - The City of Stockholm: landfill vs. incineration. Industrial Ecology, Royal Institute of Technology. Master of Science Thesis Stockholm. ISSN 1402-7615

Zaini S. (2003). Federalization of Solid Waste Management in Malaysia: A research study of Alam Flora Company. National Environment Management Seminar. Institute of Postgraduate Study, UKM. 8-9 Julai 2003. pg 742-750.

Zeleny, M. (1982). *Multiple Criteria Decision Making*. McGraw-Hill, New York.

Zhou. P., Ang, B. W., and Poh, K. L. (2006). Comparing aggregating methods for constructing the composite environmental index: An objective measure. *Ecological Economic.* 59(3), 305–311.

Zou, Z. H., Yun, Y., and Sun, J. N. (2006). Entropy method for determination of weight of evaluating in fuzzy synthetic evaluation for water quality assessment indicators. *Journal of Environmental Sciences*. 18 (5), 1020-1023.

Zurbrügg, C., Gfrerer, M., Ashadi, H., Brenner, W., and Küper, D. (2012). Determinants of sustainability in solid waste management – The Gianyar Waste Recovery Project in Indonesia. *Waste Management*. 32(11), 2126-2133.