

ECO EFFICIENCY ASSESSMENT OF DOMESTIC WASTEWATER
TREATMENT SYSTEM IN MALAYSIAN URBAN AREAS

ALI HUSSEIN HASAN SABEEN

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2019

DEDICATION

This thesis is dedicated to my father Mr Hussein Hasan Sabeen and my mother Mrs Salamh Radan, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my beloved wife Nada, my children, Emad, Wael and Arael, brothers Aziz, Daiffallah, Ameen, Hassan, Ahmed, Saleh and my sisters Samiah, Jamilah, Hanan, Amal, my uncles Gieeb, Salem and their families who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. First and foremost I would like to thank both of my supervisors, Associate prof. Dr. Norzita Ngadi and Prof. Dr. Zainura Zainoon Noor for their endless guidance and support throughout the process of finishing this research works. I am grateful to all my beloved family member for supporting me, my father, my mother my wife Nada , my sons Emad, Waile and Awael, my Brothers, Aziz, Daifallah, Ameen, Hasan, and my sisters. Besides, not forgetting to thank my uncle Gaeab Hassan and his family. Their encouragement, guidance, advice and motivation enabled me to complete this project successfully. To the ministry of higher education of Yemen, and Sanaa, university. Without their continued support and interest, this thesis would not have been the same as presented here. I would also like to take this opportunity to express my deepest appreciation to IWK represented by Siti Fairuz of Bunus Kuala Lumpur, Mr Shilan Jelutong Penang and Eng Zullkifili of Medini Johor Bahru for their professional advice, guidance, and continued support throughout this study. Not forgetting to thank the JPP Kuala Lumpur for the help and support.

A heartfelt thanks also goes to Dr. Hafizan che UTM, Associate prof. Salem S.Abu Amr, environmental engineering university technology Kuala Lumpur, Dr. Jalla Tavalý, Dr. Zakrya Abdulwahid Hameed Maousel University, Engineer Ali Alnahary Canadian Nexen Petroleum Yemen, Eng .Rasha Al-Jabali UTM, Eng. Yaseen Al-wesabi industrial Engineering at Binghamton University USA, Mr Mohmmad Jarady Mohsen and Mr Abdullah Mohammed Bahnan for the support and advice.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

ABSTRACT

The main purpose of wastewater treatment is to protect humans against waterborne diseases and safeguard aquatic bio-resources like fish. However, there are environmental costs associated with attaining the required level of water quality such as greenhouse gas emissions due to energy production and eco-toxicity from sludge applications on land. The goal of this study is to assess the eco-efficiency of large-scale sewage treatment plants (STPs) in urban areas, focusing specifically on variations in treatment technologies. Life cycle assessment (LCA) and cost benefit-analysis (CBA) were the analytical tools used to evaluate environmental and economic impacts, respectively. For the purpose of this assessment, three STPs in the major Malaysian cities of Kuala Lumpur, Penang, and Johor Bahru were chosen. These STPs employed different treatment technologies. The Jelutong STP in Penang used a sequence batch reactor to treat domestic wastewater. The Bunus STP in Kuala Lumpur as well as the Medini STP in Johor Bahru employed Aerobic activated sludge. Based on the STP data, Bunus STP had the highest performance in terms of wastewater pollutant removal through 96% biological oxygen demand, 90% chemical oxygen demand, and 68% phosphorus. Based on the LCA for 1m³ treated wastewater, STP Bunus Kuala Lumpur had the highest global warming potential(GWP) and acidification potential (AP) at 2.69E-01 kg CO₂-eq and 2.11E-03 kg SO₂, respectively. Jelutong STP had the highest eutrophication potential (EP) and human toxicity potential (HTP) at 1.47E-02 kg PO₄⁻³ and 5.63E-02 kg DCB-eq, respectively. Medini STP had the highest terrestrial toxicity (TETP) at 2.0E-02 kg DCB-qq. From CBA analysis, Medini STP had the highest operating cost for 1m³ domestic wastewater treatment with RM 0.635 per day and RM232 per year, followed by Bunus STP with RM 0.311 per day and RM 111.6 per year as well as SBR Jelutong Penang with RM 0.157 per day and RM 57.4 per year. In terms of electricity consumption for 1m³ domestic wastewater treatment, aerobic activated sludge Medini STP consumed the highest amount of energy at RM1.02 per day. This is followed by Bunus STP at RM 0.27 per day and Jelutong with RM 0.19 per day. The LCA and CBA framework developed for Bunus plant 1 m³ domestic wastewater flow rate (as a hypothetical example) minimized the environmental impact of GWP by 25%, EP by 3%, AP by 26%, TETP by 3%, and HTP by 3%. In addition, the suggested scenario maximized the benefit of 1m³ domestic wastewater by RM 2.17 per day. The study revealed very different impacts for the three plants, drawing attention to the importance of treatment process choice. The integration of LCA and CBA using the developed framework improve the sustainability of domestic wastewater treatment system in Malaysian urban areas.

ABSTRAK

Tujuan utama rawatan air kumbahan adalah untuk melindungi manusia daripada penyakit bawaan air dan untuk melindungi sumber hidupan bio akuatik seperti ikan. Walau bagaimanapun, terdapat kos persekitaran yang berkaitan bagi mencapai tahap kualiti air yang diperlukan seperti pelepasan gas rumah hijau akibat pengeluaran tenaga, dan ketoksikan-eko dari aplikasi enapcemar ke atas tanah. Matlamat kajian ini adalah untuk menilai kecekapan eko loji rawatan kumbahan (STP) berskala besar di kawasan bandar, dengan memberi tumpuan khusus kepada variasi dalam teknologi rawatan. Penilaian kitaran hayat (LCA) dan analisis-manfaat-kos (CBA) adalah alat analisis yang digunakan masing-masing untuk menilai kesan alam sekitar dan ekonomi. Bagi tujuan penilaian ini, tiga STP di bandar utama Malaysia iaitu Kuala Lumpur, Pulau Pinang dan Johor Bahru telah dipilih. STP ini menggunakan teknologi rawatan yang berbeza. STP Jelutong di Pulau Pinang menggunakan reaktor kelompok turutan untuk merawat air kumbahan domestik. STP Bunus di Kuala Lumpur dan STP Medini di Johor Bahru menggunakan enapcemar aktif. Berdasarkan data STP, STP Bunus menunjukkan prestasi yang tertinggi dalam penyingkiran pencemaran air sisa melalui 96% permintaan oksigen biologi, 90% permintaan oksigen kimia dan 68% fosforus. Berdasarkan LCA untuk 1m^3 air kumbahan dirawat, STP Bunus Kuala Lumpur menunjukkan potensi pemanasan global (GWP) dan potensi pengasidan (AP) masing-masing pada $2.96\text{E}-01$ kg $\text{CO}_2\text{-eq}$ dan $2.11\text{E}-03$ kg SO_2 . STP Jelutong mempunyai potensi eutrofikasi (EP) dan potensi toksisiti manusia (HTP) paling tinggi masing-masing Pada $1.47\text{E}-02$ kg PO_4^{3-} dan $5.63\text{E}-02$ kg DCB-eq. Medini STP mempunyai ketoksikan terestrial tertinggi (TETP) pada $2.0\text{E}-02$ kg DCB-eq. Dari analisis CBA, STP Medini mempunyai kos operasi tertinggi untuk rawatan air kumbahan domestik 1m^3 dengan RM 0.635 sehari dan RM232 setahun diikuti oleh STP Bunus dengan RM 0.311 sehari dan RM 111.6 setahun serta SBR Jelutong Penang dengan RM0.157 sehari dan RM57.4 setahun. Dari segi penggunaan elektrik untuk rawatan 1m^3 air kumbahan domestik, AS STP Medini menggunakan jumlah tenaga tertinggi sebanyak RM1.02 sehari. Ini diikuti oleh STP Bunus pada RM 0.27 sehari dan STP Jelutong dengan RM 0.19 sehari. Rangka kerja LCA dan CBA yang dibangunkan untuk loji Bunus 1m^3 kadaran air kumbahan domestik (sebagai contoh hipotesis) meminimumkan kesan alam sekitar GWP sebanyak 25%, EP sebanyak 3%, AP sebanyak 26%, TETP sebanyak 3 % dan HTP sebanyak 3%. Di samping itu, senario yang dicadangkan memaksimumkan manfaat 1m^3 air sisa domestik sebanyak RM 2.17 sehari. Kajian ini menunjukkan impak yang sangat berbeza untuk ketiga-tiga rawatan yang menarik perhatian kepada kepentingan pemilihan jenis rawatan. Mengintegrasikan LCA dan CBA menggunakan rangka kerja yang dibangunkan meningkatkan kelestarian sistem rawatan air sisa domestik di kawasan bandar Malaysia.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiv
	LIST OF FIGURES	xix
	LIST OF ABBREVIATIONS	xxiii
	LIST OF SYMBOLS	xxv
	LIST OF APPENDICES	xxvi
CHAPTER 1	INTRODUCTION	1
1.1	Problem Background	1
1.2	Problem Statement	2
1.3	Study Objectives	4
1.4	Study Scope	5
1.5	Significance of Research	7
1.6	Thesis Layout	7
CHAPTER 2	LITERATURE REVIEW	9
2.1	Introduction	9
2.2	Type of Wastewater	9
2.3	Domestic Wastewater Treatment System	10
2.3.1	Problems Associated with Wastewater	13
2.3.2	Current Wastewater Treatment Practices in Malaysia	14
2.3.3	Physical Treatment Process	16
2.3.4	Chemical Treatment Process	17
2.3.5	The Biological Treatment System	19

2.3.5.1	Activated Sludge System	19
2.3.5.2	Sequencing Batch Reactor (SBR)	21
2.3.5.3	Activated Sludge with an Extended Aeration	23
2.4	The Differences Between Aerobic and Anaerobic Treatment Technology	24
2.5	Life cycle Assessment	26
2.5.1	Goal and Scope Phase	28
2.5.2	The Life Cycle Inventory (LCI) Phase	29
2.5.3	Life cycle Impacts Assessment (LCIA) Phase	29
2.5.4	Interpretation	31
2.5.5	Limitation of LCA	31
2.6	LCA Application in Wastewater Treatment Plant	32
2.7	The Current Studies in Wastewater Treatment	34
2.7.1	Review of the LCA of Domestic Wastewater Treatment	43
2.8	Gabi 6 Software	58
2.9	Cost Benefit Analysis	60
2.10	Cash Flow	60
2.11	Cost Benefits Threshold Values	61
2.11.1	The Net Profit Value (NPV)	61
2.11.2	Benefits Cost Ratio	62
2.12	The Cost Benefits Analysis Application	62
2.13	Integration of LCA, LCC and CBA	63
2.14	Eco efficiency standards	65
2.14.1	Advantages and disadvantages of Eco- efficiency	66
2.15	Summary	67
CHAPTER 3	RESEARCH METHODOLOGY	69
3.1	Introduction	69
3.2	Selected Sewage Treatment Plants	72
3.3	Data Quality	76
3.4	Data Collection	76

3.4.1	Collection and Analysis of Wastewater Samples	79
3.5	System Boundary and Study Function Units	80
3.6	Life Cycle Impact Assessment	82
3.6.1	CML. 2001 LCIA Impact Assessment Method	83
3.6.2	Allocation	85
3.6.3	Sensitivity Analysis	85
3.7	Assessing the Cost and the Economic Feasibility	86
3.8	Proposed Framework	90
3.9	Cost Estimation Procedure for all Plants	93
3.10	Summary	94
CHAPTER 4 LIFE CYCLE ASSESSMENT OF DOMESTIC WASTEWATER TREATMENT IN MALAYSIAN URBAN AREAS		97
4.1	Introduction	97
4.2	Plants System Boundaries	98
4.3	Results and Discussions	105
4.4	Bunus Kuala Lumpur Wastewater Treatment Plant Case Study	105
4.4.1	The LCIA Results and Analysis for Bunus KI Plant	105
4.4.3	LCIA Result Weighting for Bunus DWWTP	113
4.4.4	Bunus Kuala Lumpur Plant Results and Their Comparison with Previous Studies and Eco-Invent Threshold Values	115
4.4.5	Sensitivity Analysis for Bunus DWWTP	118
4.5	Jelutong Penang Domestic Wastewater Treatment Plant Case Study	119
4.5.1	The LCIA Results and Discussion for Jelutong Penang WWTP	119
4.5.1	LCIA Result Normalization for SBR Jelutong Penan	124
4.5.2	LCIA Result Weighting for SBR Jelutong Penang DWWTP	126

4.5.3	Result Comparison for SBR Jelutong Penang with Previous Studies and Eco-Invent Threshold Values	127
4.5.4	Sensitivity Analysis for SBR Jelutong Penang DWWTP	130
4.6	Medini Johor Bahru Domestic Wastewater Treatment Case Study	131
4.6.1	The LCIA Results and Discussion for Aerobic AS Medini Johor Bahru	131
4.6.4	Result Comparison for Aerobic AS Medini Johor Bahru with Previous Studies and Eco-Invent Threshold Values	139
4.6.5	Sensitivity Analysis for Medini Johor Bahru Plant	141
4.7	Wastewater Treatment Technology Comparisons Based on Life Cycle Assessments	143
4.7.1	Efficiency Comparisons for the Removal of Organic Waste	143
4.7.2	Environmental Impact Category and LCIA Category Weight Comparisons with Previous Studies	145
4.8	Summary	150
CHAPTER 5 COST AND BENEFITS ESTIMATION FOR DOMESTIC WASTEWATER TREATMENT IN MALAYSIAN URBAN AREAS		153
5.1	Introduction	153
5.2	The Source Data Used in this Research	153
5.3	CBA Assumption for all Plants	154
5.3.1	The Plant Outline	154
5.3.2	The Capital Cost For Bunus Kuala Lumpur Plant	155
5.3.2.1	Engineering (Design)	155
5.3.2.2	Procurement and Construction Cost of Bunus DWWTP	156
5.3.3	The Operation Cost of Bunus DWWTP	157
5.3.3.1	The Cost of Electricity for Bunus Kuala Lumpur DWWTP	157

5.3.3.2	The Labor Cost of Operation for Bunus DWWTP	159
5.3.3.3	The Cost of Sludge Disposal for Bunus DWWTP	159
5.3.3.4	The Cost of Chemicals for Bunus DWWTP	160
5.3.4	The Estimation of Bunus DWWTP Revenues	161
5.3.4.1	Revenue from Reusing the Effluent Water	162
5.3.4.2	Revenue from Sludge	162
5.3.4.3	Estimating the Benefit of Producing Electricity for Bunus DWWTP	163
5.3.5	The Present Value (PV), Net Present Value (NPV), and Benefit Cost Ration (BCR) for Bunus DWWTP	165
5.3.6	Cash Flow of Bunus DWWTP During the Plant Life Span	167
5.4	CBA for Jelutong Penang DWWTP	168
5.4.1	The Plant Outline	168
5.4.2	The Capital Cost for Jelutong Penang DWWTP	169
5.4.2.1	Engineering (Design)	169
5.4.2.2	Procurement and Construction of Jelutong DWWTP	170
5.4.3	The Operation Cost for Jelutong DWWTP	171
5.4.3.1	Electricity Cost for Jelutong, Penang DWWTP	171
5.4.3.2	The Labor Cost of Operation for Jelutong DWWTP	172
5.4.3.3	The cost of Sludge Disposal for Jelutong Penang DWWTP	173
5.4.3.4	The Cost of Chemical for Jelutong DWWTP	173
5.4.4	The Estimation of Jelutong DWWTP Revenues	174
5.4.4.1	Revenue from Reusing the Effluent Water	174
5.4.4.2	Revenue from Sludge	175

5.4.4.3	Estimation the Benefits of Producing Electricity for Jelutong DWWTP	176
5.4.5	The Present Value (PV), Net Present Value (NPV) and Benefit Cost Ratio (BCR) for Jelutong Penang DWWTP	177
5.4.6	Cash Flow of Jelutong DWWTP During the Plant Life Span	178
5.5	CBA for Aerobic As Medini Johor Bahru DWWTP	178
5.5.1	The Plant Outline	178
5.5.2	The Capital Cost of Medini DWWTP	179
5.5.2.1	Engineering Design	179
5.5.2.2	Procurement and Construction of Medini DWWTP	180
5.5.3	The Operation Cost of Medini Johor Bahru DWWTP	180
5.5.3.1	The Cost of Electricity for Medini Johor Bahru DWWTP	181
5.5.3.2	Operational Labor Costs for Medini Johor Bahru DWWTP	181
5.5.3.3	The Cost of Sludge Disposal for Medini DWWTP	182
5.5.3.4	The Cost of Chemical for Medini DWWTP	182
5.6	The Estimation of Medini DWWTP Revenues	183
5.6.1	Revenue from Reusing the Effluent Water	183
5.6.2	Revenue From Sludge	184
5.6.3	Estimating the Benefit of Producing Electricity For Merdini DWWTP	185
5.6.4	The Present Value (PV), Net Present Value (NPV) and Benefit Cost Ratio (CBR) for Medini Johor DWWTP	185
5.6.5	Cash Flow of Medini Johor Bahru DWWTP During the Plant Life Span	187
5.7	Discussion and Comparing the Cost and Benefits for all plants	187
5.8	Summary	192

CHAPTER 6	ECO EFFICIENCY FRAMEWORK TOWARD SUSTAINABILITY	193
6.1	Introduction	193
6.2	Sustainability Indicators	193
6.2.1	Environmental Sustainability Indicators	194
6.2.2	Economic Sustainability Indicators	194
6.3	The Proposed Framework for LCA and CBA	196
6.3.1	Life Cycle Assessment of 1m ³ Domestic Wastewater Treatment	197
6.3.2	Estimation the Cost of Domestic Wastewater Framework	198
6.5	Benefits Cost Ratio BCR	202
6.6	Application of the Proposed Sustainability Assessment Framework	203
6.7	Evaluation the LCA and CBA Sustainability Framework	205
6.8	Comparing of ISO 14040 and ISO 14045 Standards	210
6.9	Summary	211
CHAPTER 7	CONCLUSIONS	213
7.1	Introduction	213
7.2	Conclusion	213
7.3	Limitation and Recommendation	219
REFERENCES		221
APPENDIX A		237
APPENDIX B		257
APPENDIX C		264
LIST OF PUBLICATIONS		285

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Type of sewage and the percentage of various systems in Malaysia source (Consortium, 2011; Abdullah <i>et al.</i> , 2017)	11
Table 2.2	Malaysian Standard Limit of Sewage to any Inland Waters or Malaysian Water (Regulation, 2009)	12
Table 2.3	Problems associated with wastewater pollutants source	14
Table 2.4	The advantages and disadvantages of activated sludge adopted from (Flows, 2003; Guo <i>et al.</i> , 2013)	20
Table 2.5	Advantage and disadvantages of SBR (EPA, 1999; Wellby <i>et al.</i> , 2010)	22
Table 2.6	Advantage and disadvantages of extended aeration (Plants, 2000)	23
Table 2.7	The differences between aerobic and anaerobic treatment technology (Breisha and winter, 2010; Cakir and Stenstrom, 2005; Kumar and Singh, 2006; Law <i>et al.</i> , 2012; Singh <i>et al.</i> , 2009)	24
Table 2.8	The differences between aerobic and anaerobic treatment technology (Breisha and winter, 2010; Cakir and Stenstrom, 2005; Kumar and Singh, 2006; Law <i>et al.</i> , 2012; Singh <i>et al.</i> , 2009)	25
Table 2.9	The characterization process example base on ISO 14044 2006	27
Table 2.10	Summary of the previous study in wastewater treatment	38
Table 2.11	Summary of LCA in the previous studies included in the review study	50
Table 3.1	Summarizing the daily flow rate and outflow rate for the selected plants	75
Table 3.2	Data Collection Sources	77
Table 4.1	Inventory input and output data for Bunus Kuala Lumpur domestic wastewater treatment plant	98
Table 4.2	Inventory input and output data for Jelutong Penang domestic wastewater treatment plant	100

Table 4.3	Inventory input and output data for Medini domestic wastewater treatment plant	103
Table 4.4	The total LCIA for the selected environmental impact categories for aerobic AS Bunus DWWTP	111
Table 4.5	The main environmental impact categories for the Bunus Kuala Lumpur wastewater treatment plant (global reference)	112
Table 4.6	Weighting values for Bunus Kuala Lumpur DWWTP (PE international, 2014)	114
Table 4.7	Comparison of the environmental impact results for 1 m ³ of Bunus DWWTP with previous studies and eco-invent threshold values	116
Table 4.8	The Total environmental impact categories for Jelutong	124
Table 4.9	Normalization of environmental impact categories for the Jelutong Penang wastewater treatment plant using global reference	125
Table 4.10	Weighting value for Jelutong, Penang DWWTP source (PE international, 2014)	127
Table 4.11	Total Environmental Impact Category Results Comparison for 1 m ³ DWWT using Previous Studies and the Eco-Invent Threshold Values	127
Table 4.12	The Total Environmental Impact of selected impact categories for Medini Johor Bahru DWWTP	136
Table 4.13	Impact category normalization for the environmental impact of the Medini Johor Bahru domestic wastewater treatment plant using global references	137
Table 4.14	LCIA result weightings for Medini Johor Bahru DWWTP (PE international, 2014)	138
Table 4.15	Total Environmental Impact Categories Result Comparisons for 1 m ³ DWWT with Previous Studies and Eco-Invent Threshold Values	140
Table 4.16	The influent and effluent values for the selected plants	144
Table 4.17	LCIA Rankings for AS Bunus Kl, SBR Jelutong Penang, AS Medini Johor Bahru	148
Table 4.18	Plants environmental impact rankings based on global weight factors	150
Table 5.1	Estimation of the capital cost percentages for the Bunus Kuala Lumpur plant	157

Table 5.2	Estimation the electricity consumption based on the quantity of equipment	158
Table 5.3	Estimation of electricity consumption costs using IWK annual data for Bunus Kuala Lumpur domestic wastewater plant	159
Table 5.4	Monthly and annual labour cost for Bunus DWWTP source (IWK)	159
Table 5.5	Estimation of daily, monthly and annually sludge disposal costs for Bunus DWWTP	160
Table 5.6	Cost estimation for thickening and dewatering sludge for the Bunus DWWTP plant with total load 80% and RM 20 for 1 Kg dosage	161
Table 5.7	Revenue estimates for daily, monthly, and annually reuse for Bunus Kuala Lumpur based off RM 0.60 per m ³	162
Table 5.8	Revenue estimates for fertilizer production using sludge nitrogen with a price of RM 1.2 for 1 kg fertilizer	163
Table 5.9	Factor values for energy generation from biosolid incineration based on previous studies	164
Table 5.10	Electricity generation estimates using two scenarios for Bunus DWWTP	165
Table 5.11	The total revenue of the estimated scenario per year for Bunus DWWTP	165
Table 5.12	The PV value by RM for two years construction of Bunus DWWTP	166
Table 5.13	The total operational cost and the present Value PV for Bunus DWWTP of life span of 30 years	166
Table 5.14	The total revenue and PV for Bunus DWWTP for a life span of 30 years with an 50% increase in revenue every five years	166
Table 5.15	Net Present Value (NPV) and Benefit Cost Ratio for Bunus DWWTP over a 30 year life span	167
Table 5.16	Capital Cost Percentage Estimates for Jelutong Penang WWTP	170
Table 5.17	Total per year electricity cost estimates using IWK data for the Jelutong Penang domestic wastewater plant	172
Table 5.18	Monthly and annually labour costs for Jelutong Penang DWWTP source (IWK)	173

Table 5.19	The daily, monthly, and annual cost of sludge treatment and disposal	173
Table 5.20	Cost estimations in RM for sludge thickening and dewatering for Jelutong Penang DWWTP with a total load of 80% and a cost of RM 20 for 1 Kg of polymer	174
Table 5.21	Daily, Monthly, and Annual Revenue Estimates for Water Reuse for Jelutong Penang with a price per M ³ of RM 0.60	175
Table 5.22	Revenue estimates for fertilizer production using sludge nitrogen for a price of RM 1.2 per 1 kg fertilizer	175
Table 5.23	Annual revenue estimates for electricity production using Bio-gas and Bio-solid incineration for Jelutong DWWTP	176
Table 5.24	The total revenue of the selected scenario for Jelutong DWWTP	176
Table 5.25	The PV in RM for two years of construction for Jelutong DWWTP	177
Table 5.26	The total operational cost and the PV for Jelutong DWWTP of life span of 30 years	177
Table 5.27	The total revenue and PV for the Jelutong DWWTP for a life span of 30 years with an increase in revenue of 50% every five years	177
Table 5.28	The NPV and BCR for the Jelutong DWWTP for a life span of 30 years	178
Table 5.29	Capital cost estimations for the Medini Johor Bahru plant based on the percentage	180
Table 5.30	IWK electrify cost estimates provided per year for the Medini Johor Bahru domestic wastewater plant	181
Table 5.31	Monthly and annual labour costs for Medini Johor Bahru DWWTP	181
Table 5.32	Polymer sludge for sludge thickening and dewatering for Medini Johor Bahru DWWTP with 80% total load and RM 20 for 1 Kg dosage	183
Table 5.33	Monthly and annual revenue estimates for reusing wastewater for Medini Johor Bahru plant with a price per M ³ of RM 0.60	184
Table 5.34	Fertilizer production revenue estimates from sludge using nitrogen with a price of RM 1.2 per 1 kg fertilizer	184
Table 5.35	Electricity generation estimates using two scenarios for the Medini Johor Bahru Plant	185

Table 5.36	The two year construction cost and PV for Medini Johor Bahru DWWTP	186
Table 5.37	The total operational cost and PV for Medini Jobhor Bahru DWWTP over a 30 year life span	186
Table 5.38	The total revenue and PV for Medini Johor Bahru DWWTP over a 30 year life span	186
Table 5.39	The total NPV and BCR for Medini Johor Bahru DWWTP over a 30 year life span	186
Table 6.1	Used economic indicators and the determination methods	195
Table 6.2	Economic threshold values for this study	195
Table 6.3	The LCIA of 1m ³ domestic wastewater treatment using the CML 2001 Method (Gabi6 software)	197
Table 6.4	The 1 m ³ construction cost for 30 years life span per year and per day	198
Table 6.5	The 1m ³ operation cost for 30 year life span, per year and per day	198
Table 6.6	The 1m ³ capital cost for 30 year life span, per year and per day	199
Table 6.7	The annual revenue of 1m ³ domestic wastewater using different practices	199
Table 6.8	The PV value for the construction cost for two years of construction for Bunus DWWTP	201
Table 6.9	The PV value for the construction cost for two years of construction for Bunus DWWTP	201
Table 6.10	The PV value for the construction cost for two years of construction for Bunus DWWTP	201
Table 6.11	The total operational cost and PV for Bunus DWWTP over a 30 year life span	201
Table 6.12	The total revenue and PV for Bunus DWWTP over a 30 year life span with a 5% revenue increase every five years	201
Table 6.13	The net present value over a 30 year life span	202
Table 6.14	The Benefit Cost Ratio for 1 m ³ domestic wastewater	202
Table 6.15	Comparison of the environmental indicator threshold values before and after the suggested scenarios	207
Table 6.16	Total NPV over a 30 year life span	209

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Type of wastewater (Edokpayi <i>et al.</i> , 2017)	10
Figure 2.2	UTM Stabilization pond systems	16
Figure 2.3	Laboratory scale jar test assembly for coagulation source (Kumar and Singh, 2006).	18
Figure 2.4	Activated sludge process (Wanner, 2014)	20
Figure 2.5	The sequences of SBR process step. Source : (Grady Jr <i>et al.</i> , 2011)	23
Figure 2.6	ISO 14041, ISO 14042 and 14043 adopted after modifying according to (Abba, 2014; Akwo, 2008)	27
Figure 2.7	An overview of the steps following in LCIA (Akwo, 2008)	30
Figure 2.8	Eco-efficiency framework based on ISO 14045	66
Figure 3.1	Overall Study Framework	71
Figure 3.2	Flow diagram of Activated sludge Bunus domestic wastewater treatment plant (Source IWK)	73
Figure 3.3	Flow diagram of SBR domestic wastewater treatment Jelutong Penang (Source IWK)	74
Figure 3.4	Flow diagram of activated sludge domestic wastewater treatment Medini Johor Bahru (Source IWK)	74
Figure 3.5	Locations of domestic wastewater plants of Malaysia urban areas	75
Figure 3.6	Study System Boundaries	80
Figure 3.7	Method used to analyse the potential environmental impact of domestic wastewater treatment system in Malaysian urban areas	83
Figure 3.8	Framework for the assessment of DWWT economic feasibility in Malaysia, urban areas	87
Figure 3.9	Developed Framework Implementation Procedures	91
Figure 3.10	Cost Estimation Flow Chart	94
Figure 4.1	The LCA system boundary	99

Figure 4.2	Simulation the treatment for Bunus Kuala Lumpur plant using Gabi6 software	101
Figure 4.3	Simulation the treatment for Jelutong Penang plant using Gabi6 software	102
Figure 4.4	Simulation the treatment for Medini Johor plant using Gabie6 software	104
Figure 4.5	LCA Components used for each wastewater treatment plants	106
Figure 4.6	Global warming potential for As Bunus Kuala Lumpur DWWTP	107
Figure 4.7	The Eutrophication potential for As Bunus Kuala Lumpur DWWTP	108
Figure 4.8	The Acidification potential for As Bunus Kuala Lumpur DWWTP	109
Figure 4.9	Terrestrial Eco toxicity potential for As Bunus Kuala Lumpur DWWTP	110
Figure 4.10	Human Toxicity HTP for As Bunus Kuala Lumpur DWWTP plant	111
Figure 4.11	Normalization of environmental impact categories using the global reference for aerobic AS Bunus Kual Lumpur DWWTP	113
Figure 4.12	The impact category weights for As Bunus Kuala Lumpur DWWTP	115
Figure 4.13	Comparison results for (a) GWP; (b) EP; (c) AP; (d) TETP; and (e) HTP LCIA results for AS Bunus Kuala Lumpur DWWTP with previous study and eco-invent threshold values	117
Figure 4.14	Environmental impact sensitivity results for (a) BOD, COD, P, Nitrate, Nitrite, and TN; (b) electricity	119
Figure 4.15	Global warming potential for SBR Jelutong Penang DWWTP	120
Figure 4.16	The EP potential for SBR Jelutong Penang DWWTP	121
Figure 4.17	The Acidification potential for SBR Jelutong Penang DWWTP	122
Figure 4.18	Terrestrial Eco toxicity potential for SBR Jelutong Penang DWWTP	123
Figure 4.19	Human toxicity HTP for SBR of Jelutong Penang DWWTP	124

Figure 4.20	Normalization of the environmental impact categories using the worldwide reference for SBR Jelutong Penang DWWTP	125
Figure 4.21	Impact category weight values for SBR Jelutong Penang DWWTP	126
Figure 4.22	Comparison results for (a) GWP; (b) EP LCIA results for SBR Jelutong Penang plant with previous studies and eco-invent threshold values	129
Figure 4.24	Global warming potential for aerobic AS Medini Johor Bahru DWWTP	132
Figure 4.25	The EP for aerobic AS Medini Johor Bahru DWWTP	133
Figure 4.26	The Acidification potential for aerobic AS Medini Johor Bahru DWWTP	134
Figure 4.27	Terrestrial eco-toxicity potential for aerobic AS Medini Johor Bahru DWWTP	135
Figure 4.28	Human Toxicity HTP of Medini Johor Bahru DWWTP	136
Figure 4.29	Environmental impact category normalization using global references for Medini Johor Bahru DWWTP Weighting the LCIA Results for Aerobic As Medini Johor Bahru	137
Figure 4.30	Impact category weights for Medini DWWTP	138
Figure 4.31	Comparisons of (a) GWP, and (b) EP (c) AP; and (d) TETP;	140
Figure 4.32	Environmental impact sensitivity results for (a) BOD, COD, P, nitrate, nitrite, ammonia, and TN, for aerobic As Medini Johor Bahru DWWTP	142
Figure 4.33	Efficiency removal estimations for DWWT technologies in mg/ L for BOD, COD, and phosphorus based on IWK data	145
Figure 4.34	Environmental impact category comparisons for (a) GWP EP; (b) AP; (c) TETP; (d); and HTP (E) for 1 m ³ from selected DWWTPs with Eco-invent threshold values and previous studies	147
Figure 4.35	Environmental Impact Rankings for selected plants based on impact category weights	150
Figure 5.1	Layout of Bunus Kuala Lumpur domestic wastewater treatment Plant using Aerobic Activated Sludge (AS)	155
Figure 5.2	The cost estimation procedure for Bunus Kuala Lumpur Plant	156

Figure 5.3	Cash flow during plant life span (30 years) for Bunus Kuala Lumpur DWWT Plant	168
Figure 5.4	Jelutong wastewater treatment plant	168
Figure 5.5	Layout of the Jelutong Penang domestic wastewater treatment plant Sequencing Batch Reactor SBR	169
Figure 5.6	The cost estimation procedure for Jelutong Penang Plant	170
Figure 5.7	Cash flow for Jelutong Penang DWWT plant	178
Figure 5.8	Domestic Wastewater Treatment Layout for the Medini Johor Bahru Plant using Aerobic Activated Sludge (AS)	179
Figure 5.9	The cumulative cash outflow and inflow for Medini DWWTPs	187
Figure 5.10	Costs and Benefits for the AS Bunus, SBR Jelutong, and AS Medini plants	188
Figure 5.11	Operation cost comparisons for 1m ³ for AS Bunus, SBR Jelutong and	189
Figure 5.12	Per day electricity consumption cost comparisons for all plants for 1m ³ domestic wastewater	189
Figure 5.13	The NPV for the AS Bunus, SBR Jelutong, and AS Medini plants	190
Figure 5.14	The BCR for Bunus, Jelutong and Medini plants	191
Figure 6.1	Eco-efficiency framework for domestic wastewater treatment sustainability using LCA and CBA tools	204
Continue Figure 6.2	Comparison of the environmental impact of 1 m ³ ; (c) AP; (d) TETP; and (e) HTP before and after applying the suggested scenario	208
Figure 6.3	The percentage reduction for every impact category after applying the selected scenarios	208

LIST OF ABBREVIATIONS

AP	-	Acidification Potential
AS	-	Activated Sludge
BAF	-	Biological Aerated Filter
BCR	-	Benefit Cost Ratio
BL	-	Baseline Scenario
BOD	-	Biological Oxygen demand
CBA	-	Cost Benefit Analysis
CC	-	Climate Change
CML	-	Centre for Environmental Studies Methodology
COD	-	Chemical oxygen demand
DWWT	-	Domestic wastewater treatment
DWWTP	-	Domestic wastewater treatment Plant
DWWTS	-	Domestic wastewater treatment system
EP	-	Eutrophication Potential
FDP	-	Fossil Depletion Potential
FOFP	-	Photochemical Oxidant Formation Potential
FU	-	Functional unit
GC-MS	-	Gas Chromatography–Mass Spectrometry
GHG	-	Green Gas Emission
GW	-	Grey Water
GWP	-	Global Warming Potential
HFCW	-	Horizontal Flow Constructed Wetland
HTP	-	Human toxicity Potential
IDEA	-	Intermittent Decanted Extended Aeration
IPCC	-	Intergovernmental Panel on Climate Change
ISO	-	ISO - International Organization for Standardization
IWK	-	Indah Water Konsortium
JPP	-	Jabatan Perkhidmatan Pembetungan
KW	-	Kilowatt
LCA	-	Life Cycle Assessment

LCC	-	Life Cycle Costing
LCI	-	Life cycle inventory
LCIA	-	Life cycle Impact Assessment
NPV	-	Net present Value
PMFP	-	Particulate Matter Formation Potential
PPCPs	-	Pharmaceuticals Personal Care Products
PPM	-	Parts Per Million
PV	-	Present Value
RBCs	-	Rotating Biological Contactors
SA	-	Sensitivity Analysis
SBR	-	Sequencing Batch reactor
SS	-	Suspended Solid
TETP	-	Terrestrial Toxicity Potential
TSS	-	Total Suspended Solid
UASB	-	Ultra-High Rate Fluidized Bed
VFCW	-	Vertical Flow Constructed Wetland
VSSF	-	Vertical subsurface flow
YRW	-	Yellow Reduced Water
YW	-	Yellow Water

LIST OF SYMBOLS

Cd	-	Cadmium
CH ₄	-	Methane
CO ₂	-	Carbon dioxide
H ₂ O ₂	-	Hydrogen peroxide
Hg	-	Mercury
N ₂ O	-	Nitrogen Oxide
NH ₃	-	Ammonia
NH ₄	-	Ammonium
NO ₂	-	Nitrite
NO ₃	-	Nitrate
OH	-	Hydroxide
P	-	Phosphorus
PO ₄	-	Hydrogen Phosphate
TN	-	Total nitrogen

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Questionnaire Submitted For data Collection	237
Appendix B	LCIA RESULTS	257
Appendix C	CBA results	264

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Malaysia has a long history of environmental pollution due to rapid economic development and population growth (Hezri, 2014). The current Malaysian population is estimated to be 31,127,247 million, most of which are concentrated in urban areas. The contributes to environmental problems through the generation of domestic wastewater (Meters, 2014). The amount of sewage has rapidly increased due to the migration of citizens from rural to urban areas. This has made sewerage networks more become extensive in Malaysia. Furthermore, water consumption has increased, with the volume of wastewater generated by municipal and industrial sectors in Malaysia estimated to be 2.97 million cubic meters annually (Mat *et al.*, 2013; Cann *et al.*, 2013; Dhama *et al.*, 2013).

In recent years, domestic wastewater in urban areas has become a noticeable source of environmental pollution. In addition, human well-being could be at risk because of diseases such as cholera and E coli that can quickly spread without adequate sewage treatment. Electricity consumption for domestic wastewater treatment is a major source of global warming. This is due to the high rate of energy consumption (Ozgun *et al.*, 2013). High energy consumption, operation, and technology maintenance costs can reduce the quality of treated wastewater, which further affects human health and the environment. Also, discharged wastewater will increase Eutrophication Potential (EP) and Terrestrial Eco Toxicity (TETP) while negatively impacting soil, vegetation, and human health. Therefore, the provision of environmental and economic sustainable wastewater treatments is very important.

Hong *et al.* (2009) reported that the inadequate treatment of wastewater leads to disposal of effluent with high organic content such as Chemical Oxygen Demand

(COD), Biological Oxygen Demand (BOD), nitrite, nitrate, Total Nitrogen (TN), and phosphorus. This contributes to eutrophication and increases the pollutions of water bodies, soil, and waterways, which further affects human health and the environment. On the other hand, the remnants of domestic and wastewater treatment (sludge) have many substances that damage the soil and subject the environment to heavy metals (Mara, 2013; Maldonado *et al.*, 2008). This increases the impact of Terrestrial Toxicity (TETP) on the ecosystem. This study assesses the environmental impact of domestic wastewater treatment systems in Malaysian urban areas.

The CML2001 Life Cycle Impact Assessment (LCIA) method using the Gabi6 database was used to determine what technology has the highest and lowest impact on human health and the environment. Normalization and result weighting for CML 2001 was done based on global references to obtain a single impact score for available emissions based on the Gabi6 database. Cost Benefit Analysis (CBA) was used to assess the operation costs, energy use, fuel consumption, chemical substances, maintenance, wages, and economic gain. The eco-efficiency framework was done through a combination of Life Cycle Assessment (LCA) and Cost Benefit Analysis (CBA). CBA was selected instead of LCC because CBA reflects benefits while LCC reflects costs. The minimization of the environmental impact and cost of domestic wastewater treatment plants was supported by both scenarios. The first scenario produced electricity using biogas and bio solids while the second scenario reused effluent water to produce fertilizer and annamox process bacteria. This minimized the environmental impact and cost of domestic wastewater treatment systems. The developed framework proposed the best solution for the environmental and economic sustainability of domestic wastewater treatment systems in Malaysian urban areas.

1.2 Problem Statement

Environmental pollution from wastewater disposal is a concern in many nations around the world. Wastewater effluent contains high-levels of organic substances that have a significant environmental impact on water bodies, rivers, and

waterways. Developing countries like Malaysia face serious wastewater pollution problems that affect water bodies, groundwater, human health, and the environment (Adnan *et al.*, 2012). The technology presently in use is an aerobic process that consumes large amounts of energy (Azimi and Rocher, 2017). This technology also has a high Global Warming Potential (GWP) due to the adverse negative impact and high rate of energy consumption, which reflects a high rate of fuel consumption. The current technology in use increases energy consumption (Soares *et al.*, 2017). According to Grzes *et al.* (2014), wastewater handling represent 54% of Greenhouse Gas Emissions (GHG). Mohd Safuan *et al.* (2014) reported that the common way of disposing sludge on land or sea is costly and environmentally harmful. Converting sludge to useful energy is cheap and has negative environmental consequences due to the energy consumption of drying sludge.

Wastewater treatment in many places around the world is characterized by high surplus biomass, high operation costs, and high maintenance costs (Soares *et al.*, 2017). This process emits gases such as carbon dioxide and methane that play an important role in Global Warming Potential (Gu *et al.*, 2017; Li *et al.*, 2017; Plants, 2000; Qiu *et al.*, 2010; Vigneswaran *et al.*, 2009). Furthermore, substances such as ammonia, nitrogen, COD, BOD, nitrates, aluminium, ferric salts, lime, and residual phosphorus precipitation from wastewater treatments have contributed greatly to environmental pollution (Semerjian and Ayoub, 2003). For the environmental impact and cost of domestic wastewater treatment systems to be reduced there is a need for new domestic wastewater treatment processes. Eutrophication (EP) and Terrestrial Toxicity Potential (TETP) are the main parts affected by increases or decreases in domestic wastewater treatment process efficiency (McNamara, 2016).

High energy consumption in term of grid costs comes from fuel consumption and contributes to climate change through the emission of CO₂ and CO (Gu *et al.*, 2017). In addition, high operational and maintenance costs for current wastewater treatment technologies had led to the use of cheap materials and equipment that affects the quality of treated wastewater. Attempts to increase the efficiency of these technologies in removing pollution has led to a high rate of energy consumption, which consequently affects the environment as well as firm and government costs.

Inefficiencies in existing technologies in removing waste pollution (in terms of performance, environmental impact, and cost) created the research gap addressed by this study. Cornejo (2015) and Lim *et al.*, (2008) studies on wastewater, Combined Life Cycle Assessment (LCA), and Life Cycle Costs (LCC) have reduced the cost and environmental impact of wastewater treatments. Previous studies have revealed that the use of LCC did not reflect wastewater benefits (Koul and John, 2015; Rodriguez-Garcia *et al.*, 2011). The advantage of using CBA instead of LCC is that CBA reflects wastewater benefits. Therefore, research on the use of domestic wastewater that accommodate its benefits, reduces environmental damage, maximizes pollution removal efficiency, and reduces costs is lacking. Studies that integrated the effect of LCA and CBA for domestic wastewater treatment sustainability is lacking. This study developed a framework for minimising the cost and impact of domestic wastewater treatment system, which is novelty of the study. Integrating LCA and CBA provides a solution for improving the environmental and economic efficiency of domestic wastewater treatment systems in Malaysian urban areas.

1.3 Study Objectives

The aim of this research is to assess the environmental and economic sustainability of domestic wastewater treatment systems using LCA and CBA. This study developed framework for minimising the cost and impact of domestic wastewater treatment systems. This was done by integrating LCA and CBA. The objectives of this research are as follows:

- (a) To collect inventory input and output data for different domestic wastewater treatment systems in Malaysian urban areas.
- (b) To analyse the potential environmental impacts of different domestic wastewater treatment systems using the LCA approach.
- (c) To assess the cost and economic feasibility of the domestic wastewater treatment systems in Malaysian urban areas.

- (d) To develop an eco-efficiency framework for sustainable domestic wastewater treatment systems that minimizes environmental impact and cost.

1.4 Study Scope

The study scope consisted of three domestic wastewater treatment plants in Malaysian urban areas. Domestic wastewater treatment plants were selected based on daily domestic wastewater generation, plant scale, and wastewater treatment efficiency. The first part assesses the potential impact of domestic wastewater treatments in terms of environment and economic aspects in three Malaysian urban areas (Kuala Lumpur, Johor, and Penang). The system in Bunus Kuala Lumpur and Medini Johor Bahru were aerobic activated sludge system. While the system in Jelutong Penang was sequencing batch reactor. The system boundary of this study was from gate to gate.

Sampling was conducted to collect primary data that was compared with data with from Indah water Konsortium IWK. Secondary data was collected from IWK (data average). Data collection in the three urban areas took approximately five months to finish. Some data such as the construction cost of the selected plants was taken from Jabatan Perkhidmatan Pembetulan (JPP). Other secondary data such as the cost of one person equivalent for the Bunus Kuala Lumpur plant was collected from the literature.

The purpose of this assessment was to minimize the environmental impact of Domestic Wastewater Treatment (DWWT) in urban areas. This was achieved by the use of soil reclamation, recycling, and domestic wastewater reuse in addition to current domestic wastewater practices (DWW disposal). Besides, electricity and biogas was produced from the methane in domestic wastewater. Data for the study was taken from Indah Water Konsortium (IWK). The second part of this study compared the environmental impact of adopted technologies and economic aspects (chemical and biological treatments) such as sequence batch reactors, and activated sludge. LCA was used to assess the environmental impact of domestic wastewater

treatment and the used technologies while CBA was applied to assess economic costs.

The selection of wastewater treatment plant sites was done based on their location in urban areas, their use of non-conventional wastewater treatment technologies, and the quality of their effluent wastewater. Another consideration was done the environmental impact of the 1m³ of wastewater. This study integrated LCA and CBA instead of LCC because CBA reflect wastewater benefits. The study considered the cost and present values of the selected plants based on a plant life span 30 years. The selection of a 30 year life span was best in terms of benefits because past 30 years maintenance increases and benefits decrease.

Cost estimation was done co-operatively with IWK. Microsoft excel was used to calculate the cost and the economic feasibility of domestic wastewater. The third part analysed the potential environmental impact of domestic wastewater system inputs and outputs from different points of view (Materials, chemical substances, energy requirements, and environmental impact). The obtained data was imputed into Gabi software to analyse the potential environmental impact of domestic wastewater and the technologies use. In summary, the scope of this study achieved the following objectives:

- (a) Input and output data for domestic wastewater treatment systems in Malaysia were collected using IWK. Input and output data contained the use of electricity, transportation fuel, COD, BOD, nitrate, nitrite, and phosphorus.
- (b) This research covers only domestic wastewater treatment systems in Malaysian urban areas. The Bunus Kuala Lumpur plant, Medini Johor Bahru plant, and Jelutong Penang plant were considered during data collection.
- (c) The potential environmental impact assessment of different domestic wastewater treatment systems was limited to the LCA approach.
- (d) Analysis of the potential environmental impacts of different domestic wastewater systems was limited to the Gabi6 software.

- (e) The fuel consumption costs for the transportation of materials and chemicals within investigated plants were included.
- (f) The system boundaries included raw materials and gate to gate wastewater processing.

1.5 Significance of Research

A framework was developed to evaluate the eco-efficiency of wastewater treatment plants. This study minimized the environmental impact and cost of domestic wastewater treatment systems. The integration of LCA and CBA using the suggested framework decreased the environmental impact below the selected environmental threshold values. The developed framework is important to guiding decision makers to choose the best domestic wastewater treatment technologies with the lowest environmental impact and cost. In addition, this research will increase awareness on how to use recycle domestic wastewater for economic gain (fertilizer, soil reclamation, electricity generation, and cooking gas). Furthermore, this research is important for choosing the best solution for sustaining sewage systems without negative odours and pathogens by suggesting the best treatments with the lowest cost and environmental impact. This enhances the balance between human health and environment by reducing pathogens, costs, and environmental impact. The cost of domestic wastewater treatment systems was minimized to less than the selected economic threshold values. Therefore, the suggested framework provided the best solution for increasing the eco-efficiency of domestic wastewater treatment, which enhanced environmental and economic sustainability in Malaysian urban areas.

1.6 Thesis Layout

The layout of this study is structured as follows:

Chapter 1 gives the introductory background. It also highlights the problems associated with the research area. In addition, this chapter outlines the goal and significance of this study.

Chapter 2 discuss previous studies related to Domestic Wastewater Treatment (DWWT) technologies. The analysis-based techniques are presented. Important concepts such as LCA, cost benefits tools, and Gabi software are discussed.

Chapter 3 describes the methodology used in this research. It explains the research tools and processes. It also explains the economic and environmental domestic wastewater analysis using LCA and CBA.

Chapter 4 presents the results of the LCA approach to analyse the potential environmental impact of domestic wastewater treatments and technologies.

Chapter 5 presents the cost estimates done using inventory data, IWK annual reports, and consultations with IWK executives. Costs included operational costs and maintenance as well as daily, monthly, and annual wages. The calculation of these case studies was done in sequence, starting from operation to polymer cost.

Chapter 6 shows the results for the 1m³ domestic wastewater flow rate framework in terms of treatment sustainability

Chapter 7 presents the conclusion and recommendations for future research based on the study findings

LIST OF PUBLICATIONS

<https://scholar.google.com/citations?user=EJTTcOMAAAAJ&hl=en>

Sabeen, A. H., Noor, Z. Z., Ngadia, N., Almuraisya, S., and Raheema, A. B. (2018). Quantification of Environmental Impacts of Domestic Wastewater Treatment using Life Cycle Assessment: A Review.

Sabeen, A., Kamaruddin, S., and Noor, Z. Environmental impacts assessment of industrial wastewater treatment system using electroless nickel plating and life cycle assessment approaches. *International Journal of Environmental Science and Technology*, 1-12.

Sabeen, A., Ngadi, N., and Noor, Z. Z. (2016). Minimizing the cost of municipal solid waste management in Pasir Gudang Johor Malaysia. *Journal of Materials and Environmental Science*, 7(5), 1819-1834

Sabeen, A. H., Ngadi, N., Noor, Z. Z., Raheem, A. B., Agouillal, F., Mohammed, A. A., & Abdulkarim, B. I. (2018). Characteristics of the Effluent Wastewater in Sewage Treatment Plants of Malaysian Urban Areas. *Chemical Engineering Transactions*, 63, 691-696

Sabeen, A., H Anwar, A., and Noor, Z. (2012). Sustainable Public Transportation in Malaysia. *International Journal of Engineering and Advance Technology Journal of Engineering and Advance Technology IJEAT*, 1, 2249-8958.

Raheem, A. B., Noor, Z. Z., Hassan, A., Hamid, M. K. A., Samsudin, S. A., and **Sabeen, A. H.** (2019). Current developments in chemical recycling of post-consumer polyethylene terephthalate wastes for new materials production: A review. *Journal of Cleaner Production*.

Al-Muraisy, S. A. A., Ali, N., Hassan, O., and **Sabeen, A. H.** (2017). Alkali Pretreatment and Acid Hydrolysis of Oil Palm Mesocarp Fiber (OPMF) to Produce Glucose. *Advanced Science Letters*, 23(9), 8832-8836.

Ademola Bolanle Raheema, Azman Bin Hassana, Zainura Zainon Noora, Sani, Bin Samsudina, Med Aassad Hamida, Aliyu Belloa, Olagoke Oladokuna, **Ali Hussein**, K Sabeen , Ahmad Shamiria lessPublished 2018, Process Simulation of Bis (2-hydroxyethyl) terephthalate and Its Recovery Using Two – stage Evaporation Systems. *Journal of chemical engineering transaction*

Ali, A. M., Hassan, M. A. A., Ibrahim, R. R., Jalil, A. A., Nayan, N. H. M., Abdulkarim, B. I., and **Sabeen, A. H.** (2019). Analysis of Solid residue and Flue Gas from Thermal Plasma Treatment of Petroleum Sludge. *Journal of Environmental Chemical Engineering*, 103207.

Bala I. Abdulkarim¹, Mohd A. Abu-Hassan², Raja R.K. Ibrahim³, Muhammad. A. A. Zaini⁴, Abubakar M. Ali, **Ali S. Hussein**, Sheila M. Su, and Muhd Azril. Mohd Halim, Characterisation of Galvanic Sludge from Hot Dip Galvanising Process for Metal Surface Treatment, *International Journal of Engineering and Science (IJES)*, ISSN (p): 2319 – 1805.

Venmathy Samanaseh, Zainura Zainon Noor, Che Hafizan, **Ali Hussein Sabeen**, Water-Energy-Nexus in Water Supply: A Case Study on Greenhouse Gases Emissions Trends of a Water Utility Company in Johor, Malaysia, *Journal of chemical engineering transactions*, VOL. 56, 2017

AB Raheem, ZZ Noor, A Hassan, MKA Hamid, SA Samsudin, **AH Sabeen** *Journal of Cleaner Production*

Abdulkarim, B. I., Abu-Hassan, M. A., Ibrahim, R. R., Zaini, M. A., Ali, A. M., **A. Hussein**, A. S., . . . Halim, M. I. M. Characterisation of Galvanic Sludge from Hot Dip Galvanising Process for Metal Surface Treatment.