OPTIMIZATION PLANNING MODEL FOR CARBON DIOXIDE EMISSIONS REDUCTION VIA RENEWABLE ENERGY SWITCH IN A COAL POWER STATION

SITI HAFSHAR BINTI SAMSEH

UNIVERSITI TEKNOLOGI MALAYSIA

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SITI HAFSHAR BINTI SAMSEH

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Faculty of Engineering
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ABSTRACT

Stable economy status has made many foreign investors invested in various industries sectors in Malaysia. Therefore, rapid development of industrial sector has caused the energy demand to increase tremendously year by year. To continue attract foreign investors, Malaysia has taken various efforts to maintain economic stability by developing a sustainable energy sector to ensure electricity demand is sufficient for industries with less cost, reliable supply, and also less impact to the environment. However, over dependence on fossil fuels as the main energy source could not guarantee the energy security and also could evoke issues of environmental problem mainly the increase in carbon dioxide (CO_2) emission in the atmosphere. In this study, a linear programming model and mixed integer linear programming optimization model under carbon constraints was developed to address issue of rising atmospheric concentrations of CO_2 from energy sector. The developed model was able to determine the optimum energy sources mix which is most economical and to satisfy the forecasted electricity demand at Tanjung Bin Power Station (TBPS) in Iskandar Malaysia region. The model includes energy source switching and analyzing different renewable energy technologies such as biomass system, biogas system, solar thermal and photovoltaic (PV) plant in power generation. The applicability of the model was tested on various CO_2 emission reduction targets which is at 6, 25, 40 and 50 % under several scenarios either without or with government subsidy. The results in this study indicated that the optimum energy source mix for TBPS is the mix of coal and solar energy (mainly solar thermal for without government subsidy and solar PV for with government subsidy). The results show that with government subsidy, the electricity tariff was acceptable for the consumers. The average electricity tariff at 6, 25, 40 and 50 % CO_2 emission reduction is RM 0.35, RM 0.44, RM 0.51 and RM 0.57 per kWh, respectively. Increase of CO_2 emission reduction show increase in electricity tariff compared to current tariff at RM 0.21 per kWh. Finally, by applying energy source switching, TBPS can significantly reduce CO_2 emission by avoiding 1.00 Mt of CO_2 emission at 6 % of CO_2 emission reduction, 4.14 Mt of CO_2 emission at 25 % of CO_2 emission reduction, 6.63 Mt of CO_2 emission at 40 % of CO_2 emission reduction, and 8.28 Mt of CO_2 emission at 50 % of CO_2 emission reduction by 2030. This is great contributions for TBPS in CO_2 reduction effort. The results gained in this study provide better understanding to the factors and impact of energy source switching to the capacity, CO_2 emission, and also cost of electricity. The model developed could help the TBPS to plan their future energy direction. The model develop also can serve as an example for other sectors, territories, states, and even countries.

ABSTRAK

Status ekonomi yang stabil telah membuat ramai pelabur asing melabur dalam pelbagai sektor industri di Malaysia. Oleh yang demikian, pembangunan pesat sektor industri telah menyebabkan permintaan tenaga meningkat pada setiap tahun. Bagi menarik lebih ramai pelabur asing, Malaysia telah mengambil pelbagai usaha untuk mengekalkan kestabilan ekonomi dengan mewujudkan sektor tenaga yang mampan untuk memastikan permintaan bekalan elektrik mencukupi bagi industri dengan kos yang rendah, bekalan yang boleh dipercayai, dan mengurangkan kesan terhadap persekitaran. Walaubagaimanapun, kebergantungan terhadap bahan api fosil sebagai sumber tenaga utama tidak dapat menjamin keselamatan tenaga serta boleh juga menimbulkan masalah persekitaran terutamanya terhadap pelepasan gas karbon dioksida (CO_2) di dalam atmosfera. Dalam kajian ini, satu model pengaturcaraan linear dan pengoptimuman pengaturcaraan linear integer campuran telah dirumus di bawah kekangan karbon bagi menangani isu kenaikan kepekatan CO_2 di dalam atmosfera dari sektor tenaga. Model yang telah dirumus berkebolehan untuk menentukan campuran tenaga yang optimum pada kadar yang ekonomi dan dapat memenuhi permintaan elektrik di Tanjung Bin Power Station (TBPS) yang terletak di dalam rantau Iskandar Malaysia. Model ini mengambilkira penukaran sumber tenaga dan menganalisa pelbagai teknologi tenaga boleh diperbaharui seperti sistem bio jisim, sistem bio gas, loji solar terma dan solar fotovoltan (PV) di dalam penghasilan tenaga. Kebolehan model yang dirumus telah diuji kepada beberapa sasaran untuk mengurangkan pelepasan gas CO_2 iaitu pada 6 %, 25 %, 40 % dan 50 % di bawah beberapa senario sama ada dengan atau tanpa subsidi kerajaan. Keputusan kajian menunjukkan campuran sumber tenaga yang optimum untuk TBPS adalah campuran antara arang batu dan tenaga solar (terma solar menjadi pilihan untuk tanpa subsidi kerajaan dan solar PV menjadi pilihan untuk dengan subsidi kerajaan). Keputusan kajian menunjukkan sekiranya dengan subsidi kerajaan, tarif elektrik boleh diterima oleh para pengguna. Purata tarif elektrik pada 6 %, 25 %, 40 % dan 50 % pengurangan pelepasan CO_2 adalah masing-masing RM 0.35/kWh, RM 0.44/kWh, RM 0.51/kWh dan RM 0.57/kWh. Peningkatan terhadap pelepasan gas CO_2 menunjukkan peningkatan terhadap tarif elektrik berbanding tarif semasa pada RM 0.21/kWh. Kesimpulannya, dengan mengaplikasikan penukaran sumber tenaga, TBPS akan dapat mengurangkan gas CO_2 dengan mengelakkan penjanaan gas CO_2 sebanyak 1.00 Mt pelepasan gas CO_2 iaitu pada 6 % pengurangan pelepasan gas CO_2, 4.14 Mt pelepasan gas CO_2 iaitu pada 25 % pengurangan pelepasan gas CO_2, 6.63 Mt pelepasan gas CO_2 iaitu pada 40 % pengurangan pelepasan gas CO_2, dan 8.28 Mt pelepasan gas CO_2 iaitu pada 50 % pengurangan pelepasan gas CO_2 menjelang tahun 2030. Ini merupakan sumbangan terbesar untuk TBPS dalam usaha pengurangan pelepasan gas CO_2. Keputusan yang diperoleh di dalam kajian ini memberi pemahaman terhadap faktor dan impak dari penukaran sumber tenaga terhadap kapasiti, pelepasan CO_2 dan kos elektrik. Model yang dibangunkan dapat membantu TBPS untuk merancang arah masa depan tenaganya. Model yang dibangunkan juga boleh menjadi contoh bagi sektor, wilayah, negeri, dan juga negara lain.

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LIST OF ABBREVIATIONS

AC	-	Alternate Current
AIM	-	Asia-Pacific Integrated Model
BAU	-	Business as Usual
BioGen	-	Biomass Power Generation
BPMB	-	Bank Pembangunan Malaysia Berhad
CC	-	Carbon Content
CCS	-	Carbon Capture and Storage
CDM	-	Clean Development Mechanism
CETREE	-	Centre for Education and Training in Renewable Energy and Energy Efficiency
CEMS	-	Continuous Emissions Monitoring System
CHP	-	Combined Heat and Power
CH_4	-	Methane
CO_2	-	Carbon Dioxide
COE	-	Cost of Electricity
COP21	-	Conference of the Parties 21
COP15	-	Conference of the Parties 15
CPV	-	Concentrating Solar PV
DC	-	Direct Current
DOE	-	Department of Environment
EC	-	Energy Commission
EE	-	Energy Efficiency
EED	-	Electricity Dependent Scenario
EF	-	Emission Factor
EFB	-	Empty Fruit Bunches
EID	-	Electricity Independent Scenario
ETS	-	Emission Trading Scheme
EPA	-	Environmental Protection Agency
EPF	-	Employees Provided Fund
FiT	-	Feed-in Tariff
GAMS	-	General Algebraic Modelling System
GDP	-	Gross Domestic Product

GEF	-	Global Environment Facility
GHG	-	Greenhouse Gas
GST	-	Goods and Services Tax
GT	-	Green Technology
GTFS	-	Green Technology Financial Scheme
HHV	-	Higher Heating Value
IEA	-	International Energy Agency
IM	-	Iskandar Malaysia
IPP	-	Independent Power Producer
ICPT	-	Imbalance Cost Pass-Through
IPCC	-	Intergovernmental Panel on Climate Change
IGCC	-	Integrated Gasification Combined Cycle
IRDA	-	Iskandar Regional Development Authority
ISMP	-	International Symposium on Mathematical Programming
LCA	-	Life Cycle Assessment
LCS	-	Low Carbon Scenario
LP	-	Linear Programming
LPG	-	Landfill Gas
LSSPV	-	Large Scale Solar Photovoltaic
MC	-	Mono-crystalline
MBIPV	-	Malaysia Building Integrated Photovoltaic
MF	-	Mesocarp Fibres
MEA	-	Monoethanolamine
MILP	-	Mixed Integer Linear Programming
MOLP	-	Multi Objective Linear Programming
MINLP	-	Mixed Integer Nonlinear Programming
MMD	-	Malaysia Meteorological Department
MYR	-	Malaysian Ringgit
MSW	-	Municipal Solid Waste
NEM	-	Net Energy Metering
N_2O	-	Nitrous Oxide
NP	-	Nonlinear Programming
NGCC	-	Natural Gas Combined Cycle
PC	-	Poly-crystalline
PC	-	Pulverized Coal

PV	-	Photovoltaic
PGPS	-	Pasir Gudang Power Station
PKS	-	Palm Kernel Shells
POME	-	Palm Oil Mill Effluent
RE	-	Renewable Energy
REBF	-	Renewable Energy Business Fund
SGD	-	Singapore Dollar
SREP	-	Small and Renewable Energy Program
SESB	-	Sabah Electricity Sdn. Bhd
SEDA	-	Sustainable Energy Development Authority
TBPS	-	Tanjung Bin Power Station
TJSB	-	Teknik Janakuasa Sdn. Bhd.
TNB	-	Tenaga Nasional Berhad
UAE	-	United Arab Emirates
UKM	-	Universiti Kebangsaan Malaysia
UNDP	-	United Nations Development Programme
USA	-	United States of America
USD	-	United States Dollar
WEMO	-	World Energy Market Observatory
b	-	Biomass resources
d	-	Type of weather
e	-	Fuel type
g	-	Type of greenhouse gases
r	-	Solar irradiation
w		Weather occurrence probability
C	-	Capital cost
E	-	Electricity generation
F	-	Fixed cost
M	-	Maintenance cost
O	-	Operating cost
D	-	Electricity demand
Coal	-	Coal
PV	-	Solar photovoltaics
Tr	-	Solar thermal
Biom	-	Biomass

Biog	-	Biogas
T	-	Capacity
NMS	-	Net metering scheme
i	-	Operating time
f	-	Efficiency
AFPV	-	Area factor for solar PV
AFTR	-	Area factor for solar thermal
LR	-	Land availability for solar installation on rooftop
LG	-	Land availability for solar installation on the ground
J	-	Lower boundaries electricity capacity
U	-	Upper boundaries electricity capacity
CO2red	-	Percent of CO_2 reduction
CO2	-	CO_2 emission
L	-	Land availability
G	-	Emission rate
P	-	Conversion factor for HHV
V	-	Ratio of carbon
NCV	-	Net calorific value
EF	-	Emission factor
Q	-	Quantity of fuel
Cost	-	Annual total cost
X	-	Binary variable for selection
s	-	Total electricity supply
A	-	Area
H	-	Total CO_2 emission
K	-	Total amount (MW) of coal fuel
N	-	Total amount (MW) of RE mix
I	-	Emissions of GHG
P	-	Saving cost
C	-	celcius
mm	-	millimetre
Mt	-	million tonnes
MW	-	megawatt
GW	-	gigawatt
TWh	-	terawatt-hour

GWh	-	gigawatt-hours
mtpa	-	million tonnes per annum
MT/yr	-	million tonnes per year
kWh	-	kilowatt-hour
kWh/m^2	-	kilowatt-hour per square metre
MWh/year	-	megawatt-hour per year
tonne/MWh	-	tonne per megawatt-hour
MW/tonne	-	megawatt per tonne
MYR/MWh	-	malaysian ringgit per megawatt-hour
MYR/tonne	-	malaysian ringgit per tonne
MYR/kWh	-	malaysian ringgit per kilowatt-hour
hr/year	-	hour per year
mmBtu	-	million British thermal units
gCO_2/kWh	-	grams of carbon dioxide per kilowatt hour
kWp	-	kilowatt ‘peak’
MJ/kWhe	-	millijoule per kilowatt-hour electric
MJ/m^2	-	millijoule per square metre
m^2/MW	-	square metre per megawatt

LIST OF SYMBOLS

%	-	Percent
º	-	Degree
~	-	Approximate
=	-	Equals
+	-	Plus
≤	-	Less than or equal to
≥	-	Greater than or equal to
-	-	Minus
×	-	Multiplication
∑	-	Summation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Emissions of carbon dioxide (CO_2) from the combustion of fossil fuel in power station is considered as one of the main environmental issues. This is because CO_2 is the main greenhouse gas (GHG) that associated with global warming. In order to continue utilization of fossil fuels to generate electricity to meet the country's energy demand, reduction of CO_2 emission from power station has become a primary focus. This chapter highlights on generation of CO_2 emissions, trends and environmental effects, CO_2 emissions from coal fired power station, CO_2 reduction through energy source switching, and also information need for optimal planning of CO_2 emissions reduction in General Algebraic Modelling system (GAMS).

1.2 CO_2 Emissions Generation, Trends and Environmental Effects

CO_2 emission is the main GHG on earth that is produced from human activities and responsible for global warming (Chouhan *et al.,* 2017). In 2018, the world human population contributes approximately 36.42 billion tonnes of CO_2 a year to the atmosphere. This value indicates a per capita share of CO_2 emissions to be around 4.72 tonnes annually (Ritchie and Roser, 2019). CO_2 emission increases in nations is due to increasing population, urbanization and rapid economic growth (Anwar *et al.,* 2020). This indirectly cause the reliance on the fossil fuel for electricity generation is growing. Fossil fuel is responsible for 65 % of world CO_2 emissions (IPCC, 2014). Table 1.1 shows the top global CO_2 emitters with China at 1^{st} ranked followed by the United States of America (USA).

Table 1.1 Global ranking of CO_2 emitters (Boden *et al.*, 2017; Investopedia, 2019; ICQI, 2021)

Rank	Nation	Status	CO_2 emission (thousand metric tonnes)
1	China	Developing	2,806,634
2	USA	Developed	1,432,855
3	India	Developing	610,411
4	Russian Federation	Developing	465,052
5	Japan	Developed	331,074
6	Germany	Developed	196,314
7	Iran	Developing	177,115
8	Saudi Arabia	Developing	163,907
9	Korea	Developing	160,119
10	Canada	Developed	146,494
11	Brazil	Developing	144,480
12	South Africa	Developing	133,562
13	Mexico	Developing	130,971
14	Indonesia	Developing	126,582
15	United Kingdom	Developed	114,486
16	Australia	Developed	98,517
17	Turkey	Developed	94,350
18	Italy	Developed	87,377
19	Thailand	Developing	86,232
20	France	Developed	82,704
21	Poland	Developing	77,922
22	Taiwan	Developed	72,013
23	Kazakhstan	Developing	67,716
24	Malaysia	Developing	66,218
25	Spain	Developed	63,806
26	Ukraine	Developing	61,985
27	United Arab Emirates (UAE)	Developed	57,641
28	Argentina	Developing	55,638
29	Egypt	Developing	55,057
30	Venezuela	Developing	50,510

Traditionally, developed countries are known as the main emitters of CO_2. However, some developing countries have now surpassed developed country in emit of CO_2 due to rapid development activities as listed in Table 1.1 (Boden *et al.*, 2017). In the world's view, CO_2 emissions is the main issue to the environmental problem as CO_2 emissions contributes to climate change and global warming significantly (Li and Zhao, 2017). CO_2 emission has caused increase in the earth surface temperature. The global mean temperature has risen by about 1.5 ºC and most of this warming is due to increases in CO_2 concentration in atmosphere (European Commission., 2019). This warming is expected to be accompanied by sea level rising, melting of glacier, and produce changes in precipitation patterns and storm severity (European Commission., 2019).

1.3 CO_2 Emission from Coal Fired Power Station

The largest source of CO_2 emissions in the world is generated from burning of fossil fuel for electricity production. PBL Netherlands Environmental Assessment Agency (2016) reported that global coal combustion was responsible for 46 % of CO_2 emissions from fossil fuel combustion, with 31 % of CO_2 emitted from coal fired power stations. It was expected that in 2030 the CO_2 emissions will increase rapidly due to coal is going to overtake gas and be the main energy source in electricity sector (IEA, 2016).

In the past decades, Malaysia had shifted from agriculture to industrialization caused the CO_2 emissions increased tremendously every year. The electricity demand has also increased approximately 3 % since 2008 as shown in Figure 1.1.

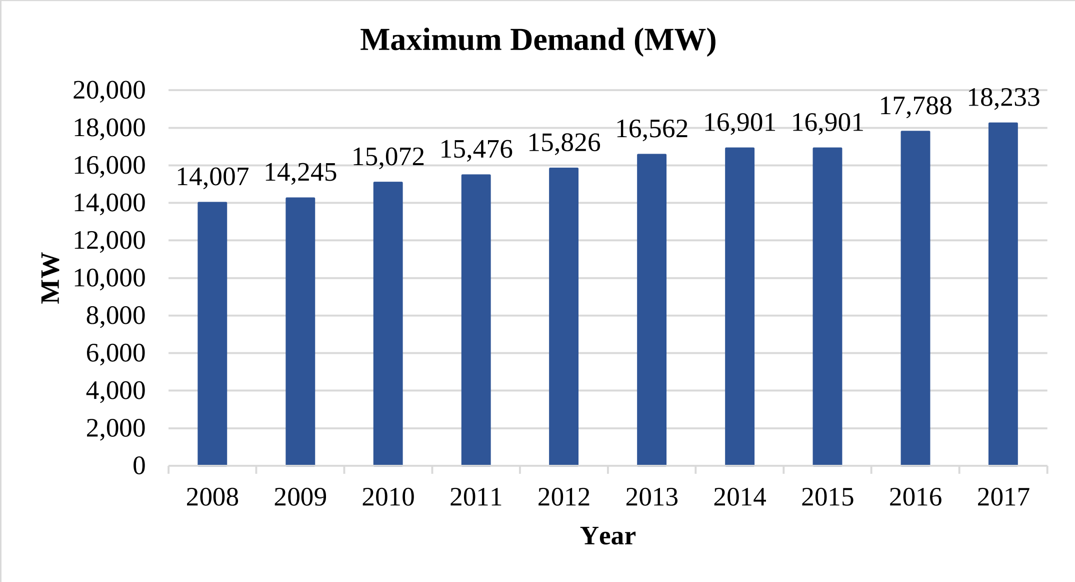

Figure 1.1 Electricity demand (Energy Commission, 2014; Energy Commission, 2016; Energy Commission, 2017)

Note that the increase of electricity demand is considered as linear relationship with CO_2 emission. This is because Malaysia is utilizing fossil fuel especially coal as the main energy source in electricity generation. In year 2017, coal share in electricity generation has reached 42.8 % of total energy source. Table 1.2 shows the energy mix for electricity generation in Malaysia.

Table 1.2 Energy mix for electricity generation in Malaysia between 2015-2020 (Energy Commission, 2019 and Energy Commission, 2020)

Energy source	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Coal	41.1	41.7	42.8	43.4	43.8	44.0
Gas	46.4	44.0	38.6	39.1	38.4	37.0
Hydro	10.6	12.8	16.6	15.6	15.9	8.0
Other	1.9	1.5	2.0	1.9	1.9	10.0

The increase of coal utilization in power stations has contributed to the changes of CO_2 emissions pattern in Malaysia. Martunus *et al.* (2008) stated that CO_2 emissions from coal fired power stations in Malaysia had grown 4.1 % per year since 2003. It was estimated CO_2 emissions from coal consumption in coal fired power stations to be around 98 million tonnes by 2020 as shown in Figure 1.2.

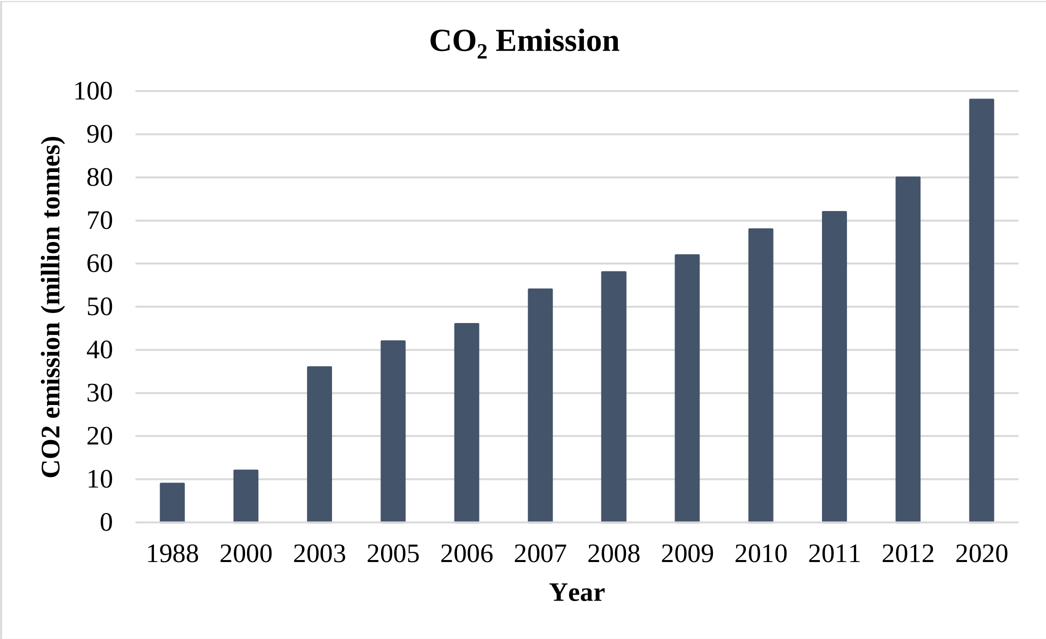

Figure 1.2 CO_2 emissions from coal fired power station in Malaysia (in million tonnes) (Martunus *et al.*, 2008)

In other study, Zubir et al. (2017) indicated that coal type power stations in Malaysia has emitted 6,113,273 metric tonnes of CO_2 in year 2008. The CO_2 emissions continuously increased year by year until CO_2 emissions reaches 14,452,314 metric tonnes of CO_2 in year 2020. Table 1.3 shows CO_2 emissions per year to the atmosphere from 2008 to 2020 in Malaysia.

Table 1.3 CO_2 emissions from coal fired power station in metric tonnes per year (Zubir *et al.*, 2017 and Energy Commission, 2020)

Year	CO_2 emissions (Metric tonnes per year)
2008	6,113,273
2009	6,824,615
2010	9,018,423
2011	9,954,041
2012	10,560,342
2013	10,238,676
2014	10,566,253
2015	11,785,284
2016	12,984,216
2017	13,497,736
2018	14,378,952
2019	14,415,633
2020	14,452,314

In the future, it was expected that in each year, CO_2 emissions will continue to increase due to the increment of production capacity and new construction of coal fired power stations (Martunus *et al.,* 2008). With several new coal power stations coming into operation, coal consumption is expected to increase to more than 30 million tonnes per year (Energy Commission, 2017). In the medium term, coal is expected to maintain as the most used fossil fuels in the electricity generation. Increase of coal consumption by the power sector in electricity generation are depicted in the Table 1.4.

Table 1.4 Coal consumption from 2014 to 2020 by coal fired power stations in Malaysia (in mtpa) (Energy Commission, 2017 and Energy Commission, 2020)

Year / **Station**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Kapar	3.5	3.7	4.1	4.4	4.8	4.8	4.8
Manjung	7.1	10.4	9.5	11.4	14.2	14.2	14.3
Jimah	3.2	4.1	4.3	4.6	5.0	5.1	5.1
Tanjung Bin	4.9	6.5	7.6	8.8	10.3	10.4	12.6
Total (mtpa)	18.7	24.6	25.4	29.2	34.3	34.5	36.8

1.4 CO_2 Reduction by Energy Source Switching

The effects from CO_2 emission such as climate change and global warming that is happening now makes the country start to realize that immediate action is needed to escalate cuts in CO_2 emissions. In the context to reduce the CO_2 emissions from power stations, there are several environmentally sound technologies available. However, energy source switching (also known as fuel switching) is considered as one of the best technical solutions for the time being (Arasto *et al.*, 2014). Energy source switching is switching the energy source to less or zero carbon intensive industrial fuels in a cost effective manner. Adoption of energy source switching by electricity sector is one of the direct and effective measures in reduction of CO_2 emissions. It could give benefits to energy security and also environmental impact. In term of environmental impact, the benefit is in air pollution reduction by savings of 20 % CO_2/year by 2020 for electricity sector (DOE, 2007).

In electricity sector, energy source switching is necessary for successful reduction of CO_2 emissions. A study by Gelman *et al.* (2014) stated that energy source switching from coal to natural gas in the USA power sector be able to mitigate over 500 million metric tonnes of CO_2 from power sector. On the other hand, a study conducted at UAE by Torcat and Almansoori (2015) encountered that energy source switching to renewable energies (RE) could reduce at 0.43-0.59 MT/yr of CO_2 emissions from UAE power sector. The researchers also stated that switching to clean alternative energies particularly nuclear power is recommended when the CO_2 emissions in electricity sector is skyrocketing. It could be reduced approximately 16 MT/yr of CO_2 emissions. In another study by Winyuchakrit *et al.* (2011), after implementing of fuel shifting in power sector in Thailand, CO_2 emissions is reduced by 85,863 kt-CO_2 in 2030. In Malaysia, study by Muis *et al.* (2008) at power sector in Peninsular Malaysia concluded that switching to nuclear power is needed for maximum CO_2 reduction. It will reduce the CO_2 emissions by 50% from current CO_2 emission level. It is estimated as much of 13.59 MT/yr of CO_2 emissions could be avoided by adopting the nuclear power. In another study, Muis *et al.* (2010) stated that by switching to RE mix in power sector, the cost of electricity (COE) will be double from the current COE. Currently, the COE is USD 0.045/kWh (~ MYR 0.153/kWh). By mixing 5 % of RE in electricity supply generation, it makes the COE increase to United States Dollar (USD) 0.096/kWh (~ Malaysian Ringgit (MYR) 0.326/kWh) (Muis *et al.*, 2010). Energy source switching costs may vary considerably between projects due to national and regional differences (Sims *et al.*, 2003). Implementation of energy source switching could provide energy security benefit and co-benefit of climate change mitigation (Winyuchakrit *et al.*, 2011).

1.5 Energy Source Switching from Coal to Solar Energy

Employing energy source switching and use of RE is essential to reduce the CO_2 emissions intensity at coal fired power station. In Malaysia, solar energy was identified as the highest potential of energy source (Ho *et al.*, 2014). This is because Malaysia received sunshine duration ranging from 4-8 hour per day with the average daily solar radiation of 4,500 kWh/m^2 (Johari *et al.*, 2011). Even though energy source switching from coal to solar energy at power station could give high impact on CO_2 emissions reduction, several factors such as technologies availability for harnessing solar energy, economic cost to install solar system, accessibility of solar energy, and acceptability by the public toward solar energy technologies need to be considered during planning process. Figure 1.3 lists several key challenges to switch to solar energy.

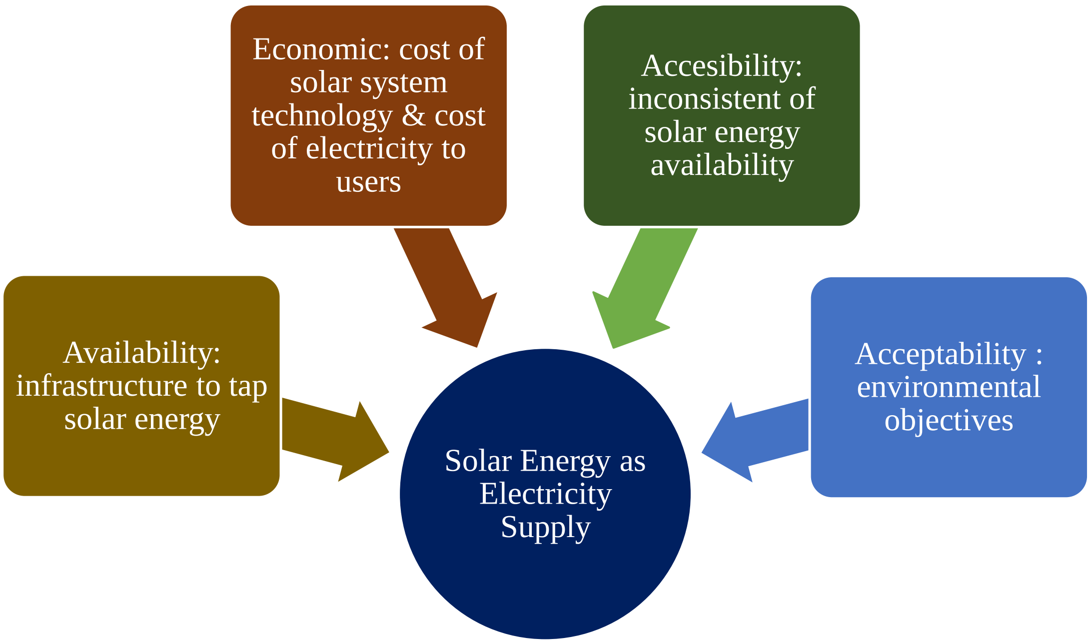

Figure 1.3 Key challenges to switch to solar energy (KeTTHA, 2014)

Among all the key challenges listed in Figure 1.3, the economic perspective of solar system technology is a major factor need to be considered. This is because the capital cost of solar in electricity generation is still relatively high compared to other RE. Muis *et al.* (2008) stated that the capital cost of solar power plant is estimated as 20,000,000 MYR/MW. In another study, Ho *et al.* (2014) estimated that the capital cost of solar power plant is 16,414,620 MYR/MW. This clearly shows that costs to install solar has decreased by more than 15 % since 2009. This also proves that market development of solar system technology has reduced the solar cost. Other than cost, adoption of solar system technology also needs consideration on land availability for large scale deployment of solar panels. Brawner *et al.* (2017) stated that solar farm must not use lands that have already been built on, and avoiding areas with vegetation. Understanding on factors that affect the energy source switching from coal to solar energy is important, in order to minimize negative aspects and maximize benefits of project.

1.6 Optimization Approach for CO_2 Emissions Reduction with GAMS

An optimization is a principle to analyze many complex decision or allocation problems. Optimization is used as an approaches for a complex decision problem that involving the selection of values for a number of interrelated variables, by focusing attention on a single objective designed to quantify performance and measure the quality of the decision. The objective is set to maximized or minimized, depending on the formulation subject to the constraints that may limit the selection of decision variable values. There are many applications of optimization such as to measure the profit or loss in a business setting, speed or distance in a physical problem, expected return in the environment of risky investments, or social welfare in the context of government planning. Optimization may provide a suitable framework for analysis.

In this study, an optimization approach is required in planning to reduce the CO_2 emissions in electricity sector. The planning include aspect of economic, environment, and technical in order to ensure the unhindered equilibrium between electricity demand, supply, reserve margin, and CO_2 emissions reduction. There are many factors which are included in the planning such as electricity generation (i.e. plant capacity, demand, reserve margin requirement), energy source selection (i.e. type and cost, resource availability), and CO_2 emissions reduction at certain target. All the listed factors have economic and environmental benefits. However, the important benefit to be considered during planning is to mitigate CO_2 emissions.

Optimization approach starts with the formulation of accurate model for the problem that is under investigation. There are several types of model available in the process of solving an optimization problem. The common model is Linear programming (LP), Nonlinear programming (NP), Mixed Integer Linear programming (MILP), and Mixed Integer Nonlinear programming (MINLP). Linear programming is problem investigation which the objective function is linear in the unknowns and the constraints consist of linear equalities and linear inequalities whilst nonlinear programming is problem investigation where the objective function or the constraints or both contain nonlinear parts. Linear programming has proved as a significant model of numerous allocation problems and economic phenomena. Some examples of situation such as manufacturing problem, the transportation problem, the maximal flow problem, and a warehousing problem.

In order to solve CO_2 emissions problem in electricity sector, Generalized Algebraic Modeling System (GAMS) software has been selected to use. GAMS is considered as a fast and effective software. GAMS is a combination of a modeling system and a library of solvers. The advantages of GAMS are the software is not case sensitive such as other software and the solvers are capable in solving optimization problems up to millions of variables. Once the optimization model is created, based on the model type specification GAMS knows by default which solver to use to solve the problem (Geletu, 2008).

1.7 Problem Statement

The increase of CO_2 emissions is pointed as main cause of climate change. This is because of dependency on fossil fuels in generation of electricity. Therefore, optimal planning for CO_2 emissions reduction at power station is becomes important. This optimal planning also become interesting among researchers and policy makers when coal usage as fuel in power station is reaching more than 50 % in electricity generation (Energy Commission, 2016). Several factors need to be considered in order to plan for CO_2 emissions reduction at power station such as plant capacity, electricity demand and reserve margin, energy source selection and price, CO_2 emissions reduction target, resource availability, weather pattern, land availability and other key elements such as minimizing cost and environmental benefits. In this study, energy source switching is adopted in power station as technology to reduce CO_2 emissions. Several renewable energy (RE) source such as solar, biogas and biomass are introduced in the plan as strategy to reduce CO_2 emissions. Tanjung Bin Power Station (TBPS) that is located in Iskandar Malaysia (IM) region was selected as study area. Among RE introduced, solar is considered as potential RE for sustainable energy source due to IM region has received average yearly solar radiation of 1,575 kWh/m^2 as shown in Appendix B (IRDA, 2013). Other than that, IM region also has enough total land area that are suitable to develop solar farm. Approximately, large scale solar photovoltaic (LSSPV) with the size about 29 MW can be built on the land available in this region as shown in Appendix C (Energy Commission, 2017). There are 14 areas that are in the lists as potential to be built with solar farm. The area includes Pasir Gudang, Ulu Tiram, Johor Bahru, Senai and Kulai as shown in Appendix D and E (IRDA, 2013). In this study, by using real industrial data, a LP and MILP model to analyzing low carbon scenario (LCS) was developed. The model developed help to analyze the different RE technologies used to generate electricity and to reduce the CO_2 emission at minimum cost. To makes RE as one of the source of energy in electricity generation, the government subsidies was also considered in the model in order to makes the cost of electricity (COE) is acceptable among the consumers.

1.8 Motivation of the Research

With the aim to reduce CO_2 emissions at IM region, this study was carried out at TBPS that located in this region. IM region is new developed region with a vision to be "*A Strong and Sustainable Metropolis of International Standing*". The "*sustainable*" term in the vision is focus on low carbon by encourage the use of RE sources to ensure energy security (Iskandar Malaysia, 2017). In order to achieve aim to reduce the CO_2 emissions, adopting energy source switching and use of RE such as solar, biogas and biomass has been indicated as one of the effective mitigation strategies to reduce CO_2 emission. An optimization model was developed to analyzing LCS and different technologies used in order to reduce CO_2 emission at minimum cost.

1.9 Thesis Objectives

The main objective of this study is to develop an optimization model to reduce CO_2 emission at minimum cost as well as maintaining the electricity supplied and energy reserves. This is achieved through the following objectives:

1. To develop a linear programming (LP) model as mathematical tool for business as usual (BAU) scenario to analyzing low carbon scenario (LCS).
2. To develop a multi period, multi-type of energy source for electricity generation by using mixed integer linear programming (MILP), for LCS with low percentage of CO_2 emission reduction.
3. To analyze different technologies used to reduce the CO_2 emission and to estimate the COE.
4. To calculate the COE if there are subsidies from the government for RE technologies.

1.10 Research Scope

The scope of the main and minor objectives covers the development of LP and MILP model to analyzing LCS. The LP model is developed to estimate the total amount of RE mix to meet the electricity demand and to reduce the CO_2 emission at minimum cost. The MILP model is developed to analyze the different RE technologies used to generate electricity and to reduce the CO_2 emission at 6 %, 25 %, 40 % and 50 % at minimum COE. Then, the government subsidies for RE technologies is considered in MILP model in order to makes the COE is acceptable by the consumer and RE be the one of energy source for electricity generation.

In this study, the objective one is to develop LP model to analyzing low carbon scenario. This objective is to find the total amount of RE mix to meet demand, and reduce CO_2 with minimize cost.

The objective two is to develop MILP model, a multi-type of energy source. The model develops consider capital cost, retrofit cost, O&M cost, resources availability, land availability, weather and etc.

The objective three is to analyze different technologies such as coal fired power plant, biomass system, biogas system, solar thermal plant, and solar PV plant to reduce the CO_2 emission. The COE also was estimate for different technologies used.

The objective four is to consider subsidies from the government to make RE into the picture. The subsidies are available for solar PV.

To achieve all the objectives set, two case studies were developed namely case 1 to developed LP model to test scenario I while case 2 to developed MILP model to test scenario II until V. Details of the scenario was discussed in section 3.4.

1.11 Research Contribution

The main contribution of this research is the development of optimization model for CO_2 emissions reduction at coal fired power station. The model determines the economic performance (i.e. minimize cost), and environmental benefits (i.e. CO_2 emissions avoided). This research used real industrial information or data in analysis process. This research provides vital information on CO_2 emission from coal fired power station and management that is essential to reduce the emission.

Previously, there are many research works have been done in development of optimization model for electricity generation, however, implementation of solar energy into electricity supply generation still get less attention. Less attention towards solar energy implementation cause the economic perspective of technology cannot be obtained accurately. The operation of solar energy technology may be cheap but the buildup process can be expensive. Thus, through this study the electricity producer could calculate the actual cost, estimate the revenue and surplus, and also speculate the risk that will exist during the adoption of solar energy technology.

In addition, the significance of the research also lies in the fact that the optimization model developed and formulation methodology can be applied to other electricity sector. In any electricity sector, one of the challenges in CO_2 emissions reduction is the economic and environmental benefits from the energy source switching technology adopted. The benefits depend on revenue from the technology adoption and also CO_2 emission reduction potential. To ensure broad applicability beyond case studies considered, the optimization model developed incorporated components (i.e. binary variables and parameters) that can forecast all of the aforementioned variables when applied to any case study.

1.12 Thesis Organization

The thesis was arranged into five chapters: Chapter 1 (Introduction); Chapter 2 (Literature Review); Chapter 3 (Methodology); Chapter 4 (Results and Discussion) and Chapter 5 (Conclusion and Recommendations). The details are as follows:

Chapter One: Introduction – This chapter gives general background of the study. It also highlights the problems associated with the research area. In addition, the chapter outlines the main aim, scope, assumptions and significance of the study.

Chapter Two: Literature Review – This chapter focuses on evaluations of relevant researches to the study area. Important information on potential energy source switching to RE especially solar were also discussed. Overview on coal fired power plant, such as generation, demand, energy source use was presented. Research on energy source mix were reviewed and their limitations, which is the gap for the research are presented.

Chapter Three: Methodology – This chapter consists of the general research approaches adopted for the study. It explained the model and superstructure development that represent the CO_2 emissions reduction. It also gave explanation of the optimization software – GAMS.

Chapter Four: This chapter presented the Case I (scenario I) and Case II (Scenario II - V); which also presents the achievement of the thesis objectives. The economic and environmental benefits from the adoption of energy source switching are explained in this chapter.

Chapter Five: Conclusions and Recommendations – In this chapter, important inferences were discussed based on the findings from the previous chapter. In addition, recommendations were made for the application based of the outcome of the research and aspects for further studies.

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