OPTIMAL PLANNING OF HYBRID POWER GENERATION SYSTEM TOWARDS LOW CARBON DEVELOPMENT

ZARINA AB MUIS

UNIVERSITI TEKNOLOGI MALAYSIA

OPTIMAL PLANNING OF HYBRID POWER GENERATION SYSTEM TOWARDS LOW CARBON DEVELOPMENT

ZARINA AB MUIS

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

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2014

I declare that this thesis entitled "*Optimal Planning of Hybrid Power Generation System Towards Low Carbon Development*" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature of the author	: ……………………..
Name of the author	: ZARINA AB MUIS
Date	: 13 NOVEMBER 2014

This thesis is especially dedicated to my husband, Muhammad bin Mat Junoh, my beloved children, Nur Nabilah and Muhammad Farhanuddin, my beloved parents, Ab Muis bin Mohd and Bidah bt Karim, my mother in law, Kamariah bt Hamat and not forgotten my late father in law,Mat Junoh bin Yaakob. You are all the sources of my strength. May Allah bless us all forever.

ACKNOWLEDGEMENTS

Alhamdulillah, praise be to Allah The Al-Mighty. I wish to express my gratitude to my supervisors, Associate Professor Dr. Haslenda Hashim and Prof. Dr. Zainuddin Abd Manan for their strong support, constant comments, suggestions, guidance and encouragement throughout this work. May all your contributions will be paid off by blessings from the merciful Allah Azzawajalla.

Very special thanks to loving and helpful husband, Mr. Muhammad Mat Junoh, for his wisdom in offering me advices either academically or otherwise.

Grateful appreciation to PROSPECT’s student and staff for their support; Prof. Dr Peter Douglas from Department of Chemical Engineering, University of Waterloo who guided me during my attachment. The hardships I encountered were certainly more or less lightened by the aid offered. I would also like to acknowledge Universiti Teknologi Malaysia, not only for their financial support but for all other assistances in enlightening my route to this academic success

Special thanks to Mr Ho Wai Shin, who had the most supportive and helpful in aiding the completion of this thesis. Many thanks to Pn Aziatul Niza and Ms Norliyana Shamsuddin. who had also been supporting me in making this thesis possible.

Last but certainly not the least, a mountain of love and appreciation towards my parents and family for their encouragement and moral support and doa. May Allah reward all of you here and in the hereafter.

ABSTRACT

In Malaysia, the energy sector is identified as one of the major carbon dioxide (CO_2) emitters. Electricity in Malaysia is primarily generated from coal, natural gas, diesel, oil and hydro. The government of Malaysia encourages power producers to shift towards the use of renewable energy (RE) and reduce their reliance on fossil fuels. There is a clear need for a systematic method to sustainably plan the fleet-wide electricity generation and capacity expansion towards fulfilling the forecasted electricity demand and simultaneously meet the emission reduction target. A comprehensive superstructure consisting of all existing (i.e. Pulverized Coal (PC), Natural Gas Open Cycle (NGOC)) and new power generation technologies (i.e., Natural Gas Combined Cycle (NGCC), nuclear, solar, biomass and Municipal Solid Waste (MSW)) was constructed at the early stage of model development in this study. Towards this end, three different models have been developed and implemented in the General Algebraic Modeling System (GAMS) as follows: 1) Single period model for electricity generation mix that is designed to satisfy the electricity demand until the year 2020 for Peninsular Malaysia, 2) Multi period model for selection of power generation technology that is designed to satisfy the forecasted electricity demand from year 2012 to 2025 in Iskandar Malaysia (IM) and 3) Multi-period optimization model that is developed to determine the optimal location of new RE generation stations to reduce transmission losses and transportation cost in IM. Options are made available by models 1 and 2 to switch the coal plants to natural gas power plants and to increase the use of renewable energy in order to meet CO_2 target and to minimize cost. Model 3 is capable of predicting the cost-optimal generation capacity, type of biomass-energy conversion technology and location for the construction and operation of new biomass power plants. The models can provide vital tools to assist the government in policy making.

ABSTRAK

Di Malaysia, sektor tenaga dikenalpasti sebagai penyumbang utama pembebasan karbon dioksida (CO_2). Penjanaan elektrik utama di Malaysia adalah daripada arang batu, gas asli, diesel, minyak dan hidro. Kerajaan Malaysia menggalakkan penjana tenaga untuk beralih ke arah penggunaan tenaga diperbaharui dan mengurangkan pergantungan kepada bahan api fosil. Sangat jelas bahawa kaedah yang sistematik untuk merancang secara lestari penjanaan *'fleet-wide'* dan penambahan kapasiti elektrik ke arah memenuhi ramalan kehendak elektrik dan dalam masa yang sama mencapai matlamat pengurangan pembebasan karbon dioksida. Satu struktur super yang komprehensif terdiri daripada semua jenis penjana elektrik sedia ada, (arang batu terhancur (PC), kitaran terbuka gas asli (NGOC)) dan teknologi penjanaan yang baru (iaitu gas asli kitar padu (NGCC), nuklear, solar, bio-jisim dan sisa buangan pepejal (MSW)) telah dibina pada peringkat awal pembinaan model di dalam kajian ini. Pada akhirnya, tiga model yang berbeza telah dibina dan digunakan di dalam General Algebraic Modeling System (GAMS), seperti berikut: 1) Model tempoh tunggal untuk campuran penjanaan elektrik yang direka untuk memenuhi kehendak keperluan elektrik pada tahun 2020 untuk Semenanjung Malaysia, 2) Model tempoh berganda untuk pemilihan teknologi penjanaan yang direka untuk memenuhi ramalan keperluan elektrik dari tahun 2013 hingga 2025 di Iskandar Malaysia (IM) dan 3) Model tempoh berganda yang dibina untuk menentukan lokasi yang optimum untuk pembinaan loji penjanaan tenaga diperbaharui untuk mengurangkan kehilangan penghantaran elektrik dan kos pengangkutan di IM. Pilihan telah diwujudkan dalam model 1 dan 2 untuk menukar loji janakuasa arang batu kepada loji janakuasa gas asli dan meningkatkan penggunaan tenaga diperbaharui untuk mencapai matlamat pengurangan CO_2 dan meminimumkan kos. Model 3 berupaya untuk meramalkan kos optimum bagi kapasiti penjanaan, jenis teknologi biojisim-tenaga dan lokasi untuk pembinaan dan pengoperasian loji janakuasa biojisim yang baru. Model-model ini menyediakan peranti penting bagi membantu kerajaan dalam pembangunan polisi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

°C - Degree Celcius
AC - alternating current
BioGen - Biomass Generation and Demonstration
CDM - clean development mechanism
CETREE - Centre for Education and Training in Renewable Energy and Energy Efficiency
CH_4 - methane
CO - carbon monoxide
CO_2 - Carbon dioxide
COE - Cost of Electricity
DANIDA - Danish International Development Agency
DC - direct current
DEG - Distributed energy generation
EFB - Empty Fruit Bunches
EFOM - energy flow optimisation model
EPM - Energy planning model
FiT - Feed-in Tariff
GA - genetic algorithm
GAMS - General Algebraic Modeling System
GDP - Gross Domestic Product
GHG - greenhouse gases
GOM - government of Malaysia
GWh - Gigawatthour

HCl	-	hydrochloric acid
HFCs	-	hydrofluorocarbons
HV	-	heating value
IEA	-	International Energy Agency
IGCC	-	Integrated gasification combined cycle
IM	-	Iskandar Malaysia
IPP	-	Independent Power Producer
KeTTHA	-	Ministry of Energy, Green Technology and Water
kJ/kg	-	Kilojoule/kilogram
kWh	-	Kilowatthour
LNG	-	liquefied natural gas
LP	-	Linear Programming
LULUCF	-	land use, land-use change and forestry
MBIPV	-	Malaysia Building Integrated Photovoltaic
MILP	-	Mixed Integer Linear Programming
MINLP	-	Mixed Integer Non Linear Programming
MIP	-	integer programming
MMt	-	million metric tonnes
MOLP	-	Multi Objectives Linear Programming
MSW	-	Municipal Solid Waste
mtoe	-	Metric tonnes oil equivalent
MW	-	Megawatts
N_2O	-	nitrous oxide
NG	-	natural gas
NGCC	-	Natural gas combined cycle
NGOC	-	Natural Gas Open Cycle
NLP	-	Non Linear Programming
NOx	-	nitrogen oxide
O&M	-	operation and maintenance
PC	-	Pulverised Coal
PETRONAS	-	Petroleam Nasional Berhad
PFCs	-	perfluorocarbons
PJ	-	Petajoule

PKS	-	Palm kernel shell
POME	-	palm oil mill effluent
PV	-	Photovoltaic
RE	-	renewable energy
RES	-	renewable energy sources
SCORE	-	Sarawak Corridor of Renewable Energy
SF_6	-	sulphur hexafluoride
SOx	-	sulphur oxide
SREP	-	Small Renewable Energy Power
Tcf	-	Trillion cubic feet
TNB	-	Tenaga National Berhad
UNDP	-	United Nations Development Programme
UNFCC	-	United Nations Framework Convention on Climate Change
Wp	-	Watt power

LIST OF SYMBOLS

$A^b_{biom,t}$	-	Biomass availability in year ‘*t*’ (GJ)
A^C_c	-	annual capacity factor for coal power plant
A^F_f	-	annual capacity factor for new fossil fuel power plant
A^G_g	-	annual capacity factor for NG power plant
A^R_r	-	annual capacity factor for renewable energy power plant
ACF^b	-	Annual capacity factor for biomass power plant
b	-	biomass
B_i	-	Existing biomass power plants
B_i^{new}	-	New biomass power plants
B_{bt}	-	renewable resources consumption amount during year ‘*t*’
BG	-	biogas availability
BGE	-	biogas lower heating value
C_i	-	Existing coal power plants
$Cap^b_{tech,lc,tc}$	-	Capital cost of biomass type ‘*b*’plant size, built in year ‘*tc*’, and operates in year ‘*t*’ (MW) using technology, “*tech*” at location “*lc*”
CD_t	-	Capacity demand during year ‘*t*’
$CO2^C$	-	CO_2emission of coal
$CO2^G$	-	CO_2 emission of natural gas
$CO2^F_f$	-	CO_2 emission of fuel for new fossil fuel power plant (coal and natural gas)
$CO2lim$	-	CO_2 emission limit

D_i - Existing diesel power plants

E_b^R - heating value of the resource

E_{ij} - Actual electricity generation from ith fossil fuel using jth fuel type for existing power plant (MWh)

E_j - Actual electricity generation from non fossil fuel (MWh)

E_j^{new} - Electricity generation for new power plant (MWh)

$e^b_{tech,lc,tc,t}$ - Electricity generation (MW) from biomass type ‘*b*’ using technology type ‘*tech*’, at location ‘*lc*’ to be build in year ‘*tc*’

ED_{lt} - energy demand in period ‘*l*’ during year ‘*t*’

Ef - efficiency of solar PV modules

F - Fossil fueled power plants

$FOM^b_{tc,t}$ - Fixed O&M cost for biomass power plant built in year ‘*tc*’, and operates in year ‘*t*’(RM/MW)

H_i - Existing hydroelectric power plants

H_i^{new} - New hydroelectric power plants

H_c^C - heat rate of the coal power plant

H_{fdt}^F - heat rate of the new fossil fuel power plant during year ‘*t*’

H_g^G - heat rate of the NG power plant

HR^b_{tech} - Heat rate for biomass type ‘*b*’(MW) for technology, “*tech*” (GJ/MWh)

i - power stations

I^C - operating and maintenance (O&M) cost of the coal power plant

I^G - operating and maintenance (O&M) cost of the NG power plant

I_{fdt}^F - operating and maintenance (O&M) cost of the NG power plant

I_{rdt}^R - operating and maintenance (O&M) cost of the new renewable energy power plant

IG_i^{new} - New IGCC power plants

In - average solar intensity

j - fuels

L - Transmission loss

LA - land area availability

lb - Palm oil mill

lc - Locations

LFG - capacity of landfills

$LCD_{lc,subt}$ - Distance from location of power plant to substation location (km)

$LBD_{lb,lc}$ - Distance from palm oil mill to location of power plant (km)

$Loss$ - Transmission and distribution loss

LP_{lc} - Land price for location '*lc*' (RM per ft^2)

M - waste allocated for direct incineration

M_i^{new} - Operating & Maintenance (O&M) cost for new power stations (RM/MWh)

ME - lower heating value of the solid wastes

MG - waste allocated for landfill gas capturing

MGE - lower heating value of landfill gas

MSW - total MSW generated annually

N^F_{rdt} - construction lead time for fossil fuel power plant

N^R_{rdt} - construction lead time for RE power plant

new - New power plants

NF - Non-fossil fueled power plants

NG_i - Existing natural gas power plants

NG_i^{new} - New natural gas combined cycle power plants

N_i^{new} - New nuclear power plants

O_l - operation hour for on-off peak periods

O_i - Existing oil power plants

$optime$ - Annual operating time (hours/year)

P^b - Price of biomass (RM per GJ)

PB_b - price of renewable resources

PC_t - price of coal in year '*t*'

PC_i^{new}, - New pulverized coal power plants

PF_{ft} - price of fossil fuel in year ‘*t*’

PG_t - price of NG in year ‘*t*’

R_{ij} - Retrofit cost (RM/MW)

RM - reserve margin

S_c^C - capacity of the existing coal power plant

S_{fd}^F - capacity of the new fossil fuel power plant

S_g^G - capacity of the existing natural gas power plant

S_{rd}^R - capacity of the new renewable energy power plant

S_i^{new} - Capital cost for new power plant (RM/MW)

SG - sewage gas availability

SGE - sewage gas lower heating value

SO_i^{ne} - New solar power plants

$subt$ - substations

t - Time horizon of planning

T_{fdt}^F - capital cost of the new fossil fuel power plant in year ‘*t*’

T_{rdt}^R - capital cost of the new renewable energy power plant in year ‘*t*’

tc - Time horizon of building

$tech$ - energy conversion technologies

TR - Construction trend

V^C - variable O&M cost for coal power plant

V^G - variable O&M cost for NG power plant

V_{fdt}^F - variable O&M cost for new fossil fuel power plant

V_{rdt}^R - variable O&M cost for new renewable energy power plant

V_{ij} - Operating & maintenance (O&M) cost for existing power stations (RM/MWh)

$VOM^b_{tech,tc,t}$ - Variable O&M cost for biomass power plant built in year ‘*tc*’, and operates in year ‘*t*’(RM/MWh)

W_{ctl}^C - power generated by the coal power plant in period ‘*l*’ during year ‘*t*’

W_{fdtl}^F - power generated by the new fossil fuel power plant in period ‘*l*’ during year ‘*t*’

W^{G}_{gtl} - power generated by the NG power plant in period ‘*l*’ during year ‘*t*’

W^{R}_{rdtl} - power generated by the new renewable energy power plant in period ‘*l*’ during year ‘*t*’

W_{i}^{new} - New wind power plants

$X^{b}_{tech,lc,tc}$ - Amount of biomass power plant to be build in year ‘*tc*’ (MW), b= type of biomass, using technology, “*tech*” at location “*lc*”.

X^{C}_{ct} - binary variable of the existing coal power plant during year ‘*t*’(1 indicates plant in operation while 0 indicates plant shut down)

X^{G}_{gt} - binary variable of the existing NG power plant during year ‘*t*’(1 indicates plant in operation while 0 indicates plant shut down)

x_{ij} - Binary variable ; 1 if coal-fired boiler *i* is operational using fuel *j;* 0 otherwise

y_i - Binary variable ; 1 if power plant *i* is operational; 0 otherwise

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Current Scenario of Electricity Generation in Malaysia

In Malaysia, natural gas, coal, diesel, fuel oil (distillate), hydro and biomass are used to generate electricity. The share of natural gas, as energy input into power stations, has decreased from 62.30% in 2005 to 55.52% in 2010. The share of coal, however, has slightly increased from 28.10% in 2005 to 28.26% in 2010. As for the other forms of energy input, the share of hydro accounted for 7.78%, while the remainder was provided by diesel and fuel oil at 4.7% and 0.95% each, respectively. Installed capacity and generation mix by fuel type are indicated in the pie charts shown in Figure 1.1 and Figure 1.2 (Energy Commission, 2012).

The total electricity consumption for Malaysia recorded a growth from 81.243 billion kWh in 2006 to 127.069 billion kWh in 2011. The share in electricity demand was highest for the industrial sector at 48.5%, followed by the commercial sector at 31.3% and the residential sector at 20.1%. Nevertheless, under a four-fuel diversification strategy, the power sector has successfully decreased its dependency on oil (Ministry of Energy, Water and Communication, 2005). In 2006, biomass-based renewable energy (RE) plants were operating to create 441 MW (Energy Commission, 2008). In 2011, RE (biomass-based) generated 1538 GWh from 740 MW power plants (Energy Commission, 2012).

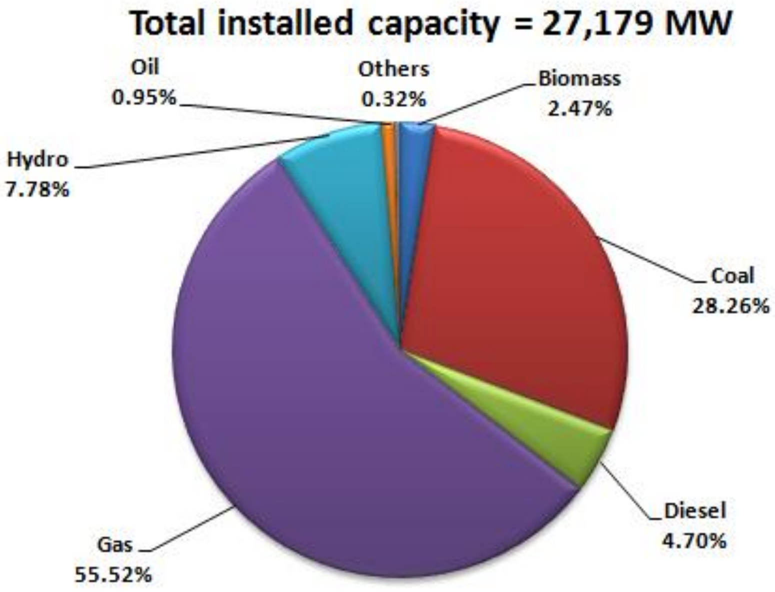


Figure 1.1 Malaysia’s Current Installed Capacity by Fuel Type (Energy Commission, 2012).

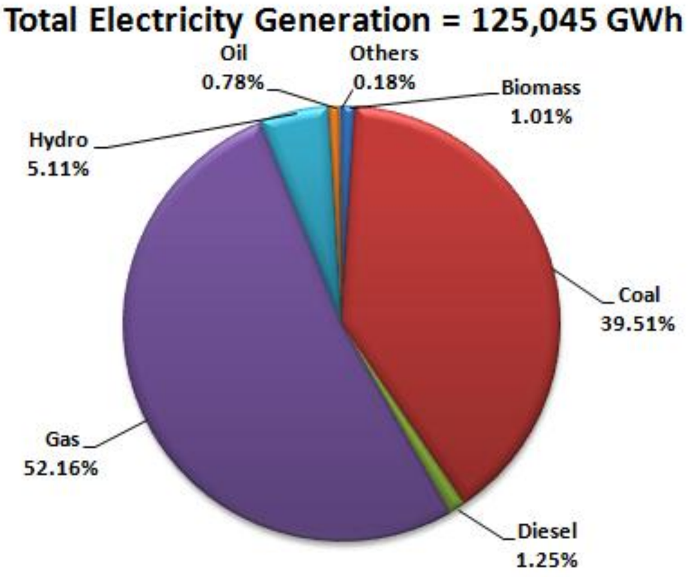


Figure 1.2 Malaysia’s Electricity Generation by Fuel Type (Energy Commission, 2012).

The discovery of new gas fields contributed to the increase in reserves from 84.3 trillion cubic feet (tcf) in 2000 to 88.93 trillion cubic feet (tcf) in January 2008 and is expected to last for 33 years (Gas Malaysia Sdn. Bhd., 2009). The government heavily subsidised natural gas (NG) to attract investors to its abundant resources. As a consequence, electricity generation from NG became the most attractive fuel option and contributed up to 52.16 % of electricity generation, followed by coal at 39.51%, hydro at 5.11%, diesel at 1.25 %, biomass at 1.01 %, fuel oil at 0.78 % and others at 0.18% – as shown in Figure 1.2 (Energy Commission, 2012). In early June 2008, the government announced the restructuring of fuel subsidies amidst the continuing global escalation of oil prices. Therefore, with the new electricity tariff rates, the average selling price decreased to 31.31 sen/kWh compared to the previous average selling price of 31.54 sen/kWh (Energy Commission, 2010).

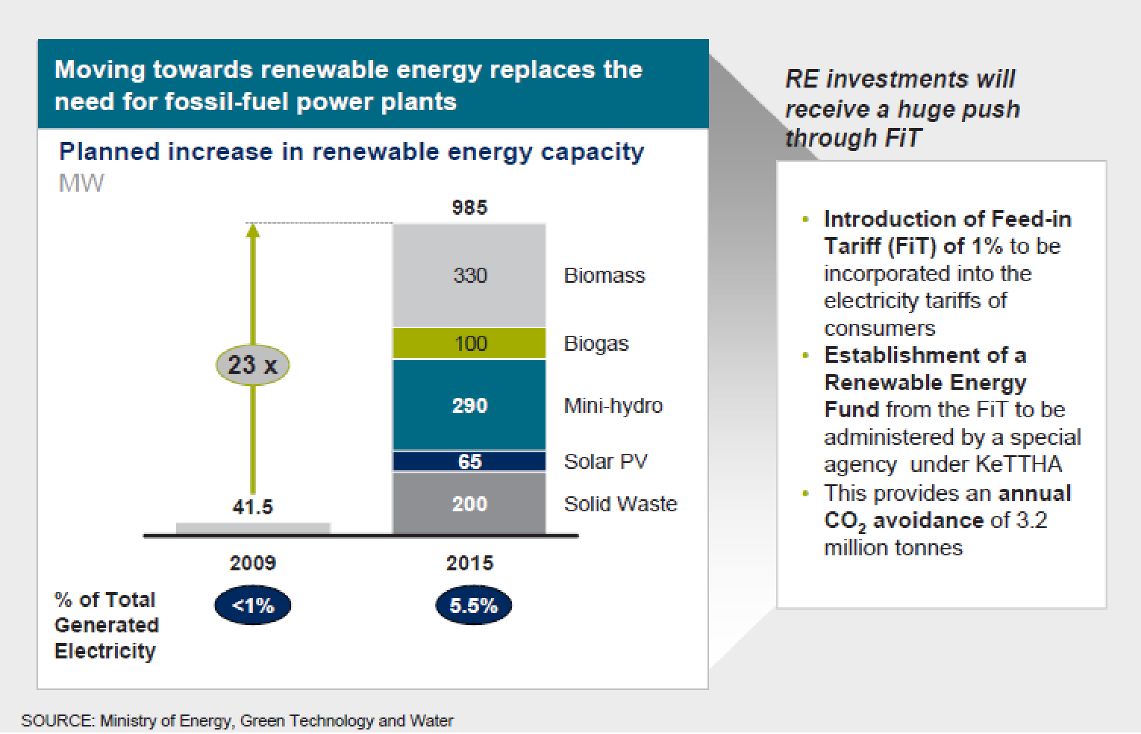
Having learned a lesson from the world oil crises of 1973 and 1979, in the 8th Malaysia Plan (from 2001 to 2005) the government initiated the five-fuel diversification strategy. This strategy encouraged the use of renewable energy (RE), as an alternative to fossil fuel, and promoted biomass, biogas, municipal waste, solar and mini-hydro as RE resources. Under this plan, the government had set a target of 5% of the country's power generation mix from RE. However, this target has not been accomplished until now. Therefore, the 9th Malaysia Plan (2006–2010) was aimed at strengthening the previous plan by enhancing the use of RE and biomass resources from oil palm, wood, and rice-husk residue for the purpose of heat and electricity generation and biomass co-generation systems. It is expected that electricity generation from RE will reach 300 MW (Peninsular) and 50 MW (Sabah) by the end of the 9th Malaysia Plan (Energy Information Bureau, 2006). However, as of 2010, fossil fuel still predominates as the source of Malaysia’s electricity generation – with RE contributing a mere 0.7%. This figure reveals that the government has failed to achieve the targets set. One of the key barriers is the poor cost-competitiveness of generating electricity from RE in comparison to conventional fossil fuels such as coal and NG. NG is more environmentally friendly compared to coal, and it continues to become the most promising fuel for electricity generation with Petronas currently subsidising up to 60% of Malaysia’s NG price.

This scenario has encouraged the Malaysian government to introduce a new gas price structure with reduced subsidies. Under the new structure, the industrial and power sectors are getting an 80% discount on the market price of gas starting from July 2008, and the discount will be gradually reduced until the gas price reflects the actual market price in 2022. This would lead to positive developments in terms of enhancing RE cost competitiveness. Besides, rising global concern for the environmental impact of fossil fuel utilisation is another major push for promoting the utilisation of RE resources. An econometric study has been conducted by Gan and Li (2008), and their projections under the reference scenario indicated that Malaysia's gross domestic product (GDP) is expected to average 4.6% from 2004 to 2030, and total primary energy consumption will triple by 2030. Coal imports will increase following the governmental policy of intensifying its use for power generation. Oil imports are predicted to take place by 2015 and reach 45 mtoe in 2030. Hence, Malaysia's energy import dependency will rise, and by using the same sources of fuel, carbon emissions will triple by 2030. On the other hand, their projections under an RE scenario showed that the utilisation of RE is a strategic option to improve the long-term energy security and environmental performance of Malaysia. However, substantial governmental involvement and support, as well as the establishment of a regulatory framework, is necessary.

Under the 10th Malaysia Plan, several new initiatives – anchored upon the Renewable Energy Policy and Action Plan – will be undertaken to achieve a renewable energy target of 985 MW by 2015, contributing 5.5% of Malaysia's total electricity generation mix, as shown in Figure 1.3. Amongst the measures taken will be:

i) Introduction of a Feed-in Tariff (FiT) of 1% that will be incorporated into the electricity tariffs of consumers to support the development of RE. This mechanism allows electricity produced from RE to be sold to utilities at a fixed premium price and for a specific duration; and

ii) Establishment of a Renewable Energy Fund from the FiT to be administered by a special agency, the Sustainable Energy Development Authority, under the Ministry of Energy, Green Technology and Water (KeTTHA) to support development of RE.



Moving towards renewable energy replaces the need for fossil-fuel power plants

Planned increase in renewable energy capacity

RE investments will receive a huge push through FiT

- **Introduction of Feed-in Tariff (FiT) of 1%** to be incorporated into the electricity tariffs of consumers
- **Establishment of a Renewable Energy Fund** from the FiT to be administered by a special agency under KeTTHA
- This provides an **annual CO_2 avoidance** of 3.2 million tonnes

SOURCE: Ministry of Energy, Green Technology and Water

Figure 1.3 RE is expected to increase from <1% in 2009 to 5.5% of Malaysia's total electricity generated by 2015 (Ministry of Energy, Green Technology and Water, 2013)

1.1.1 Carbon Dioxide Emissions

Carbon dioxide (CO_2), methane, nitrous oxide (NOx) and sulphur oxide (SOx) emissions are categorised as greenhouse gases (GHGs) that are attributed to climate change. Rising concentrations of GHGs produce an increase in the average surface temperature of the earth over time. Rising temperatures may, in turn, produce changes in precipitation patterns, storm severity, and sea level – commonly referred to as "climate change".

The use of fossil fuels for energy production is the primary source increasing the concentration of CO_2 in the atmosphere. Energy use is largely driven by economic growth, as well as changes in the fuel used in electricity generation. Back in 1998, the United Nations Framework Convention on Climate Change already developed the Kyoto Protocol to stabilise the GHG emissions in the atmosphere by having industrialised countries commit to reduce their GHG emissions. The legally binding accord was signed by 165 countries.

Southeast Asia collectively ranks third highest in GHGs emissions among developing countries, after China and India. Under the business-as-usual scenario of the International Energy Agency World Energy Outlook Projection, with 2003 as the base year, Southeast Asia's carbon dioxide emissions will increase by 350 per cent by 2050. This is an unacceptable scenario in the face of warnings issued by scientists about the direct consequences if the total global GHGs emissions are not cut to a half by the mid-century.

Among the Southeast-Asian countries, Malaysia is the highest emitter of CO_2. Even worse, Malaysia, which has rapidly transformed from an agricultural economy to an industrialised one in the last four decades, is now ranked as the 26th largest GHGs emitter in the world (International Herald Tribune, 2007). Carbon dioxide emissions in Malaysia increased by 21% between 2006 and 2010. Fossil fuels contributed to more than half of the total CO_2 increment. Figure 1.4 shows an increment of carbon emissions in Malaysia between 2006 and 2010 (IEA, 2011).

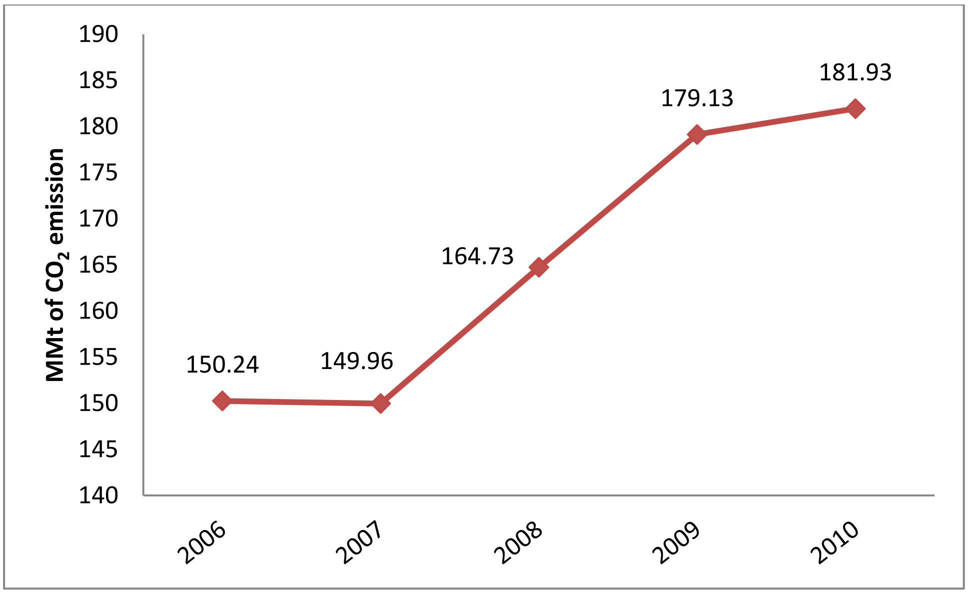


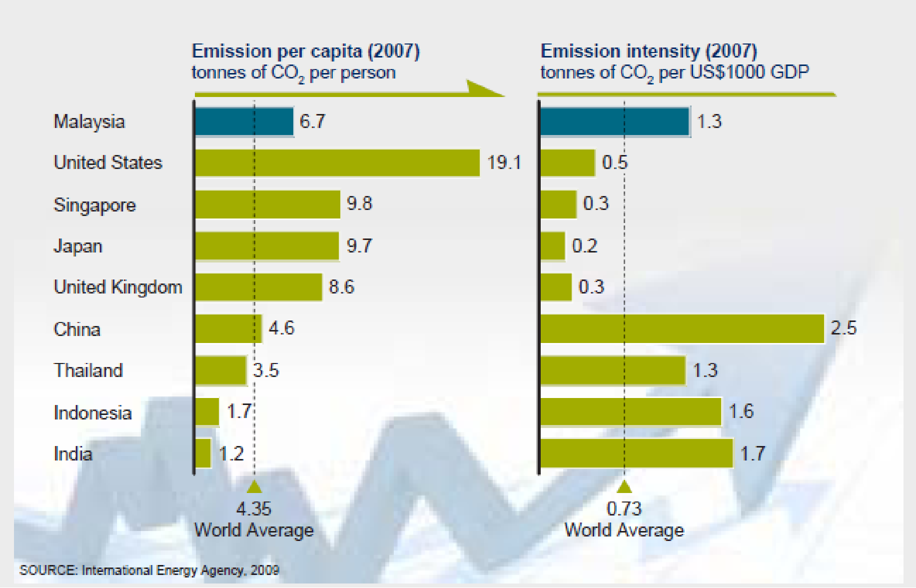
Figure 1.4 Carbon dioxide emissions in Malaysia from fossil fuel (IEA 2011).

During the Kyoto Protocol's first commitment period, developed-country signatories committed to reduce their GHGs emissions by 5.2 per cent from their 1990 levels within the period between 2008 and 2012. The signatories gathered in Bali, Indonesia, in December 2007, to negotiate the second phase of the agreement, covering the period between 2013 and 2017. Within this timeframe, industrialised countries need to reduce their CO_2 emissions by 18 per cent from 1990 levels, and then by 30 per cent between 2018 and 2022, with a target of a 75 per cent reduction by the mid-century. Only with these cuts is there a reasonable chance of keeping the average increase in global temperatures to less than 2°C – beyond which the effects of climate change will become catastrophic. During the United Nations Climate Change Conference, 2009 (COP 15), in Copenhagen, Prime Minister Datuk Seri Najib Tun Razak announced that Malaysia has agreed to reduce its carbon dioxide emissions by up to 40 per cent by 2020 compared with its 2005 level.

Malaysia contributes only 0.7% to global CO_2 emissions based on the UNDP Human Development Report 2007/2008. However, on an emission-intensity levels basis, calculated as a ratio of GHGs emissions to the country's GDP, Malaysia's emission-intensity levels are above the global average in the energy sector, as shown in Figure 1.5. In the 10th Malaysia Plan, major efforts will be introduced to reduce emission intensity. As Malaysia moves towards a high-income economy, its emission intensity is expected to decline.

The government has embarked on several programmes aimed at reducing emissions of GHGs. During the planned period, these efforts will continue to focus on five areas:

i) Creating stronger incentives for investments in renewable energy (RE);
ii) Promoting energy efficiency to encourage the efficient use of energy;
iii) Improving solid waste management;
iv) Conserving forests; and
v) Reducing emissions to improve the air quality.



SOURCE: International Energy Agency, 2009

Figure 1.5 Malaysia’s emission intensity was higher than the global average for energy sector in 2007 (International Energy Agency, 2009)

1.1.2 Renewable Energy Potential in Malaysia

Malaysia's potential for RE generation is substantial. Its equatorial location is superb for harnessing solar energy, and its extensive tropical forests can supply large quantities of biomass. Hydropower already plays a significant part in the nation's energy mix, particularly on the island of Borneo, and mini-hydropower from streams and rivers has boosted the electricity supply in rural areas. Municipal solid waste is also as an option for energy generation in Malaysia.

As one of the largest palm-oil producers in the world, there is an abundance of resources of palm-oil residues that can be utilised to generate electricity. Other sources, such as paddy and wood-processing residues, municipal waste and landfill gas, can be used for electricity generation. Malaysia has abundant hydropower potential with a total potential capacity of 29 GW (with 70% in Sarawak) (Meteorological Department of Malaysia, 2009). Only 2.119 GW has been tapped so far: 1.191 GW from Peninsular Malaysia and the rest from Sabah and Sarawak (Energy Commission, 2010).

Utilisation of biomass, especially oil palm, has been investigated through several pieces of research (Sumathi *et al*., 2008; Wicke *et al*., 2008). Palm oil not only can be used as a source of edible oil but can also be enhanced into excellent RE. Biomass can be converted to electricity through several processes: direct-fired, gasification, anaerobic digestion, pyrolysis and small modular systems (Sumathi *et al*., 2008). Oil palm biomass is one of the promising RE resources in Malaysia and can act as an example to other countries in the world that have huge biomass feedstocks (Shuit *et al*., 2009).

High and volatile natural gas prices have increasingly led to calls for investments in RE. Evaluating studies and benchmarking several findings against economic theory, other modelling results, and a limited empirical literature, Wiser and Bolinger (2007) found that many uncertainties remain regarding the absolute magnitude of this effect, and that the reduction in natural gas prices may not represent an increase in aggregate economic wealth. They conclude that many of the studies of the impact of RE on natural gas prices appear to have represented this effect within reason – given the current knowledge. These studies specifically suggest that a 1% reduction in US natural gas demand could lead to long-term average wellhead price reductions of 0.8–2%, and that each megawatt-hour of renewable energy may benefit natural gas consumers to the tune of at least $7.5–20 (Wiser & Bolinger, 2007).

Biomass can be considered as the best option and has the largest potential to meet these requirements and could ensure fuel supply in the future. The modernisation of biomass technologies, leading to more efficient biomass production and conversion, is one possible direction for biomass use in developing countries. It is critical, therefore, that the biomass processes used in developing countries are sustainable.

In industrialised countries, the main biomass processes utilised in the future are expected to be the direct combustion of residues and wastes for electricity generation, ethanol and biodiesel as liquid fuels, and combined heat and power production from energy crops. The future of biomass electricity generation lies in biomass integrated gasification / gas turbine technology, which offers high energy conversion efficiencies (Wiser *et al*, 2004).

Utilisation of biomass resources will be one of the most important factors for environmental protection in the 21st century. Biomass absorbs CO_2 during growth, and emits it during combustion. Therefore, biomass helps the atmospheric CO_2 recycling and does not contribute to the greenhouse effect. Biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion. In addition, overall CO_2 emissions can be reduced because biomass is a CO_2 neutral fuel (Demirbas *et al*., 2009).

Currently, more than 80% of the world’s biodiesel production is from rapeseed oil. However, the cost of palm oil, which is at least US$200 per tonne cheaper than rapeseed oil, indicates that palm oil could be a more suitable and attractive candidate as the source of biodiesel compared to other vegetable oils. Palm oil is known to be a multi-purpose vegetable oil with products ranging from food to biodiesel (Tan *et al*., 2009).

1.2 Problem Statement

In Malaysia, the efforts and developments to mitigate issues of security, energy efficiency and environmental impact have been on-going since 30 years ago. The Malaysian government has developed key policies and strategies to achieve the nation’s aims.

In the context of RE, during the 8th Malaysia Plan (8MP – 2001–2005), the five-fuel strategy was introduced to promote the use of RE as well as to address rising global concern for climate change. A year after the introduction of the five-fuel policy, the Small Renewable Energy Power (SREP) programme was launched in May 2001, and in order to ensure the development during 8MP, the Biomass Generation and Demonstration (BioGen) Project was then launched (Mustapa *et al*., 2010). Under the 9th Malaysia Plan (9MP – 2006–2010) the National Biofuel Policy (2006) and the National Green Technology Policy (2009) were launched in an effort to promote RE resources. Additionally, two other RE programmes were also launched under the 9MP: Malaysia Building Integrated Photovoltaic (MBIPV) and Centre for Education and Training in Renewable Energy and Energy Efficiency (CETREE). MBIPV is mainly for solar energy developments while CETREE's main target is to increase the public's awareness of the importance of RE through education and training. However, RE projects in Malaysia only achieved a capacity of 56.7 MW out of the targeted 350 MW by the end of the 9MP.

Subsequently, the National Renewable Energy Policy (2010) was launched under the 10th Malaysia Plan (10MP), with a new target of achieving 985 MW of power capacity consisting of RE by 2015. Therefore, electricity power planning to achieve the said targets is highly needed. Yet, electricity power capacity expansion planning is highly complicated, involving a large number of technologies, technological constraints, intermittent resources, weather variability, and fuel-price fluctuation, coupled with complex temporal and spatial variability. Previously, Hashim (2006) developed an MINLP model for electricity generation in Ontario, Canada. The model then had to be linearised to MILP. However, time index has not been addressed in her work. The most recent research related to this work has been done by Mirzaesmaeli (2007). He extended Hashim's (2006) work and developed a multi-period deterministic model for electricity capacity expansion planning in Ontario, Canada. However, RE for intermittent and non-intermittent resources, such as solar, wind, hydro and biomass, has not been taken into consideration. In addition, the selection of optimal locations for new plant construction will be considered in this model.

This study is therefore conducted to develop cost optimal multi-period electricity planning modelling to fulfill forecasted electricity demand for a specified time horizon as well as to ensure that RE and CO_2 intensity reduction targets can be met. This model is also able to determine locations for building new RE power plants. Note that this model can be applied to any location in the world.

1.3 Objectives of the Study

The main objective of this research is to develop a multi-period mixed integer linear programming (MILP) model with considerations of emission reduction.

1. To design and optimise the cost-optimal integrated energy system, i.e. capacity and type of technologies, comprising both fossil fuel and RE sources.

2. To determine the optimal energy mix from available options, fossil fuel and RE for fleet-wide Peninsular Malaysia and a region (Iskandar Malaysia) with the implementation of CO_2 mitigation strategies.

3. To propose optimal electricity system power planning over a period of 13 years (from 2013 to 2025) towards fulfilling the forecasted electricity demand and simultaneously meeting the emissions reduction target.

4. To determine the optimal location for construction and operation of new biomass power plants to reduce transmission losses and transportation costs.

1.4 Scope of the Study

To achieve the intended research objective, the scope of work has been drawn as follow:

1. Collection of data from Peninsular Malaysia and Iskandar Malaysia (IM) on the average annual energy demand (includes the increment over the 15 years), availability of RE sources, RE implementation targets, CO_2 reduction targets, solar intensity of the five flagships of IM, location of substation, distribution line distances and suitable location for power-plant development.

2. Collection of data on the forecasted cost of various power plants (capital cost, fixed operating and maintenance cost, and variable operating and

maintenance cost) and forecasted fuel price (coal, oil, natural gas, and biomass).

3. Design of an integrated energy system consisting of commercial sources (fossil fuel as centralised generation) and RE sources (solar, biomass, biogas, and mini-hydro as decentralised generation).

4. Formulation of a mathematical model for electricity capacity planning for an integrated system that minimises the overall cost of the power-generation system and simultaneously satisfies various constraints (forecasted energy demand, RE target, and CO_2 emission-reduction target).

5. Coding of mathematical model in GAMS.

6. Perform sensitivity analysis on the model by changing various inputs, i.e. CO_2 emission reduction (0 to 40 per cent reduction) and natural gas price fluctuation.

7. Applying the optimisation model to Peninsular Malaysia and Iskandar Malaysia.

1.5 Research Contributions

The key specific contributions of this work are summarised as follows:

1) A new single period optimisationoptimisation model for electricity capacity planning, comprising existing power plant (fossil and non-fossil fuel) and new power plant (fossil and RE) for Peninsular Malaysia with the target of reducing CO_2 emissions at the minimum cost:
– A generic mixed integer linear programming (MILP) model has been developed based on superstructure to simultaneously set the targets.
– The model was tested to observe natural gas price fluctuation.

2) A new multi-period optimisation model for electricity capacity planning, comprising existing power plant (fossil and non-fossil fuel) and new power plant (fossil and RE) for Iskandar Malaysia with the target of reducing CO_2 emissions at the minimum cost:

– A generic mixed integer linear programming (MILP) model has been developed based on superstructure to simultaneously set the targets.

– The model includes time index, construction lead time and electricity generation for peak and off-peak. It can predict capacity building and generation for 13 years.

3) A new multi-period optimisation model to select the best location to build new RE power plant in Iskandar Malaysia:

– A new generic optimisation model is able to select the best location with different capacity and type of technologies with the target to minimise the capital cost, transmission lost and transportation cost.

4) The optimisation model is generic, and can therefore be employed to any case study.

5) The optimisation model can be applied to a wide range of fuel sources, not only fossil fuel or biomass.

Appendix A lists all the publications and output of this work and the associated key contributions of this thesis towards global knowledge on electricity planning.

1.6 Summary of the Thesis

This thesis consists of six chapters. Chapter 1 is an overview of the electricity generation issues, problem background, problem statement, objectives and scope of the research, which aims to develop a new electricity-generation model for electricity planning using the mathematical approach. Chapter 2 describes the fundamental theory and relevant literature review related to electricity planning, generation and its environmental impact. Chapter 3 represents an overview of methodology of this study to achieve the targeted objectives. Chapter 4 represents a detailed methodology, model, results and discussion for single-period electricity planning using Peninsular Malaysia as a case study. Chapter 5 describes a detailed methodology, model, results and discussion for multi-period electricity planning in Iskandar Malaysia. Chapter 6 represents a detailed methodology, model, results and discussion for multi-period RE electricity planning in Iskandar Malaysia. Finally, Chapter 7 concludes the key contributions of this research, prior to the recommendation of possible future work.

REFERENCES

Ab. Majid, K., and Abd Rahman, A. (2012) Biomass Combustion and Testing, Centre for Renewable Energy, Universiti Tenaga Nasional,

Abnisa, F., Wan Daud, W.M.A., Husin, W.N.W., and Sahu, J.N. (2011). Utilization Possibilities of Palm Shell as a Source of Biomass Energy in Malaysia by Producing Bio-oil in Pyrolysis Process. *Biomass and Bioenergy*. 35(5), 1863-1872.

Ahmad, S., Ab Kadir, M.Z.A., and Shafie, S. (2011). Current Perspective of the Renewable Energy Development in Malaysia. *Renewable and Sustainable Energy Reviews* 15: 897–904.

Akademi Sains Malaysia, 2013. Sustainable Energy Options for Electric Power Generation in Peninsular Malaysia to 2030. ASM Advisory Report 1/2013. http://www.akademisains.gov.my/download/monograph/Sustainable%20Energy%20Options.pdf

Ali, R., Dauta, I., and Taib, S. (2012). A Review on Existing and Future Energy Sources for Electrical Power Generation in Malaysia. *Renewable and Sustainable Energy Reviews.* 16, 4047– 4055

Alves, J. J., and Towler, G. P. (2005). Analysis of Refinery Hydrogen Distribution Systems. *Indust Eng Chem Res*. 41,5759–69.

Anders, E. and et al. (2005). Renewable Energy Resources. *Annual Energy Outlook*

U.S. Energy Information Administration (EIA). (2011).

Anders, E. and *et al*. (2005). Renewable Energy Resources. *Integrated Resource Planning.*

Annual Energy Outlook 2011. U.S. Energy Information Administration (EIA).

Antunes, C. H., Martins, A. G., and Brito, I.S. (2004). A Multiple Objective Mixed Integer Linear Programming Model for Power Generation Expansion Planning. *Energy*. 29(4):613–627.Aqua Media, International. (2010). Asia's Achievements and Challenges. *Third International Conference on Water Resources and Renewable Energy Development.*

Azadeh, A., Ghaderi, S.F., and Maghsoudi, A. (2008.) *Location Optimisation of Solar Plants by An Integrated Hierarchical DEA PCA Approach.*

Azadeh, A., Sheikhalishahi, M., and Asadzadeh, S.M. (2012). *A Flexible Neural Network Fuzzy Data Envelopment Analysis Approach for Location Optimisation of Solar Plants with Uncertainty and Complexity*.

Bai, H., and Wei, J. (1996). The CO_2 Mitigation Options for the Electric Sector. *Energy Policy*. 24, 221-228

Bakirtzis. G., Biskas, P., and Chatziathanasiou, V. (2012). Generation Expansion Planning by MILP Considering Mid-Term Scheduling Decisions. *Elect Power Syst Res*.86:98–112.

Bakun National Hydroelectric Project Background (2004). Malaysia–China Hydro Joint Venture. http://www.bakundam.com/background.html

Bandyopadhyay S. (2011). Design and Optimisation of Isolated Energy Systems

Banos, R., Manzano-Agugliaro, F., Montoya, F. G., Gil, C., Alcayde, A., and Gómez, J. (2011). Optimisation Methods Applied to Renewable and Sustainable Energy: A Review. *Renewable and Sustainable Energy Reviews.* 15,1753–1766.

Ba-Shammakh, M. S. (2011). A Multi-Period Mathematical Model for Integrating Planning and SO_2 Mitigation in the Power Generation Sector. *Energy Fuels*. 25(4):1504–1509.

Battistelli, C., Baringo, L., and Conejo., A.J. (2012). Optimal Energy Management of Small Electric Energy Systems Including V2G Facilities and Renewable Energy Sources. *Electric Power Systems Research*. 92,50-59.

Bazmi, A. A., Zahedi, G., and Hashim, H. (2011). Progress and Challenges in Utilization of Palm Oil Biomass as Fuel for Decentralized Electricity Generation. *Renewable and Sustainable Energy Reviews*. 15, 574–583.

Bazmi, A.A., and Zahedi, G. (2011). Sustainable Energy Systems: Role of Optimisation Modelling Techniques in Power Generation and Supply - A Review. *Renewable and Sustainable Energy Reviews.* 15, 3480– 3500.

BP Statistical Review of World Energy (2011). bp.com/statisticalreview

Cai, Y. P., Huang, G. H., Tan, Q., and Yang, Z. F. (2009). Planning of Community-Scale Renewable Energy Management Systems in a Mixed Stochastic and Fuzzy Environment. *Renewable Energy*. 34(7), 1833–1847.

Cai, Y. P., Huang, G. H., Yang, Z. F., Lin, Q. G., and Tan, Q. (2009). Community-Scale Renewable Energy Systems Planning Under Uncertainty-an Interval Chance-Constrained Programming Approach. *Renewable and Sustainable Energy Reviews*. 13(4),721–35.

Careri, F., Genesi, C., Marannino, P., Montagna, M., Rossi, S., and Siviero, I. (2011). Generation Expansion Planning in the Age of Green Economy. *IEEE Trans Power Syst.*26(4), 2214–2223.

Chen, Q., Kang, C., Xia, Q., and Zhong, J. (2010). Power Generation Expansion Planning Model Towards Low Carbon Economy and its Application in China. *IEEE Trans Power Syst*. 25(2), 1117–1125.

Choi, D. G., and Thomas, V. M. (2012). An Electricity Generation Planning Model Incorporating Demand Response. *Energy Policy*. 42, 429–441.

Chua, S. C., Oh, T. H., and Goh, W. W. (2011). Feed-in Tariff Outlook in Malaysia. *Renewable and Sustainable Energy Reviews*. 15, 705-712.

Chui, F.W.Y. (2007). An Environmentally Conscious Robust Optimisation Approach for Planning Power Generating Systems. MSc Thesis. http://uwspace.uwaterloo.ca/bitstream/10012/3117/1/Flora%20Chui%20-%20Thesis%20-%20final%2007.pdf

Comprehensive Development Plan for South Johor Economic Region 2006-2025. Khazanah Nasional.

Consumer Energy Report (2010). U.S. invests in smart grid training. http://www.consumerenergyreport.com/2010/04/12/us-invests-in-smart-grid-training/

Cormio, C., Dicorato, M., Minoia, A., and Trovato, M. (2003). A Regional Energy Planning Methodology including Renewable Energy Sources and Environmental Constraints. *Renew Sustain Energy Rev.* 7, 99–130.

Cost Development – An Analysis Based On Experience Curve. New Energy Externalities Developments for Sustainability.Integrated Project. (2006). Lund University.

Couture, T., and Gagnon, Yves. (2010). An Analysis of Feed-In Tariff Remuneration Models: Implications for Renewable Energy Investment. *Energy Policy* 38, 955–965

Daniel, J., Dicorato, M., Forte, G., Iniyan, S., and Trovato, M. (2009). A Methodology for the Electrical Energy System Planning of Tamil Nadu State (India). *Energy Policy*. 37, 904–914

Demirbas, M. F., Balat, M., and Balat, H. (2009). Potential Contribution to the Sustainable Energy Development. *Energy Conversation Management*. 50(7), 1746-1760.

Diaz, M. S., and Bandoni, J. A. (1996). A Mixed Integer Optimisation Strategy for a Large Scale Chemical Plant in Operation. *Computers & Chemical Engineering*.20(5),531-545.

Economic Planning Unit (2005), *Background Report 4 – Reference Scenario Assumptions and Results Revised Assumptions and Projections 2005*, Economic Planning Unit, Kuala Lumpur: Economic Planning Unit

Economic Planning Unit, (2010). http://www.pmo.gov.my/dokumenattached/RMK/RMK10_Eds.pdf

Economic Transformation Programme (ETP) Chapter 9: Palm Oil Energy Commission, 2012. Performance and Statistical Information 2010. http://www.st.gov.my/v4/phocadownload/Statistik2010.pdf

El-Hawagi, M. M., and Manousiouthakis, V. (1989).bSynthesis of Mass Exchange Networks. *Am Inst Chem Eng J*. 8,1233–44.

Energy Commission (2006) *Annual Report 2006*, Ministry of Energy, Water and Communications. Kuala Lumpur: Energy Commission

Energy Commission, (2008). Electricity Supply Industry in Malaysia: Performance and Statistical Information 2006. Published by Energy Commission, 2008 http://www.st.gov.my/index.php/industry/statistics-reports.html

Energy Commission, (2010). Electricity Supply Industry in Malaysia: Performance and Statistical Information 2008. Published by Energy Commission, 2010 http://www.st.gov.my/index.php/industry/statistics-reports.html

Energy Commission, (2012). Electricity Supply Industry in Malaysia: Performance and Statistical Information 2010. Published by Energy Commission, 2012 http://www.st.gov.my/index.php/industry/statistics-reports.html

Energy Commission. (2012). Performance and Statistical Information 2010.

Energy Information Administration (EIA) (2005), *International Energy Annual 2005 – CO_2 World Carbon Dioxide Emissions from the Consumption of Coal, 1980-2006 (Million Metric Tons of Carbon Dioxide).* USA: Government of US. Retrieved on 25 June, 2008, from http://www.eia.doe.gov

Energy Information Bureau (2009) *National Energy Policies*, Pusat Tenaga Malaysia, Kuala Lumpur http://eib.org.my/index.php?page=article&item=99,124 (retrieved on April 12, 2009)

Ernst and Young (2008). Renewable Energy Country Attractiveness Indices 2008, Quarter 1–2. http://www.ey.com/Global/assets.nsf/International/IndustryUtilities_Renewable_energy_country_attractiveness_indices/ampdollar;file/Industry_Utilities_Renewable_energy_country_attractiveness_indices.pdfS.

European Commission (2008). Commission Staff Working Document, Brussels, 57. http://ec.europa.eu/energy/climate_actions/doc/2008_res_working_document_en.pdfS.

Evald, A. (2005). Renewable Energy Resources, Integrated Resource Planning.

Farhad S, Saffar-Avval, M., and Younessi-Sinaki. (2008). Efficient Design of Feedwater Heaters Network in Steam Power Plants using Pinch Technology and Exergy Analysis. *International Journal of Energy Research*. 32, 1–11.

Fatih, D. M., Balat, M., and Balat, H. (2009). Potential Contribution of Biomass to the Sustainable Energy Development. *Energy Conversion and Management* 50(7), 1746–1760.

Fauziah, S.H., Simo, C., and Agamuthu, P. (2004). Municipal solid waste management in Malaysia–possibility of improvement?. *Malaysian J Sci*. 23, 61–70.

Fouquet, D., and Johansson, T. B. (2008). European Renewable Energy Policy at Crossroads: Focus on Electricity Support Mechanisms. *Energy Policy*. 36 (11), 4079–4092.

Gan, P.Y, Komiyama, R., and Li, Z. (2013). A Low Carbon Society Outlook for Malaysia to 2035. *Renewable and Sustainable Energy Reviews*. 21, 432-443.

Gan, P.Y., and Li, Z. (2008). An Econometric Study on Long-Term Energy Outlook and the Implications of Renewable Energy Utilization in Malaysia. *Energy Policy*. 36(2), 890-899.

Garcia, J. A. M., and Mena, A. J. G. (2012). *Optimal Distributed Generation Location and Size Using a Modified Teaching–Learning based Optimisation Algorithm*.

Gas Malaysia Sdn. Bhd. Tariff & Rates.

GE Oil & Gas. Gas Turbine Engines. http://www.geenergy.com/about/oil_and_gas.jsp

Genchi, Y., Saitoh, K., Arashi, N., and Inaba, A. (2002), Assessment of CO_2 Emissions Reduction Potential by using an Optimisation Model for Regional Energy Supply Systems. *6th International Conference on Greenhouse gas Control Technologies*, Oct 1-4, 2002, Kyoto, Japan

General Algebraic Modelling System (2011). http://www.gams.com/docs/intro.htm

Georgiou, P.N., Mavrotas, G., and Diakoulaki, D. (2011). The Effect of Islands' Interconnection to the Mainland System on the Development of Renewable Energy Sources in the Greek Power Sector. *Renew Sustain Energy Rev*. 15(6), 2607–2620.

Green Technology Financial Scheme (2011). http://www.gtfs.my/

Greenblatt, J. B., Succar, S., Denkenberger, D. C., and Williams, R. H. (2004). Toward Optimisation of a Wind/Compressed Air Energy Storage (CAES) Power System. *Electric Power Conference*, Baltimore, MD, March 30–April 1, 2004.

Greentech. (2012). http://cdm.greentechmalaysia.my/what-is-cdm/intro.aspx

Grid 2030 - A National Vision for Electricity's Second 100 Years (2003). Based on the Results of the National Electric System Vision Meeting Washington, DC April 2-3, 2003.

Haidar, A. M. A., John, P. N., and Shawal, M. (2010). Optimal Configuration Assessment of Renewable Energy in Malaysia. *Renewable Energy*. 36(2), 881–8.

Haidar, A. M. A., John, P. N., and Shawal, M. (2011). Optimal Configuration Assessment of Renewable Energy in Malaysia. *Renewable Energy*. 36, 881-888.

Hallale, N. A. (2002). New Graphical Targeting Method for Wastewater Minimisation. *Adv Environ Res*. 6,377–90.

Hamwey, R., and Baranzini, A. (1999). Sizing the Global GHG Offset Market. *Energy Policy*. 3(27), 123.

Han, J. H., Ahn, Y. C., and Lee, I. B. (2012). A Multi-Objective Optimisation Model for Sustainable Electricity Generation and CO2 Mitigation (EGCM) Infrastructure Design Considering Economic Profit and Financial Risk. *Appl Energy*. 95, 186–195.

Han, J. H., and Lee, I. B. (2011). Development of a Scalable Infrastructure Model for Planning Electricity Generation and CO2 Mitigation Strategies under Mandated Reduction of GHG Emission. *Appl Energy*. 88(12), 5056–68.

Haris, A. H. (2008). MBIPV Project: Catalyzing Local PV Market. Finance and Investment Forum on PV Technology.

Haris, A. H. (2009). Feed-in tariff (FIT): Driving Forward Green Technologies & Deployments. http://www.mbipv.net.my/dload/NPVC%202009/Ir.%20Ahmad%20Hadri%20Haris.pdf

Haris, A. H. (2010). Renewable Energy and Feed-In Tariff. http://www.mbipv.net.my/dload/FiT%20Presentation%20Dec%202010.pdf

Haris, A. H. (2011). Renewable Energy Bill and Subsidiary Legislations. http://seda.gov.my/go home.php?omaneg=00010100000001010101000100001000000000000000000000&s=27

Hashim, H., Douglas, P., Elkamel, A., and Croiset, E. (2005). An Optimal Fleet-Wide CO_2 Emission Strategy for Ontario. Greenhouse *Gas Control Technologies*. 7, 1427-1432.

Hashim, H., Douglas, P., Elkamel, A., and Croiset, E. (2005). An Optimisation Model for Energy Planning with CO_2 Emission Considerations. *Industrial & Engineering Chemistry Research.* 44,879-890.

Hashim. M. (2006). Renewable Energy in Malaysia: *Biomass & Biogas Utilisation. National Energy Convention*. August 26 – 27, 2006. Universiti Teknologi Malaysia, Skudai, Johor Malaysia

Hassan, M.A., Yacob, S., and Ghani, B.A. (2010). Utilization of Biomass in Malaysia : Potential for CDM Business.

Henning, D. (1997). MODEST—An Energy System Optimisation Model Applicable to Local Utilities and Countries. *Energy*. 22, 1135–50.

Ho, W.S., Hashim, H., and Muis, Z.A. (2012). Integrated Biomass Power Plant and Storage for Peak Load Management**.** *Computer Aided Chemical Engineering.* 31, 1000-1004

Ho, W.S., Hashim, H., Hassim, M.H., and Muis, Z.A. and Shamsuddin N.L.M. (2012). Design of Distributed Energy System through Electric System Cascade Analysis (ESCA). *Applied Energy*. *99, 309-315*

Hobbs B. (1995). Optimisation Methods for Electric Utility Resource Planning. *Eur J Oper Res*. 83(1), 1–20.

Hoffmann, B. S., and Szklo, A. (2011). Integrated Gasification Combined Cycle and Carbon Capture: A Risky Option to Mitigate CO2 Emissions of Coal-Fired Power Plants. *Applied Energy*. 88, 3917–3929

Hoi W.K. (1999). Biomass Energy Utilisation in Malaysia Prospects and Problems. *Renewable Energy*. 16,1122-1127. http://www.st.gov.my/v4/phocadownload/Statistik2010.pdf

Husain Z, Zainal ZA, and Abdullah, M. Z. (2003). Analysis of Biomass Residue Based Cogeneration System in Palm Oil Mills. *Biomass and Bioenergy*. 24,117–24.

Huzin, H. (2004). National Waste Recycling Program. *The study on national waste minimization in Malaysia*. Ministry of Housing and Local Government.

Ibrahim, H., Illinca, A., and Perron, J. (2008). Energy Storage Systems—Characteristics and Comparisons. *Renewable and Sustainable Energy Review*. 12(5), 1221-1250.

International Energy Agency (IEA). (2008). Deploying Renewables: Principles for Effective Policies, Paris, 978-92-64-04220-9.

IPCC Fourth Assessment Report (AR4) – Climate Change 2007: Synthesis Report. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm.

Iskandar Malayisa Integrated Solid Waste Management Blueprint_Stage 3 Final Report, (2009). Iskandar Regional Development Authority. www.irda.com.my.

Iskandar Malayisa Integrated Solid Waste Management Blueprint_Stage 3 Final Report , (2010).

Iskandar Regional Development Authority (2006). Comprehensive Development Plan for South Johor Economic Region, 2006-2025.

Iskandar Regional Development Authority (2010). Powering Iskandar Malaysia with World Class Electricity Supply, 2010-2025)

Iskandar Regional Development Authority (2011). http://www.irda.com.my/

Ismail, Z. (2011). Opportunities for Further Renewable Energy Utilization for Malaysia. *International Journal of Energy Science*. 1(3), 144-150.

Jafar, A. H., Al-Amin, A. Q., and Siwar, C. (2008). Environmental Impact of Alternative Fule Mix in Electricity Generation in Malaysia. *Renewable Energy*. 33, 2229-2235

Jamaludin, A. F. (2009). Energy Mix and Alternatives Energy for Sustainable Development In Malaysia. *9th International Students Summit on Food, Agriculture and Environment in the New Century.*

Jebaraj, S., and Iniyan, S. (2006). A Review of Energy Models. *Renewable and Sustainable Energy Reviews.* 10, 281–311.

Jiang, D. Z., Shentu, G., Li, H. X., and Wu, Z. (2009). Roles of Standardized Basic Information in Developing Smart Grid. *Automation of Electric Power System.* 33(20), 1-6.

Johari, A., Hashim, H., Mat, R. Alias, H., Hassim, M.H. and Rozainee, M. (2012). Generalization, Formulation an Heat Contents of Simulated MSW with High Moisture Content. Journal of Engineering Science and Technology. 7(6), 701-710.

Kagiannas, A., Askounis, D., and Psarras, J. (2004). Power Generation Planning: A Survey From Monopoly to Competition. *Electr Power Energy Syst.* 26(6), 413–21.

Kannan, S., Baskar, S., McCalley, J. D., and Murugan, P. (2009). Application of NSGA-II Algorithm to Generation Expansion Planning. *IEEE Trans Power Syst*. 24(1), 454–61.

Kanudia, A., and Loulou, R. (1999). Advanced Bottom-Up Modelling for National and Regional Energy Planning in Response to Climate Change. *International Journal of Environment and Pollution.* 12, 191–216.

Karthivale, S., Yunus, M.N.M., Sopian, K., and Samsuddin, A.H. (2004). Energy potential from municipal solid waste in Malaysia. *Renewable Energy*. 29(4):559–67.

Keong, C. Y. (2005). Energy Demand, Economic Growth, and Energy Efficiency – the Bakun Dam-Induced Sustainable Energy Policy Revisited. *Energy Policy*. 33(5), 679–89.

Khalib, M. N. (2011). Tenaga Nasional to Restore 26 Mini Hydro Plants by mid-2011. http://www.rechargenews.com/energy/wave_tidal_hydro/article216731.ece

Khazanah Nasional. Cost Development – An Analysis Based On Experience Curve. New Energy Externalities Developments for Sustainability.Integrated Project. (2006). Lund University.

Kiameh, P. (2003). Power Generation Handbook: Selection, Applications, Operation, and Maintenance. *McGraw-Hill.*

Klein, A., Held, A., Ragwitz, M., Resch, G., and Faber, T. (2008). Evaluation of Different Feed-In Tariff Design Options: Best Practice Paper for the International Feed-In Cooperation. Energy Economics Group & Fraunhofer Institute Systems and Innovation Research, Germany.

Kocis, G. R. and Grossmann, I.E. (1987). Relaxation Strategy for the Structural Optimisation of Process Flowsheets, *Ind. Eng. Chem. Res.* 26, 1869.

Koh, M. P., and Hoi, W. K. (2003). Sustainable Biomass Production for Energy in Malaysia. *Biomass and Bioenergy*. 25(5), 517–29.

Krajacic, G., Duic, N., Zmijarevic, Z., Mathiesen, B. V., Vucinic, A. A., Carvalho, M. d. G. (2011). Planning for a 100% Independent Energy System Based On Smart Energy Storage for Integration Of Renewables and CO_2 Emissions Reduction. *Applied Thermal Engineering*. 31,2073-2083.

Kroposki, B. (2009). An Integration Facility to Accelerate Deployment of Distributed Energy Resources in Microgrids. *Proc. 2009 IEEE Power& Energy Society General Meeting*, Jul. 2009, Calgary, Canada. 1-4.

Kunze, C., Reidl, K., and Spliethoff, H. (2011). Structured Exergy Analysis of an Integrated Gasification Combined Cycle (IGCC) Plant With Carbon Capture *Energy*. 36, 1480-1487.

Langniss, O., Diekmann, J., and Lehr, U. (2009). Advanced Mechanisms for the Promotion of Renewable Energy: Models for the Future Evolution of the German Renewable Energy Act. *Energy Policy*. 37 (4), 1289–1297.

Lee, T. Y., and Chen, C. L. (2009). Wind-photovoltaic Capacity Coordination for A Time-Of Use Rate Industrial User. *IE Transactions on Renewable Power Generation.* 3(2), 152–67.

Leo-Moggie A. (2002). Keynote address. Eighth APEC coal flow seminar/nineth APEC clean fossil energy technical seminar/fourth APEC coal trade investment liberalization and facilitation workshop, 2002. Kuala Lumpur, Malaysia.

Levin, N., and Zahavi, J. (1987). Electricity Equilibrium Models with Stochastic Demands. *Energy Economics*. 9(4), 227-240.

Li, Y. F., Li, Y. P., Huang, G. H., and Chen, X. (2010). Energy and Environmental Systems Planning Under Uncertainty—an Inexact Fuzzy-Stochastic Programming Approach. *Applied Energy.* 87,3189-3211.

Li, Y. F., Li, Y. P., Huang, G. H., and Chen, X. (2011). Planning Regional Energy System in Association with Greenhouse Gas Mitigation under Uncertainty. *Applied Energy*. 88, 599-611.

Lim, S., and Teong, L. K. (2010). Recent Trends, Opportunities and Challenges of Biodiesel in Malaysia: An Overview. *Renewable and Sustainable Energy Reviews.* 14(3), 938–54.

Lin, Q. G., and Huang, G. H. (2010). An Inexact Two-Stage Stochastic Energy Systems Planning Model for Managing Greenhouse Gas Emission at A Municipal Level. *Energy*. 35,2270-2280.

Lin, Q. G., and Huang, G.H. (2009). Planning Of Energy System Management and GHG Emission Control in the Municipality of Beijing—An Inexact Dynamic Stochastic Programming Model. *Energy Policy*. 37, 4463-4473.

Lin, Q. G., Huang, G. H., and Bass, B. (2004). Power Challenge for a Cleaner Energy Future in Saskatchewan, Canada. *International Journal of Computer Applications in Technology*. 22, 151–9.

Lin, Q. G., Huang, G. H., Bass, B., and Qin, X. S. (2009). IFTEM: An Interval-Fuzzy Two-Stage Stochastic Optimisation Model for Regional Energy Systems Planning Under Uncertainty. *Energy Policy.* 37(3), 868–78.

Linares, P., and Romero, C. (2002) Aggregation of Preferences in an Environmental Economics Context: A Goal Programming Approach. *Int. J. Manage. Sci*. 30. 89-95

Linnhoff, B., Townsend, D. W., Boland, D., Hewitt, G. F., Thomas, B. E. A., and Guy, A. R. A (1982).User Guide on Process Integration for the Efficient Use of Energy. Rugby: Institute of Chemical Engineers.

Lukasz, M.P., Raymond, R.T. Dominic, C.Y., Foo, and Jacek, M.J. (2010). Optimal Energy Planning Models with Carbon Footprint Constraints. *Applied Energy*. 87, 1903-1910.

Mahlia, T.M.I. (2002). Emissions from Electricity Generation in Malaysia. *Renewable Energy*. 27, 293–300.

Mahmoud, A., Shuhaimi, M., and Abdel Samed, M. (2009). A Combined Process Integration and Fuel Switching Strategy for Emissions Reduction In Chemical Process Plants. *Energy*. 34, 190–5.

Majumdar, S., and Chattopadhyay, D. (1999). A Model for Integrated Analysis of Generation Capacity Expansion and Financial Planning. *IEEE Trans Power Syst*. 14(2), 466–71.

Makansi, J., and Abboud, J. (2002). Energy Storage, The Missing Link in the Electricity Value Chain," An ESC White Paper Published by the Energy Storage Council, May, 2002.

Malaysia Developing a Solid Waste Management: Model for Penang. (2008). United Nations Development Programme (UNDP), Malaysia.

Malaysia Second National Communication to the UNFCCC (2007). ISBN 978-983-44294-9-2. nc2.nre.gov.my

Malaysian Growth of Carbon Emissions Highest in the World, Says UN, (2007, November 29). *International Herald Tribune.* Retrieved on 30 June, 2008, from http://www.iht.com

Malaysian Palm Oil Board (2008). Economics and Industrial Development Division. www.mpob.gov.my

Malcom, S.A. and. Zenios, S.A. (1994). Robust Optimisation for Power Systems Planning under Uncertainty. *Journal of the Operational Research Society*, 45, 1040-1049.

Malek, B. A. (2010). EU-Malaysia Cooperation in Green Technology: Renewable Energy Development in Malaysia. Ministry of Energy, Green Technology and Water Malaysia.

Manfren, M., Caputo, P., and Costa, G. (2011). Paradigm Shift in Urban Energy Systems through Distributed Generation: Methods and Models. *Appl Energy*. 88, 1032–48.

Mansor, S. A. (2008). Keynote address. Powergen Asia conference.

Martiskainen, M., and Coburn, J. (2010). The role of Information and Communication Technologies (ICTs) in Household Energy Consumption/Prospects for the UK. *Energy Efficiency* doi:10.1007/s12053-010-9094-2.

Mavrotas, G. (1999). An Energy Planning Approach based on Mixed 0-1 Multiple Objective Linear Programming. *International Transaction in Operational Research.* 6, 231-44.

Mehdi, S., and Hossein, M.H. (2006). Energy Supply Planning in Iran by Using Fuzzy Linear Programming Approach (Regarding Uncertainties of Investment Costs). *Energy Policy.* 34, 993–1003.

Mejía, D., López, J., and Gallego, L. (2012). Power System Capacity Expansion Planning Model Considering Carbon Emissions Constraints. *RevistaFacultad de Ingeniería Universidad de Antioquia*. 62, 114–25.

Mekhilef, S. *et al*. (2011). Biomass Energy in Malaysia: Current State and Prospects. *Renewable and Sustainable Energy Reviews.* 15(7), 3360–70.

Mekhilef, S., Safari, A., Mustaff, W.E.S., Saidur,R., Omar, R., and Younis, M.A.A. (2012). Solar Energy in Malaysia: Current State and Prospects. *Renewable and Sustainable Energy Reviews.* 16, 386– 396.

Mendonc-a, M. (2007). Feed-inTariffs: Accelerating the Deployment of Renewable Energy. Earth Scan, London.

Meza, J. L. C., Yildirim, M. B., Masud, A. S. M. (2007). A Model for the Multi-Period Multiobjective Power Generation Expansion Planning. *IEEE Trans Power Syst*. 22(2), 871–8.

Meza, J. L. C., Yildirim, M. B., Masud, A. S. M. (2009). A Multi-Objective Evolutionary Programming Algorithm and Its Applications to Power Generation Expansion Planning. *IEEE Trans Syst Man Cybern Part A Syst Hum.* 39(5), 1086–96.

Ministry of Energy Telecommunications and Multimedia (2008). Solar energy. http://www.kettha.gov.my/template01.asp?contentid=250

Ministry of Energy, Green Technology, and Water (2010). Small renewable energy power programme (SREP). http://www.kettha.gov.my/en/content/small-renewable-energy-power-593-programme-srep.

Ministry of Energy, Water and Communication (2006) *National Energy Balance 2006*. Kuala Lumpur, Ministry Energy, Water and Communication

Ministry of Energy, Water and Communication, 2005. Energy Policies of Malaysia.

Mirzaesmaeeli, H. (2007) *A Multi-period Optimisation Model for Energy Planning with CO_2 Emission Consideration*. MSc Thesis: University of Waterloo

Mirzaesmaeeli, H., Elkamel, A., Douglas, P.L., Croiset, E. and Gupta M. (2010). A Multi Period Optimisation Model for Energy Planning With CO_2 Emission Considerations. *Journal of Environmental Management*, 91(5):1063-1070.

Mirzaesmaeeli, H., Elkamel, A., Douglas, P.L., Croiset, E., and Gupta, M. (2010). A Multi-Period Optimisation Model for Energy Planning With CO_2 Emission Consideration. *Journal of Environmental Management.* 81,1063-1070

Mohamed, A. R., and Lee, K. T. (2006). Energy for Sustainable Development in Malaysia: Energy Policy and Alternative Energy. *Energy Policy.* 34(15), 2388–97.

Mohamed, A.R., and Lee, K.T. (2005). Energy for Sustainable Development in Malaysia: Energy Policy and Alternative Energy. *Energy Policy.* 34, 2388–97.

Mohammed, M. A. A., Salmiaton, A., Wan Azlina, W. A. K. G., Mohammad Amran, M. S., Fakhru’l-Razi, A., Taufiq-Yap, Y. H. (2011). Hydrogen Rich Gas from Oil Palm Biomass as a Potential Source of Renewable Energy in Malaysia. *Renewable and Sustainable Energy Reviews.* 15(2),1258-1270.

Mokhtar, H. (2002). Malaysia energy situation. EC-ASEAN COGEN program phase III. Malaysia: Shah Alam.

Mourmouris, J.C., and Potolias, C. (2012). A multi-criteria Methodology for Energy Planning and Developing Renewable Energy Sources at a Regional Level: A Case Study Thassos, Greece. *Energy Policy*.

Muis, Z. A., Hashim, H, Manan Z. A., and Taha, F. M,. (2010). Optimisation of Biomass Usage for Electricity Generation with Carbon Dioxide Reduction in Malaysia. *Journal of Applied Sciences.* 10, 2613–7.

Muis, Z. A., Hashim, H, Manan, Z. A., Taha, F. M., and Douglas, P. L. (2010). Optimal Planning Of Renewable Energy Integrated Electricity Generation

Schemes with CO2 Reduction Target. *Renewable Energy*. 35(11), 2562–2570.

Murugan, P., Kannan, S., and Baskar, S. (2009). Application of NSGA-II Algorithm to Single Objective Transmission Constrained Generation Expansion Planning. *IEEE Trans Power Syst*. 24(4), 1790–7.

Mustapa, S. I., Leong, Y. P., and Hashim, A. H. (2010). Issues and Challenges of Renewable Energy Development: A Malaysian Experience. *PEA-AIT International Conference on Energy and Sustainable Development: Issues and Strategies.*

Naini, A., Walden, T., Pinno, K., Stogran, M., and Mutysheva, D. (2005). *Electricity Generation Technologies: Performance and Cost Characteristics.* Canadian Energy Institute.

Nakata, T., Silva, D. and Rodionov, M. (2011). Application of Energy System Models for Designing a Low-Carbon Society. *Progress in Energy and Combustion Science*. 37(4), 462-502

Narula R.G. et al., (2002) Incremental Cost of CO_2 Reduction in Power Plants. *Proceedings of IGTI, ASME TURBO EXPO.* June 3-6, 2002, Amsterdam, Netherlands

Nasrudin, M., Akhir, M., and Alamgir, A. (2011). The sixth fuel: Nuclear energy for Malaysia. *Bulletin of atomic scientists*. http://www.thebulletin.org/web-edition/op-eds/the-sixth fuel-nuclear-energy-malaysia

National Biomass Strategy 2020: New wealth creation for the palm oil industry, Sept 2012

National Energy Balance 2012, Energy Commission 2013. http://meih.st.gov.my/documents/10620/717f207d-1308-4d2c-b5e1-9f84b24d2e0b. Retrieved on 1 July 2014

National Green Technology Policy. Ministry of Energy, Green Technology and Water (2010). http://www.ktak.gov.my/template01.asp?contentid=253. Retrieved on 1 July 2014

National Renewable Energy Laboratory (2008). PV Watts: a performance calculator for grid connected PV systems. http://www.nrel.gov/rredc/solar_resource.html

New Draft Iskandar Malaysia Blueprint, (2012). Chapter 5: Green Energy System and Renewable Energy, IRDA and UTM

Ng, S. (2011). Carbon Challenge for Iskandar Malaysia. Published on Decenber 5, 2011. http://www.greenprospectsasia.com/content/carbon-challenge-iskandar-malaysia

Oh, T. H., and Chua, S. C. (2010). Energy Efficiency and Carbon Trading Potential in Malaysia. *Renewable and Sustainable Energy Review*. 14, 2095-2103.

Oh, T. H., and Chua, S. C. (2010). Review on Malaysia's National Energy Developments: Key policies, Agencies, Programmes and International Involvements. *Renewable and Sustainable Energy Reviews.* 14(4), 2916 - 2925.

Oh, T. H., Pang, S. Y., and 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.

Oikonomou, V., Flamos, A., and Grafakos, S. (2010). Is blending of Energy and Climate Policy Instruments Always Desirable?. *Energy Policy.* 38, 4186-4195.

Ong, H. C., Mahlia, T. M. I., and Masjuki, H. H. (2011). A Review on Energy Scenario and Sustainable Energy in Malaysia. *Renewable and Sustainable Energy Reviews.* 15, 639–647

Othman, M. Y. H., Sopian, K., Yatim, B., and Dalimin, M. N. (1993). Diurnal Pattern of Global Solar Radiation in the Tropics: a Case Study in Malaysia. *Renewable Energy*. 3, 741-745.

Park, J. B., Park, Y. M., Won, J. R., and Lee, K. Y. (2000). An Improved Genetic Algorithm for Generation Expansion Planning. *IEEE Trans Power Syst.* 15(3), 916–22.

Park, N. B, Yun, S. J., and Jeon, E. C. (2013) An Analys is of Long-Term Scenarios for the Transition to Renewable Energy in the Korean Electricity Sector. *Energy Policy. 52, 288–296*

Pękala, L. M., Raymond R. T., Dominic C.Y. F., and Jeżowski M. J. (2010). Optimal Energy Planning Models with Carbon Footprint Constraints. *Applied Energy*. 87(6),1903-1910

Pereira, S., Ferreira, P., and Vaz, A. I. F. (2011). Electricity Planning in a Mixed Hydro-Thermal Wind Power System. Report 02; 2011. <http://sepp.dps.uminho.pt/ Relatorio_SP1.pdf> [accessed 11.10.12].

Powering Iskandar Malaysia with World Class Electricity Supply (2010 – 2025) Information Booklet.

Press, Winds of Change Look Bad, in The Star Online 2011: Malaysia.

Pusat Tenaga Malaysia (PTM). Comprehensive Biomass Study, 2005

Pusat Tenaga Malaysia (PTM) Study on Grid Connected Electricity Baselines in Malaysia, 2008

Pusat Tenaga Malaysia (PTM), 2008. Biogen Web Portal *www.ptm.org.my/biogen/biogas.aspx (retrieved on June 20, 2008)*

Pusat Tenaga Malaysia (PTM) (2010). Renewable Energy Business Fund. Available from: http://bris.org.my/?q=node/27

Qader, M. R. (2009). Electricity Consumption and GHG Emissions in GCC Countries. *Energies.* 2, 1201–13.

Rahman, S. H. (1988). Aggregate Energy Demand Projections for India: An Econometric Approach. *Pacific Asian J Energy*. 2,32–46.

Rardin, R. L. (1998). *Optimisation in Operations Research, Chapter 2: Deterministic Optimisation Models in Operations Research*, Prentice Hall Inc.

Raymond R. T. (2011). A General Source-Sink Model with Inoperability Constraints for Robust Energy Sector Planning. *Applied Energy*. 88,3759-3764.

REN21. (2009). Renewables Global Status Report: 2009 Update. REN21 Secretariat, Paris.

Renewable Energy Act 2011 (2011). http://seda.gov.my/go-home.php?omaneg=000101000000010101010001000001000000000000000000000&s=146

Renewable Energy and Energy Efficiency Blueprint for Iskandar Malaysia. (2010). Gading Kencana Sdn Bhd.
Renewable Energy Systems Planning Under Uncertainty- An Interval Chance Constrained Programming Approach. *Renewable and Sustainable Energy Reviews*. 13(4),721–35.

Rentizelas, A., Tolis, A., and Tatsiopoulos, I. (2012). Investment Planning in Electricity Production under CO_2 Price Uncertainty. *Int J Prod Econ.* 140(2), 622–9

Review of the Generation Costs and Deployment Potential of Renewable Electricity Technologies in the UK.Study Report. (2011). Department of Energy and Climate Change. Ove Arup & Partners Ltd.

Rising Costs Dampen TNB Outlook. Report by the Edge Malaysia. 29 July 2011.

Rubin, E. S, Rao, A. B., and Chen, C. (2005). Comparative Assessments of Fossil Fuel Power Plants with CO2 Capture and Storage. *Proceeding of 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7).*September 5-9. Vancouver, Canada 2004.

Rubin, E. S., Berkenpas, M. B., Frey, H. C., Chen, C., McCoy, S., and Zaremsky, C. J. (2007). Development and Application of Optimal Design Capability for Coal Gasification System. U.S. Department of Energy, National Energy Technology Laboratory.

Rubin, E.S. et al., (2004) Comparative Assessments of Fossil Fuel Power Plants with CO_2 Capture and Storage. *Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies,* September 5-9, 2004. Vancouver

Safaei, A., Freire, F., and Antunes, C. H. (2013). A Model for Optimal Energy Planning of a Commercial Building Integrating Solar and Cogeneration Systems. *Energy. 61, 211-223*

Salsabila A., Kadir, M. Z. A. A., and Shafie, S. (2011). Current Perspective of the Renewable Energy Development in Malaysia. *Renewable and Sustainable Energy Reviews.* 15, 897-904.

Seung, H. Y., and Tae, H.Y. (2009). The Role of the Nuclear Power Generation in the Korean National Economy: An input-output Analysis. *Progress in Nuclear Energy*. 51, 86-92

Shabani, A., and Sowlati, T. (2010). A Mixed Integer Non-Linear Programming Model for Tactical Value Chain Optimisation of A Wood Biomass Power Plant. *Applied Energy*. 104(2013), 353-361.

Shafie, S. M., Mahlia, T. M. I., Masjuki, H. H., and Ahmad-Yazid, A. (2012). A Review on Electricity Generation Based on Biomass Residue in Malaysia. *Renewable and Sustainable Energy Reviews.* 16, 5879–5889.

Shafie, S.M., Mahlia, T.M.I, Masjuki, H.H., and Andriyana, A. (2011). Current Energy Usage and Sustainable Energy in Malaysia: A Review. *Renewable and Sustainable Energy Reviews*. 15, 4370– 4377.

Sharan, I., and Balasubramanian, R. (2012). Integrated Generation and Transmission Expansion Planning Including Power and Fuel Transportation Constraints. *Energy Policy.* 43, 275–84.

Sharma, D., and Bhattacharya, K. (2009). A Planning Model for Investor Firms in the Generation Sector and Financial Analysis. *IEEE Power & Energy Society General Meeting*, PES ’09.1–7.

Shekarchian, M., Moghavvemi, M., Mahlia, T. M. I., and Mazandarani, A. (2011). A Review on the Pattern of Electricity Generation and Emission in Malaysia from 1976 to 2008. *Renewable and Sustainable Energy Reviews.* 15, 2629–2642.

Shuit, S.H., Tan, K.T., Lee, K.T., and Kamarudin, A.H. (2009). Oil Palm Biomass as a Sustainable Energy Source: a Malaysia Case Study. *Energy*. 34, 12245–21235.

Singh, S. N. (2011). *Electric Power Generation: Transmission and Distribution*. 2nd Edition. Published by Prentice Hall of India Ptd Ltd. ISBN 978-81-203-3560-8

Singhvi, A., Madhavan, K. P., and Shenoy , U. V. (2004). Pinch Analysis for Aggregate Production Planning in Supply Chains. *Comput Chem Eng*. 28, 993–9.

Singhvi, A., Shenoy, U. V. (2002). Aggregate Planning In Supply Chains by Pinch Analysis. *Chem Eng Res Des*. 80,597–605.

Sinha, A. K., and Dudhani, S. (2003). A Linear Programming Model of Integrated Renewable Energy System for Sustainable Development. *Energy Technologies for Sustainable Development*. 193–200. Uttar Pradesh, India: Prime Publishing House.

Sirikitputtisak, T., Mirzaesmaeeli, H., Douglas, P. L., Croiset, E., Elkamel, A., and Gupta, M. (2009). A Multi-Period Optimisation Model for Energy Planning with CO_2 Emission Considerations. *Energy Procedia.* 1, 4339-4346.

Sirikum, J., Techanitisawad, A., and Kachitvichyanukul, V. (2007). A New Efficient GA-Benders’ Decomposition Method: for Power Generation Expansion Planning with Emission Controls. *IEEE Trans Power Syst*. 22(3),1092–100.

Smart Grid News (2011). Smart grid 101: The traditional Grid. http://www.smartgridnews.com/artman/publish/Business_Smart_Grid_101_Resources/The-Traditional-Grid-1599.html

Sovacool, B. K., and Drupady, I. M. (2011). Examining the Small Renewable Energy Power (SREP) Program in Malaysia. *Energy Policy*. 39, 7244–56.

Sreeraj, E. S., Chatterjee, K., and Bandyopadhyay, S. (2010). Design of Isolated Renewable Hybrid Power Systems. *Sol Energy*. 84, 1124–36.

Status of Electrical Energy Storage Systems (2004). dti report, DG/DTI/00050/00/00, URN NUMBER 04/1878.

Steward, D., Saur, G., Penev, M., and Ramsden, T. (2009). Lifecycle Cost Analysis of Hydrogen Versus Other Technologies for Energy Electrical Storage. National Renewable Energy Laboratory. NREL/TP-560-46719.

Sumathi, S., Chai, S.P., and Mohamed, A.R. (2008). Utilization of Oil Palm as a Source of Renewable Energy in Malaysia. *Renewable and Sustainable Energy Reviews*. 12, 2404 – 2421

Suruhanjaya Tenaga. Electricity supply industry in Malaysia. Performance and Statistical Information; (2007).

Suruhanjaya Tenaga. Peninsular Malaysia Electricitry Supply Industry Outlook, 2013

Sustainable Energy Development Authority Act 2011 (2011). http://seda.gov.my/gohome.php?omaneg=00010100000001010101000100001000000000000000000000&s=147

Suter, C., Jovanovic, Z. R., Steinfield, A. (2012). 1 kWe Thermoelectric Stack for Geothermal Power Generation – Modelling and Geometrical Optimisation. *Applied Energy*. 99, 379-385.

Tan, K.T., Lee, K.T., Mohamed, A. R., and Bhatia, S. (2009). Palm Oil : Addressing Issues Towards Sustainable Development. *Renewable and Sustainable Energy Reviews*. 13(2), 420-427.

Tekiner, H., Coit, D. W., and Felder, F. A. (2010). Multi-period Multi-Objective Electricity Generation Expansion Planning Problem with Monte-Carlo Simulation. *Elect Power Syst R*es. 80(12),1394–405.

Tenaga Nasional Berhad (2011). History of TNB. http://www.tnb.com.my/

Tenaga Nasional Berhad (2012). Tenaga Nasional Berhad Annual Report 2012

Tennessee Valley Authority (2011). Hydroelectric Power. http://www.tva.com/power/hydro.htm

Tenth Malaysia Plan. 10 MP (2010). Chapter 6: Building an Environment that Enhances Quality of Life.

through Pinch Analysis. *Asia-Pacific J Chem Eng*.

Tiris, M., Atangunduz, G., and Dincer, I. (1994). Energy, Economy and Environment Modelling: Applications for Turkey. *Energy*. 19, 1005–9.

TNB Annual Report. 2004.

TNB Research (2003) *Added Values of Grid-Connected Solar Photovoltaic System*, TNB Research. Kuala Lumpur: TNB Research Sdn. Bhd.

Topical Report (1997). Renewable energy technology characterizations. Office of Utility Technologies,Energy Efficiency and Renewable Energy and EPRI.

Towler, G. P., Mann, R. , Serriere, A. J-L., and Gabaude, C. M. D. (1996).Refinery Hydrogen Management: Cost Analysis of Chemically Integrated Facilities. *Indust Eng Chem Res*, 35,2378–88.

Turkay, M., and Grossmann, I. E. (1996). Logic-Based MINLP Algorithms For the Optimal Synthesis Of Process Networks. *Computers and Chemical Engineering*. 20,959-978.

U. S. Energy Information Administration (2010). Updated Capital Cost Estimates for Electricity Generation Plants.

U.S. Department of Energy, Energy Efficiency and Renewable Energy (2004). Management Program: Landfill Gas to Energy for Federal Facilities Combustion. ORNL 2004-02580/abh. www.eere.energy.gov/femp

U.S. Energy Information Administration (2010). International energy outlook 2010. DOE/EIA 0484(2010). http:// www.eia.gov/oiaf/ieo/index.html.

United Nations Framework Convention on Climate Change, UNFCCC (2011) http://unfccc.int/ghg_data/items/3800.php

Malaysia: Second National Communication to the UNFCCC (2007) Retrieved July 2013 from www.nre.gov.my/secondnationalcommunicationforUNFCCC

UNITEN Press : gearing towards research excellence, February 5, (2008).

Universiti Teknologi Malaysia, Iskandar regional Development Authority, Kyoto University, Okayama University and National Institute for Environmental Studies. 2012. Low Carbon Society Blueprint for Iskandar Malaysia.2025 Retrieved December 14, 2012, from http://2050.nies.go.jp/cop/cop18/SPM_LCS%20Blueprint_Iskandar%20Malaysia.pdf

Universiti Teknologi Malaysia, Kyoto University, Okayama University and Ritsumeikan University. 2009. Low Carbon City 2025. Sustainable Iskandar

Malaysia. Retrieved December 12, 2012, from http://2050.nies.go.jp/report/file/lcs_asialocal/iskandarlcs.pdf

Unsihuay-Vila, C., Marangon-Lima, J. W., De Souz, A. C. Z., and Perez-Arriaga, I. J. (2011). Multistage Expansion Planning of Generation and Interconnections with Sustainable Energy Development Criteria: A Multi-Objective Model. *Int J Electr Power Energy Syst.* 33(2), 258–70.

Unsihuay-Vila, C., Marangon-Lima, J. W., De Souza, A. C. Z., Perez-Arriaga, I. J., and Balestrassi, P. P. A. (2010). Model to Long-Term, Multiarea, Multistage, and Integrated Expansion Planning Of Electricity And Natural Gas Systems. *IEEE Trans Power Syst*. 25(2), 1154–68.

Updated Capital Cost Estimates for Electricity Generation Plants. (2010). U.S. Energy Information Administration. Office of Energy Analysis. U.S. Department of Energy Washington, DC 20585.

Urmee, T., Harries, D., and Schapfer, A. (2009). Issues Related to Rural Electrification using Renewable Energy in Developing Countries of Asia and Pacific. *Renewable Energy*. 34, 354 – 357

Viswanathan, J., and Grossmann, I. E. (1990). A Combined Penalty Function and Outer Approximation Method for MINLP Optimisation. *Computers and Chemical Engineering.* 14, 769.

Voets, T., Neven, A., Thewys, T., and Kuppens, T. (2013). *GIS-BASED Location Optimisation of a Biomass Conversion Plant on Contaminated Willow in the Campine Region (Belgium)*.

Wan-Asma, I., Mahanim, S., Zulkafli, H., Othman, S., and Mori, Y. (2010). Malaysia Oil Palm Biomass. Regional Workshop on UNEP/DTIE/IETC in Collaboration with GEC. Osaka, Japan.

Wang, Y. P., and Smith, R. (1994). Wastewater Minimisation. *Chem Eng Sci*. 49,981–1006.

Wicke, B., Dornburg, V., Junginger, M., and Faaij, A. (2008). Different Palm Oil Production Systems for Energy Purposes and Their Greenhouse Gas Implications. *Biomass & Energy*. 32 (12), 1322-1337

Wicke, B., Dornburge, V., Junginger, M., and Faaij, A. (2008). Different Palm Oil Production Systems for Energy Purposes and Their Greenhouse Gas Implications. *Biomass and Bioenergy*. 32, 1322 – 1337

Wiser, R., and Bolinger, M. (2007). Can Deployment of Renewable Energy Put Downward Pressure on Natural Gas Prices? A Malaysian Case Study.' *In: Energy* .34 (2009) 9, 1225-1235.

Wiser, R., Porter, K., and Grace, R. (2004). Evaluating Experience with Renewables Portfolio Standards in the United States. Lawrence Berkeley National Laboratory, Berkeley, CA. LBNL-54439.

World Bank. http://data.worldbank.org/

Xydis, G. and Koroneos, C. (2012). A linear Programming Approach for the Optimal Planning of a Future Energy System. Potential Contribution of Energy Recovery from Municipal Solid Wastes. *Renewable and Sustainable Energy Reviews.*16, 369– 378.

Yokoyama, R., Hasegawa, Y., and Itu, K. (2002). A MILP Decomposition Approach to Large Scale Optimisation in Structural Design of Energy Supply Systems. *Energy Conversion and Management.* 43(6), 771-790

Zainal Abidin bin Othman, The Future of Hydropower in Malaysia, JURUTERA, May 2005. http://dspace.unimap.edu.my/dspace/bitstream/123456789/13823/1/The%20Future%20of%20Hydropower%20in%20Malaysia.pdf

Zakerinia, M., and Torabi, S. A. (2010). Multi-objective Power Expansion Planning In The Planning Horizon. *IEEE Conference on innovative technologies for an efficient and reliable electricity supply, CITRES 2010*; art.no.5619813.188–194.

Zhang, D., Liu, P., Ma, L., Li, Z., and Ni, W. (2012). A Multi-Period Modelling and Optimisation Approach to the Planning of China's Power Sector with Consideration of Carbon Dioxide Mitigation. *Comput Chem Eng*. 37, 227–47.

Zhou, W., Lou, C., Li, Z., Lu, L., and Yang, H. (2010). Current Status of Research on Optimum Sizing of Stand-Alone Hybrid Solar-Wind Power Generation Systems. *Applied Energy*. 87(2), 380–9.

Zhu, H., Huang, W. W., and Huang G.H. (2014) Planning of Regional Energy Systems: An Inexact Mixed-Integer Fractional Programming Model. *Applied Energy*. 113, 500-514.