# ENERGY PLANNING OPTIMIZATION MODELING FOR ELECTRICITY GENERATION IN MALAYSIA WITH SUSTAINABILITY CONSIDERATIONS

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CHEMICAL ENGINEERING
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**Energy Planning Optimization Modeling for Electricity Generation in Malaysia with Sustainability Considerations**

by

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24408

Dissertation submitted in partial fulfilment of
the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

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Universiti Teknologi PETRONAS,

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CERTIFICATION OF APPROVAL

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Approved by,

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(Ir. Dr. Khor Cheng Seong)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

January 2021

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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TANG XIAO HUI

**ABSTRACT**

Malaysia is a rapidly developing country that highly dependent on energy resources for its economic growth. Current data shows that about 85 percent of Malaysian electricity supply is generated from fossil fuel resources, which is projected to face premature depletion in the next 30 to 50 years. This paper addresses planning and optimization of electricity generation in Malaysia towards meeting a national target of 20 percent renewable energy generation capacity by 2025 in tandem with a 45 percent carbon dioxide emissions reduction by 2030 from 2005 baseline. This work aims to formulate a mathematical optimization model for Malaysian long-term energy planning to 2025, thereby assessing and proposing potential electricity generation options particularly renewables. The model computes least projected capacity for the following two representative cases: (1) projected business as usual electricity capacity mix in Malaysia in 2025 and (2) projected generation mix capacity with sustainability factor consideration. Solutions obtained are validated with official data available in the literature. The data collection, development of objective function and development of constraint have been performed to obtain the optimal energy planning solution. Four constraints that have been developed including the supply, demand, renewable energy (RE) capacity mix and non-negativity constraint. Results from the optimal shows that emphasis on natural gas and large scale solar is essential to meet the national demand and national target in year 2025.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Malaysia Government has been introducing numerous fuel diversification policies that considered alternatives and renewable resources in order to lengthen the premature depletion of oil and gas sources (Haiges, Wang, Ghoshray, & Roskilly, 2017). This has mentioned in the National Depletion Policy 1980 as current oil and gas reserves are showing signs of depletion in 30 years for oil and 40 years for gas. In 1981, the Malaysia government introduced the Four-Fuel Policy to sustain reliable and secure supply through diversification of fuel, mainly on oil, coal, natural gas and hydro. Realizing the importance of adopting renewable energy, the government has established the Fifth Fuel Policy and National Renewable Energy Policy in 2001 and 2010 respectively. The Fifth Fuel Policy emphasized on utilization of renewable resources such as biomass, biogas, solar and mini hydro while the second National RE policy introduced in 2010 discussing on the importance to prolong lifespan of nation's oil and gas reserves. The two policies that have been promoted in year 2011 are the Renewable Energy Act and Sustainable Energy Development Authority Act that are responsible for production and implementation of RE systems. At the 21$^{st}$ Conference of Parties 2015, Malaysia has volunteered to commit in the Paris Agreement to reduce the greenhouse gas (GHG) emission of Gross Domestic Product (GDP) to 45% by 2030, comparing the emission intensity in 2005 (COP15). Also, Malaysia Government with a target of 20% renewable energy capacity mix by 2030 has the potential to reduce up to 20 million tons of carbon dioxide (Vaka, Walvekar, Rasheed, & Khalid, 2020).

Malaysia is dependent heavily on the energy for its economic growth as energy is one of the driving forces for the country's industrial and commercial developments. Current generation status in Malaysia is still largely based on fossil fuel, particularly coal and natural gas, followed by large hydroelectric power and small percent renewable energy (RE) such as solar energy, small hydro, biogas, biomass, wind and geothermal. As of 2017, the electricity installed capacity in Malaysia shown in Figure 1.1 is largely dominated by natural gas (43.6%) followed by coal (30.9%), large hydro (17.9%), diesel (4.1%) and 3.5% of renewable energy (Energy Commission, 2017). RE generation capacity in Malaysia indicates only generation from non-large hydropower, solar photovoltaic, biogas, biomass and geothermal that excludes the large hydropower greater than 100 MW (Yeo, 2018).

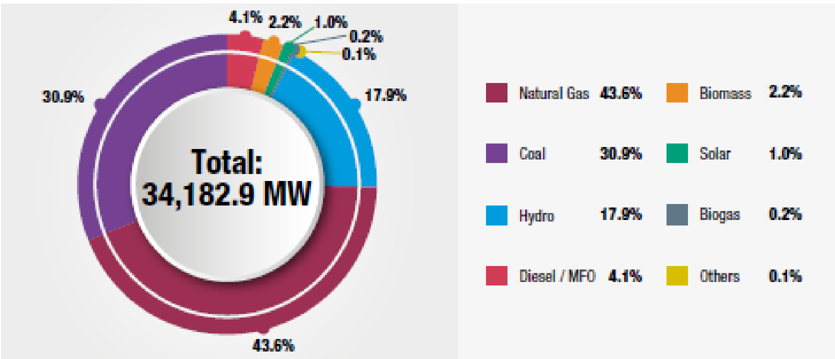


Figure 1.1: Installed capacity in Malaysia as of 31st December 2017 (Energy Commission, 2017).

The increasing trend of renewable energy capacity requires a combination of various programs and initiatives to better the RE usage step-by-step. Sustainable Energy Development Authority Act 2011 has established a statutory body named Sustainable Energy Development Authority (SEDA) Malaysia mainly to manage and control the implementation of feed-in tariff (FiT) mechanism. Malaysia's FiT system obliges the Distribution Licensees (DLs) to purchase electricity produced from renewable resources by Feed-in Approval Holders (FiAH) that include the biogas, biomass, small hydro and solar photovoltaic (PV).

Since Malaysia experiences hot and humid weather with a generous amount of rainfall over the year, our country has a high potential of solar photovoltaic electricity generation. Realizing the potential of solar energy, SEDA has initiated a few solar PV incentives such as Net Energy Metering (NEM), Large Scale Solar (LSS) and Self Consumption (SelCo) in the effort to achieve 20% energy mix by 2030. The details of these incentives are shown in Figure 1.2.

| Net Energy Metering (NEM) | Feed in Tariff (FiT) | Self Consumption (SelCo) | Large Scale Solar (LSS) |
|---|---|---|---|
| • Energy generated (Solar PV) will be consumed first and excess electricity export back to the grid on "one-on-one" offset basis. | • Distribution Licensees (DLs) purchase the electricity generated by FiAH which include the biomass, biogas, solar and mini hydro generation | • Self-consumption programme allow the applicant to generate electricity (Solar PV) for own use only | • Allow applicant to develop large scale solar plant that range from 1MW to 30MW and sell the electricity generated to the grid |

Figure 1.2: Details of Solar PV Incentives by SEDA.

## 1.2 Problem Statement

For the longest time, Malaysia relies on fossil fuel as the main source of electricity generation which causes contamination, climate change and global warming due to excessive exploitation of these natural resources (Oh, Hasanuzzaman, Selvaraj, Teo, & Chua, 2018). In order to compensate for the fast diminishing fossil fuel resources, the Malaysia government has introduced the national targets on 20% RE capacity mix and reduction of 45% carbon dioxide emission. The renewable sources like hydro, solar, biogas and biomass are extremely promising compared to fossil fuel as they will never run out and provide us green energy at the same time. Based on the official data, the 5% RE capacity mix in 2018 is still far behind the 20% target and this required massive effort from the relevant organization (Energy Commission, 2019c). The energy planning optimization that will be presented in the following section plays a crucial role in providing a projection perspective on whether the targets are achievable.

With the aim to generate an optimization plan for a greener growth and climate change mitigation in generating electricity for year 2025, there is limited examination on the power generation with alternative sources and future generation technologies (Vaka et al., 2020) . Most of the researchers studied mainly on potential renewable energy only or a specific RE category but did not consider the whole electricity generation framework. Since electricity generation directly impacts the country’s economy and human well-being, it is essential to pay emphasis on long-term planning by identifying sustainable options that will enhance energy security (Haiges et al., 2017).

## 1.3 Objectives

This thesis aims to plan and optimize the electricity generation in Malaysia with sustainability consideration by reaching the following objectives:

1. To investigate the available energy technology options for low carbon electricity generation system.
2. To formulate and solve mathematical optimization model for long term energy generation planning that investigate existing and potential electricity generation technology available for greener growth of low-carbon power generation.

## 1.4 Scope of Work

This study focuses on the area of Malaysia which involve four organizations, Tenaga Nasional Berhad (TNB), Sustainable Energy Development Authority (SEDA), Sabah Electricity Sdn Bhd and Sarawak Energy Berhad (SEB). The scope of this study with the aim provide optimal planning for electricity generation narrow down to the following aspect:

1. Determine influential variables and constraints for long term optimal solution.
2. Solve for an optimal long-term electricity generation planning using the Excel Solver.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Power Generation Technologies

The main fuel types that will be discussed in the following are coal, natural gas, hydro, solar, biogas, biomass, Ocean Thermal Energy Conversion (OTEC), geothermal and fuel cells.

### 2.1.1 Coal Fired Power Stations

Coal fired power plants in Malaysia are mainly the pulverized coal supercritical and ultra-supercritical that produce electricity by burning the fine powder coal pulverized by a large grinder to maximize the complete combustion process. The pulverized coal acts as the fuel to boil the boiler feedwater into steam. High temperature and high-pressure steam is produced then travels through a turbine, causing it to rotate extremely fast and spin a generator to generate electricity. Coal plants required higher investment costs compared to gas fired plants, but this can be compensated by the lower coal fuel costs in Europe country (European Commission, 2014). Other technologies that can study in Malaysia for the coal-fired power generator including fluidized bed combustion and pressurized fluidized bed combustion (Department of Environment).

### 2.1.2 Gas Fired Power Stations

Three types of gas fired power stations in Malaysia included open cycle gas turbine, combined cycle gas turbine and cogeneration. Open cycle gas turbine cycle (OCGT) burns fuels which is the natural gas in a combustion chamber and uses the combustion flue gas to drive a turbine to generate work. A compressor that is mounted on the same shaft as the turbine draws in the ambient air for the combustion to occur. The second technology which is the dominant gas-based technology in Malaysia is the combined cycle gas turbine (CCGT). Natural gas as the fuel is combusted in the burner to drive the gas turbine and generate work. Hot exhaust flue gas from the gas cycles will be captured by a heat recovery generator to heat up the boiler feed water and produce steams at different pressures. Therefore, the CCGT system has higher efficiency to generate more power compared to the OCGT system. Minimal development of cogeneration or combined heat and power (CHP) system in Malaysia uses fuel more efficiently as it uses a heat engine to generate electricity and useful heat at the same time.

### 2.1.3 Hydropower Stations

Most of the large hydropower plants rely on a dam that holds back water with a large reservoir for water storage. The potential energy of water from the elevated reservoir transfers into kinetic energy and strikes the turbine blades to turn the turbine that is attached to a generator by a shaft. As the turbine blades turn, the rotor inside the generator turns to produce electricity. In Malaysia, the three categories of hydropower include the large hydropower (> 100MW), small hydropower (< 30MW) and micro hydro (5kW to 500kW). The adoption of small and micro hydropower is supported by the government as it is one of the cleanest energy form and GHG emissions that is far lower compared to large hydropower (Abdullah, Osman, Kadir, & Verayiah, 2019).

Key challenges and risks that have been identified for hydropower stations include to ensure sufficient water capacity for targeted generation as well as the sediments deposition issue that might affect safety of the dams and productivity of the machines. Developing a large hydropower plant is capital intensive and overwhelming complex because it does not only involve design and construction but also considerable environmental, social and political factors (Akademi Sains, 2013).

### 2.1.4 Solar Power

The solar panel technology that is widely used in Malaysia is mainly the solar photovoltaic (PV) panel. Photons from the sun strike and ionize the photovoltaic conductor material on the panel causing the outer electron pairs to break their atomic bonds. Due to the semiconductor structure with negative conductor and positive conductor, the free electrons are forced to flow one direction and create electric current. Photovoltaic cells are not 100% efficient as part of the light within the spectrum is absorbed, some is reflected and some is too weak to generate electricity (SEIA, 2021). Hence, the other available photovoltaic technology is the concentrating solar power (CSP). CSP system produces electricity by concentrating the sun's energy with mirror reflection onto a receiver which transfers the solar energy to heat up fluid uses to drive a steam turbine. This system however requires high direct solar irradiance to work and therefore it is more suitable for installation in the Sun Belt region of the United States (IEA-ETSAP & IRENA, 2013).

### 2.1.5 BioPower Station

Malaysia being the largest palm oil producer in the world has high accumulated palm oil waste that potentially act as fuel source in electricity generation. Biomass power plants in Malaysia are mainly palm oil based by using the empty fruit bunch (EFB). Biopower technologies convert the renewable organic fuels into electricity and heat using processes similar as fossil fuel system. The most common technology in Malaysia is the direct combustion of biomass material in a grate furnace to heat up excess air into steam. Steam from the boiler is then expanded in the steam turbine and generates electricity in the generator. The direct combustion of biomass technologies is also available in combined heat and power (CHP) system and fluidized bed boiler. In either the circulating or bubbling fluidized bed systems, the biomass is burned in a bed of hot suspended and incombustible particles to produce electricity. Generally, the fluidized bed systems produce more complete carbon combustion compared to the normal grate combustor (Department of Energy, 2016). Another way to utilize energy from the biomass is through bacterial decomposition or anaerobic digestion process. The organic waste material will be collected and stored in oxygen-free tanks to produce methane throughout the bacteria decomposition process. The gas produced will then be purified and used as the renewable natural gas to generate electricity by utilizing the same technology as natural gas power stations.

### 2.1.6 Geothermal Power Station

Geothermal power plants generate electricity from the source of power found below the surface of earth or underground. There are pools of water heated up by the molten rocks below the surface that have the ability to drive a turbine by harnessing the high temperature of underground water. Three types of geothermal plant technology available includes the dry steam, flash steam and binary cycle power plants (Energy Information Administration, 2020). For steam geothermal plants, the hot water that is pumped from deep underground turns into steam when the water reaches the Earth surface due to the pressure drop. The energy produced from the steam spins a turbine which is connected to a generator and produces electricity. Before the steam pump back into the deep surface, it is cooled off in a cooling tower and condensed into water. The hot water then can be reused which makes this system a renewable energy source.

### 2.1.7 Ocean Thermal Energy Conversion

Ocean thermal energy conversion (OTEC) is a technology uses to produce energy or electricity by harnessing the differences in temperature between the deep ocean waters and ocean surface waters. The surface water with around 25 °C can be much warmer than the deep water due to the heat energy from the Sun (Woodford, 2020). The warm surface water will be pumped through an evaporator to vaporize the low boiling point working fluid. The heated vapor expands and spins a turbine to drive a generator and produce electricity. Once the heated vapor has been expanded, it is supplied to a condenser, cooled with cold deep ocean water pumped to recycle the condensed liquid back to the ocean. Two types of OTEC systems available are the open cycle and closed cycle. Closed OTEC systems recycle the condensed liquid back to the ocean while open cycle produced it as desalination water where the salt and other impurities are removed during the expansion and condensation process (Woodford, 2020).

### 2.1.8 Fuel Cells Power Station

Fuel cells as one of the renewable energy options, cleanly converts chemical energy from hydrogen rich fuels into electrical power through an electrochemical process. Similar to a battery, fuel cell consists of two electrodes, the positive cathode and negative anode. Hydrogen will be fed into the anode and air to the cathode. A catalyst at the negative electrode separates hydrogen molecules into protons and electrons which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity while the protons migrate through the electrode react electrochemically with oxygen and produce electric current. Other byproducts generated are heat and water vapor which make the hydrogen fuel cells technology an ideal solution to cut carbon emissions.

## 2.2 Potential of Renewable Energy in Malaysia

The potential of renewable energy in Malaysia has to be studied to ensure any energy development planning is achievable. The Ministry of Energy, Green Technology and Water (KeTTHA) has been exploring renewable energy resources in Malaysia and mentioned that RE is not significantly being developed in the past due to the high generation cost compared to conventional energy sources (KeTTHA, 2011). Malaysia has high potential of solar uptake with the monthly irradiation of 400-600 MJ/$m^2$ due to strategic location near to the equator (Abdullah et al., 2019). Wind energy potential is discovered at the higher altitude areas with the average wind power 9-11 m/s. but the wind power is not a promising technology yet (Abdullah et al., 2019). Biogas and biomass refers to the system where organic wastes produce fuel to generate electricity by using fuels like empty fruit bunches (EFB), mesocarp fibres and palm oil mild effluent from palm oil industry (KeTTHA, 2011). Other than these, Malaysia also has the potential to develop non-large hydropower, geothermal, ocean thermal energy conversion (OTEC) and fuel cells. The data reported by these two references have been tabulated in Table 2.1.

Table 2.0.1: Potential capacity of renewable energy in Malaysia.

| Type of energy sources | Potential generation capacity (MW) (Abdullah et al., 2019) | Potential generation capacity (MW) (KeTTHA, 2011) |
|---|---:|---:|
| Mini Hydro (< 30MW) | n.r | 490 |
| Total solar PV | 6500 | Unlimited |
| Biomass | 2400 | 1340 |
| Biogas | 388 | 410 |
| Solid Waste | n.r | 378 |
| Wind turbines | 1.5 | n.r |

Note: n.r. refers to non-reported.

## 2.3 Electricity Optimization Model

Optimization is a branch of mathematical and computational science that evaluates methods of achieving the best result of the defined optimization problem without violating the resource constraints (Geleta & Manshahia, 2017). It is a decision-making model that requires choosing the most suitable or most satisfied decision to the problem given. Optimization techniques or model are a pre-designed algorithm formula to solve wide range of optimization problems such as Linear Programming (LP), Nonlinear Programming (NLP), Mixed Integer Linear Programming (MILP), Mixed Integer Non-Linear Programming (MINLP) and Integer Linear Programming (ILP). An optimization model consists of three basic elements which are the objective functions, decision variables and constraints. Different developed optimization models will be discussed in the following section on various technique and stimulation tools.

Based on Wang, Wang, Hu, Varga and Wang (2018) that studied on Zhe Jiang Province power generation expansion from the perspective of electricity demand uncertainty, the minimization optimal model has objective function that sums up investment cost, operation and maintenance cost (O&M), fuel cost, environmental cost and electricity procurement cost. Physical constraints or the material balances should involve the demand and supply balance, safe operation, capacity and non-negativity constraints. The demand and supply balance are important to ensure the supply planning scheme is able to meet the province's increasing electricity demand and this constraint is developed as shown in Equation (1).

$$Electricity\ demand \leq Electricity\ supply\ generation \qquad (1)$$

Capacity constraint mentioned refers to installed capacity in year 2020 should be lower than the capacity in the projection model under assumption that renewable energy power supply is growing instead of withering. Findings from the study suggested that nuclear power is the second most stable electricity source that will contribute 9.56% of total installed capacity (Wang, Wang, Hu, Varga, & Wang, 2018).

Yan, Zhang, Zheng and Liang (2020) discussed the optimal design of energy systems based on forecasting data using particle swarm optimization as the optimization model. They mentioned that minimum annual cost equivalent to summation of capital costs, fixed costs and energy consumption cost. Energy consumption cost for renewable energy is equal to zero as most of the renewable resources produced naturally while the cost of coal and natural gas consumption should be taken into consideration. The constraints that were taken into consideration while developing the optimization model by Yan et al. (2020) are the energy balance, design and operation constraints. The design constraint is developed on basis of electricity generated smaller and equal to rated power of energy generation technology while the operation constraint refers to the switching constraint for MILP model where rated power of energy generation smaller and equals to product of binary variable and maximum installation capacity.

An integrated energy network with centralized and decentralized energy system was optimized by using a MINLP model with General Algebraic Modelling System (GAMS). Liu et.al. suggested that the optimization flow should start with problem definition, data collection, development of superstructure model, mathematical formulation, GAMS programming, selection of suitable optimization solver and lastly the result interpretation. Focus of this study is on the overall system cost minimization and maximization of system's operational efficiency. Similar to the demand and supply constraint (Wang et al., 2018) and design constraint (Yan, Zhang, Zheng, & Liang, 2020), power generator operation suggested here showing that the output generated within a system must not exceed its installed capacity. Yan et al. also suggested energy storage operating constraint and space and resource availability. Results from the model found that only centralized energy generation (CEG) should be installed when cost minimization as the objective function while both CEG and decentralized energy generation (DCEG) are selected for objective function to maximize operational efficiency. Therefore, a trade-off between the cost and efficiency factor need to be considered to minimize the cost and at the same time generate electricity efficiently.

Haiges et al. (2017) stated that it is necessary to pay emphasis on Malaysia's long-term electricity planning by identifying the possible sustainable options that ensure Malaysia's energy security and climate change. This paper projected the optimization model in 2050 by developing the MARKAL-EFOM (TIMES) model. The optimized least cost selection of renewable energy is developed under case study of business as usual (BAU). Resultant conclusion made from this paper is that "the quickest way to achieve Paris Agreement is by implementing existing technology plus PV and storage scenario".

Geleta and Manshahia (2019) stated that the hybrid renewable energy is becoming emerging and widely under application to satisfy the high demand of power for rural areas that are difficult for the grid extension. Difference of hybrid with normal renewable energy is that these systems incorporate a combination of two or more renewable energy sources or at least one renewable source. These renewable energy sources that are involved in hybrid optimization model are solar photovoltaic, wind, micro-hydro, biomass and geothermal. Reliability and cost are the most essential aspects in sustainability consideration and therefore the objective function for this paper is to minimize the total cost of entire hybrid system as shown in Equation (2).

$$\text{Min}\, cost = Capital\ cost + Replacement\ or\ retrofit\ cost + operating\ and\ maintenance\ cost + cost\ of\ diesel\ generator + salvage\ values\ of\ equipment \tag{2}$$

Suggested constraint in this paper are power generation constraint, power balance constraint, battery constraint and profitability of power loss constraint. Power generation constraint is similar as the capacity constraint mentioned earlier by other scholars, where the power generated from each source should be less or equal to the maximum installed capacity of the source. Power balance constraint has the equation where total power generation must be greater or equal to total load demand. The authors also highlighted the advantages, disadvantages of renewable energy and the research gap found from other analysis should be considered by other authors.

Dedinec, Tomovski and Kocarev (2015) have studied the challenges to shift towards low carbon emission electricity generation which can be achieved by replacing the conventional energy sources with renewable energy system in the Republic of Macedonia. Large scale expansion of renewable energy sources highly dependent on a balance between demand and supply to ensure the energy security of electricity. This paper explored the excess electricity production minimization optimal model that is considered on 100% renewable energy sources. Optimal results from the study show that 30% installed hydropower plants, 50% wind power generation and 20% photovoltaic power generation. One main point that is drawn by Dedinec et al. (2015) is that electricity generation from wind and solar power systems has large seasonal and daily dependence. Thus, a mixture or combination of different renewable energy sources should be applied to secure electricity generation beyond the demands.

Bourouni (2012) discussed energy planning that combines existing electricity generating abilities with expanding use of renewable energy sources. A multi-objective linear programming model was developed to discover the optimal mix of renewable energy (RE) with existing non-renewable energy electricity generation power system. Since the renewable energy sources are recognized as clean fuels that reduce or zero greenhouse gases emissions, the RE development would serve to reduce the environmental impacts due to electricity generation. Minimizing cost objective function takes into account annual generation costs that contains three subcomponents, capital investment costs, fixed operating and maintenance cost and variable operating and maintenance costs. The second objective function aims to minimize carbon footprints by assuming a linear relationship between amount of electricity generated and amount of gases emitted. A trade-off between minimizing cost and minimizing emissions required by applying the minimax criterion to the multi-objective optimization problem.

Fairuz et al. (2013) has analyzed the long-term strategy for electricity generation in Peninsular Malaysia using the software Model for Energy Supply System Alternatives and General Environment Impacts (MESSAGE) to project on the cost of expanding several energy systems over 21 years. With the optimization criterion of minimizing total system costs, Fairuz et.al. (2013) considered on investment or expanding cost, operational cost and penalty cost that will be discounted to present value at interest rate of 10%. Inputs required for the energy planning included the extrapolated energy demand, investment in technology and the upper or lower limits on existing and new power plant technologies. These inputs are significant to act as constraints for the optimization model that show results on capacity mix of natural gas (49.78%), coal (45.13%), hydropower (2.98%) and renewable energy (2.11%) in the projected 2030 under sustainability factor case study. Business as usual case study shows results of natural gas (49.98%), coal (47.03%) and hydropower (2.98%) which the consumption of non-renewable energy is greater than capacity of coal and natural gas in the previous case study. In addition, it is shown that the projected capacity mix in 2030 from 2009 could not achieve the 20% RE targets due to high renewable energy plant cost, longer payback period, land acquisition problem, ecological displacement, low efficiency and unreliable energy resources.

Kenneth E & Uhunmwangho (2014) studied on the Hybrid Optimization Model for Electrical Renewable (HOMER) which contain a mix of conventional non-renewable energy and renewable energy like wind turbines, solar photovoltaic, hydropower, batteries, fuel cells and biomass. Two case studies have been taken into consideration which include the optimization of RE system based on power system net present cost and the investigation of different load or capacity profiles effects. Case study 2 display results that show the higher the load profile, the greater the cash flow summary due to increase in capital, fuel consumption and operating cost. Therefore, the optimum load that gives the lowest overall system cost needs to be determined using the optimization model.

It is concluded that the first step to develop an optimization model is the data collection on inputs required like current demand and projected demand, capacity of current technologies and lower or upper bound of each technology. With the inputs available, the influential constraints and objective function are able to be constructed. By using an optimization software like Excel Solver, General Algebraic Modelling System (GAMS), Particle Swarm Optimization (PSO) or Long-range Energy Alternatives Planning (LEAP). An optimization model with sufficient and accurate constraints would result in continuous selection on energy resources for minimum cost objective function. The summary of the methodology development by the author mentioned earlier is shown in Table 2.2.

Table 2.0.2: Summary of literature review performed.

| Author | Title | Model development | Objective function | Constraints |
|---|---|---|---|---|
| (Haiges et al., 2017) | Optimization of Malaysia's power generation mix to meet the electricity demand by 2050 | Linear Programming (LP) using TIMES | Minimization of system cost | n.r. |
| (Wang et al., 2018) | Power Generation Expansion Optimization Model Considering Multi-Scenario Electricity Demand Constraints | Linear Programming (LP) using LEAP | Minimization of economic cost for the economic system | • Demand and supply balance<br>• Safe operation constraint<br>• Capacity constraint<br>• Non-negativity constraint |
| {Yan, 2020 #41} | Optimal Design of Energy System based on the Forecasting Data with Particle Swarm Optimization | Mixed Integer Linear Programming (MILP) model using Particle Swarm Optimization (PSO) | Minimization of total annual cost for energy supply system | • Energy balance<br>• Design & operation constraint |
| (Liu et al., 2019) | Development and optimization of an integrated energy network with centralized and decentralized energy system using mathematical modelling approach | Mixed Integer Non-Linear Programming (MINLP) using GAMS | Minimization of overall system cost and maximizing system's operational efficiency | • Power generator operation constraint<br>• Energy storage operation<br>• Space and Resource Availability |
| (Geleta & Manshahia, 2017) | Optimization of Renewable Energy System: A review | Mixed Integer Nonlinear Programming (MINLP) using Natured Inspired Computational Intelligence Techniques | Minimizing total net present cost | • Supply and demand constraint<br>• Capacity constraint<br>• Power generated constraint<br>• Battery constraint |
| (Cong, 2013) | An optimization model for renewable energy generation and its application in China: A perspective of maximum utilization | Mixed Integer Linear Programming (MILP) Renewable Energy Optimization Model (REOM) | Maximize total generation from three renewable sources (wind, solar and biomass) | • Installed capacity of a renewable energy<br>• Total investment in renewable constraint<br>• Total on grid renewable generation<br>• Supply demand constraint |

Table 2.2: Summary of literature review performed (continued).

| Author | Title | Model development | Objective function | Constraints |
|---|---|---|---|---|
| (Bourouni, 2012) | Optimization of renewable energy systems: The case of desalination | Genetic Algorithms (Gas) | Minimization of total system cost | • Battery limit constraint<br>• Non-negativity constraint |
| (Arnette & Zobel, 2012) | An optimization model for regional energy development | Multi-objective linear programming (LP) | Minimization of cost and minimization of carbon dioxide emission | • Availability constraint<br>• Maximum capacity constraint<br>• Supply demand constraint<br>• Total investment constraint |
| (Dedinec, Tomovski, & Kocarev, 2015) | Optimization model for variable renewable energy sources generation: Macedonian case study | n.r. | Minimization of excess and lack of electricity production | • Maximum capacity constraint |
| (Zeng, Cai, Huang, & Dai, 2011) | A review on Optimization Modeling of Energy Systems Planning and GHG emission mitigation under uncertainty | Nonlinear programming (NLP) using fuzzy mathematical programming (FMP) | Minimization of overall cost | n.r. |

Note: n.r. refers to non-reported.

# CHAPTER 3

# METHODOLOGY

Based on Chapter 2 literature review, the flow of this project is organized as shown in Figure 3.1 with the Gantt chart shown in APPENDIX A.

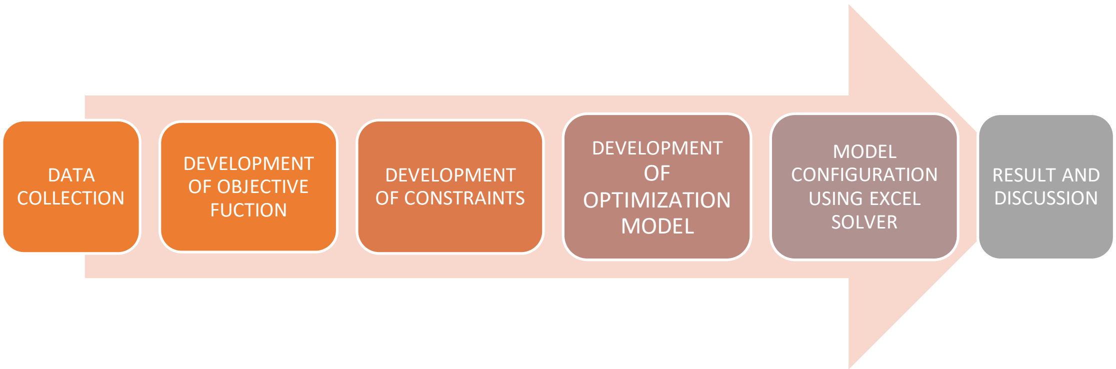


Figure 3.1: Overall project movement.

In order to solve the energy planning optimization model, the project starts with data collection on current power system capacity. The flow of project movement is then followed by development of objective function, constraints, optimization model and model configuration for an optimal energy planning result.

## 3.1 Data Gathering

Data collection section focuses on the existing electricity power system capacity, generation cost of different power plants and electricity demand projection. The capacity of existing power generation systems will be categorized based on the sources and their capacity definition while generation cost of power plants is retrieved based on the technology used by different power systems. The data required will be extracted accordingly from the sources available mentioned as below:

a) Energy Commission National Energy Balance 2017
b) Energy Commission Peninsular Malaysia Electricity Supply Outlook 2019
c) Energy Commission Malaysia Energy Statistics Handbook 2019
d) SEDA Annual Report 2018
e) SEDA and IEA Annual Report 2018
f) Europe Energy Technology Reference Indicator (ETRI) report

## 3.2 Development of Objective Function

Optimization problems are usually concerned with either maximizing profits or minimizing costs. Due to the limited data on revenue gained by the electricity power system, the objective function for this project will be developed as a minimizing cost optimal model. The overall cost includes the capital cost of new power plant, operating cost of existing and new power plant and the fuel cost for renewable and non-renewable energy. The solver engine will solve and generate the optimal solution by prioritizing the lower cost power system as shown in Equation 3.

$$Min\ objective\ function = C_{capital} + C_{fixed} + C_{variable} \tag{3}$$

where

$C_{capital}$ = capital cost of new power plant required (RM).

$C_{fixed}$ = fixed operating and maintenance cost of the power plant operation (RM).

$C_{variable}$ = variable operating and maintenance cost of the power plant operation (RM).

## 3.3 Development of Constraints

The World Energy Council (WEC) introduces the energy trilemma with core dimensions of energy security, energy equity and environmental sustainability that should be taken into consideration when developing constraints for the optimization model. Four constraints have been developed which are the supply constraint, demand constraint, renewable energy capacity mix constraint and non-negativity constraint.

### 3.3.1 Supply Constraint

Taking the current electricity generation capacity as reference, the supply constraint will act as the lower and upper bound to the optimal solution. Lower bound refers to the minimum capacity among installed, available, approved capacity and commercial operating capacity while upper bound refers to the highest value of these capacity. The constraint for non-renewable energy is formulated as Equation (4) while the constraint for renewable energy is shown in Equation (5).

$$F_i^{\mathrm{L}} \leq F_i \leq F_i^{\mathrm{U}}\ , i = \{\text{coal, natural gas}, large - hydro\} \quad (4)$$

$$F_j^{\mathrm{L}} \leq F_j \leq F_j^{\mathrm{U}}, \quad (5)$$

$$j = \{non - large\ hydro, \quad solar\ community, \quad solar\ individual, \quad LSS, \quad NEM, \quad biomass, \quad biogas, \quad geothermal\}$$

where

$F_i$ = optimal capacity for non-renewable energy source i (MW) with a lower bound value, $F_i^L$.and upper bound value, $F_i^U$.

$F_j$ = optimal capacity for renewable energy source j (MW) with a lower bound value, $F_j^L$.and upper bound value, $F_j^U$.

### 3.3.2 Demand Constraint

One of the generation capacity planning criteria that need to be considered is the demand forecast to ensure energy security (Energy Commission, 2019c). The optimal electricity generation has to greater or equal to the projected electricity demand required by sectors in year 2025.

$$\sum \mathrm{E_j CF_j} + \sum \mathrm{E_i CF_i} \geq \sum \mathrm{E_{sector,t}} \quad (6)$$

$$i = \{\text{coal, natural gas}, large - hydro\}$$

$$j = \{non - large\ hydro, \quad solar\ community, \quad solar\ individual, \quad LSS, \quad NEM, \quad biomass, \quad biogas, \quad geothermal\}$$

where

$E_j$ = electricity generation of renewable energy source j (MWh).

$E_i$ = electricity generation of non-renewable energy source i (MWh).

$E_{sector,t}$ = projection electricity demand required by sectors in year t (MWh).

CF = capacity factor of different fuel type power system.

### 3.3.3 Renewable Energy Capacity Mix Constraint

Based on the targets to achieve 20% RE capacity mix by the Ministry Energy, Science, Technology, Environment and Climate Change (MESTECC), the optimal capacity of renewable energy has to be greater or equal to the 20% of total optimal capacity that include both RE and non-RE (2015).

$$\sum F_j \ (2025) \ \geq 20\% \ x \ \left(\sum F_i + \sum F_j\right)(2025), \tag{7}$$

$$i = \{\text{coal, natural gas}, large - hydro\}$$

$$j = \{non - large\ hydro, \quad solar\ community, \quad solar\ individual, \quad LSS, \quad NEM, \quad biomass, \quad biogas, \quad geothermal\}$$

where

$F_i$ = optimal capacity for non-renewable energy source i (MW).

$F_j$ = optimal capacity for renewable energy source j (MW).

### 3.3.4 Non-negativity constraint

Non-negativity constraint is the fundamental of all optimization formulations where the decision variables involved have to be greater or equal to zero.

$$F_i \geq 0, \qquad i = \{\text{coal, natural gas}, large - hydro\} \tag{8}$$

$$F_j \geq 0\ , \tag{9}$$

$$j = \{non - large\ hydro, \quad solar\ community, \quad solar\ individual, \quad LSS, \quad NEM, \quad biomass, \quad biogas, \quad geothermal\}$$

where

$F_i$ = optimal capacity for non-renewable energy source i (MW).

$F_j$ = optimal capacity for renewable energy source j (MW)

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Data Gathering

The gathered data on the capacity, generation cost and electricity demand are essential for the development of the Excel Solver optimization model from which the optimal solutions for feasible electricity planning are generated.

### 4.1.1 Existing Capacity of Electricity Generation in Malaysia

Existing capacity of electricity generation shows the generation status updated as of December 2017. Installed capacity and available capacity are the capacity terms used by Energy Commission Malaysia while commercial operation and approved capacity are the terms used by SEDA. Due to different definitions of capacity categories and limitation of complete capacity from one particular source, the lower bound and upper bound of this data are wisely selected from the APPENDIX B. However, the upper and lower bound of non-renewable energy for 2025 Case Study (CS1 and CS2) will consider on the generation plant up and generation retirement from year 2018 to 2025 reported (Energy Commission, 2019c); (Energy Commission, February 2019) where total generation plant up of coal is 2,000 MW and total generation plant up of natural gas is 4,881 MW. There is no generation retirement for coal power system but 8,176 MW of natural gas capacity retirement. The upper and lower bound data is tabulated in Table 4.1, Table 4.2 and Table 4.3.

Table 4.1: Lower and upper bound of supply trend constraint for non-renewable energy in Malaysia as recent of December 2017.

| **Energy Sources** | **Lower bound capacity (MW)** | **Upper bound capacity (MW)** |
|---|---|---|
| Coal | 10,444.0[b] | 11,146.0[a] |
| Natural Gas | 12,664.1[b] | 14,896.6[a] |
| Large hydro (> 100 MW) | 5,792.0[a] | 5,792.0[a] |

Note on sources: [a]Installed capacity (Energy Commission, 2019b), [b]available capacity (Energy Commission, 2019b).

Table 4.2: Lower and upper bound of supply trend constraint for non-renewable energy in year 2025.

| **Energy Sources** | **Lower bound capacity (MW)** | **Upper bound capacity (MW)** |
|---|---|---|
| Coal | 10,444.0[b] | 13,146.0[a-f] |
| Natural Gas | 4,488.1[b-e] | 19,777.6[a-f] |
| Large hydro (> 100 MW) | 5,792.0[a] | 5,792.0[a] |

Note on sources: [a]Installed capacity (Energy Commission, 2019b), [b]available capacity (Energy Commission, 2019b), [e]retiring capacity (Energy Commission, February 2019), [f]generation plant up (Energy Commission, February 2019).

Table 4.3: Lower and upper bound of supply trend constraint for renewable energy in 2017 and 2025.

| **Energy Sources** | **Lower bound capacity (MW)** | **Upper bound capacity (MW)** |
|---|---|---|
| Non-large Hydro (<100MW) | 50.3[d] | 601.5[c] |
| Solar Community | 7.8[d] | 11.8[c] |
| PV rooftop (individual) | 81.9[d] | 98.4[c] |
| PV Farm (non-individual) | 292.2[d] | 330.2[c] |
| MySuria | 1.0[d] | 1.0[c] |
| LSS/USS (<20MW) | 197.1[d] | 715.38[c] |
| LSS/USS (>20MW) | 492.71[d] | 1788.39[c] |
| NEM | 9.0[d] | 27.8[c] |
| SELCO | 0[d] | 69.3[c] |
| Biomass | 48.9[b] | 748.2[a] |
| Biogas | 69.9[d] | 222.3[c] |

Note on sources: [a]Installed capacity (Energy Commission, 2019b), [b]available capacity (Energy Commission, 2019b), [c]approved capacity (SEDA, 2018) and [d]commercial operation capacity (SEDA, 2018).

### 4.1.2 Cost of Energy Resources Category

The objective function of an optimization model requires the cost factor to determine which decision variable would be selected for an optimal solution. It is observed that all electricity generation has variable operational and maintenance (O&M) costs except the solar power category. Variable O&M costs are the generation costs that vary based on the amount of electricity generated at the power plant that includes fuel cost, water consumption, utility cost, and waste treatment (Energy Information Admistration, October 2020). The solar power category does not require variable cost as the solar panel generates electricity merely from solar irradiation and does not generate waste throughout the process. Capital cost, fixed operating and maintenance (O&M) and variable O&M cost for each category are tabulated in Table 4.5. The variable O&M cost of the power plant is calculated by considering the annual capacity factor for different power plants. Capacity factor (CF) refers to the ratio of the actual energy produced by an electricity generation system to the maximum amount of energy that can be produced at full rated power (U.S. Department of Energy, 2020). This parameter will examine on the reliability of various power plant as shown in Table 4.4, the greater the capacity factor percentage, the higher its reliability in generating electricity. Also, the currency used to convert Euro from (European Commission, 2014) to Malaysia Ringgit is 4.93 RM/Euro.

Table 4.4: Capacity factor of the electricity generation power system.

| Power Plant | Capacity Factor, CF |
|---|---|
| Coal | 0.475[a] |
| Natural Gas | 0.568[a] |
| Hydro | 0.6[b] |
| Solar | 0.17[b] |
| Biomass | 0.5[b] |
| Biogas | 0.6[b] |

Note on sources: [a]Capacity factor for non-renewable energy(U.S. Department of Energy, 2020); [b]Capacity factor for renewable energy (Energy Commission, 2019c)

Table 4.5: Cost details of different electricity power plants.

| Fuel Types | Category | Capital cost (RM/MW) | Fixed O&M cost | | Variable O&M cost | |
|---|---|---|---|---|---|---|
| | | | % of Capital Cost[a] | RM/MW | Euro/ MWh[a] | RM/MWh *8760 hrs * CF = RM/MW |
| Coal | Pulverized coal supercritical | 7.89million[a] | 2.5 | 0.20million | 3.6 | 0.07million |
| Natural Gas | CCGT | 4.19million[a] | 2.5 | 0.10million | 2.0 | 0.05million |
| Large Hydro (>100MW) | Hydropower >100MW | 10.85million[a] | 1.0 | 0.11million | 3.0 | 0.08million |
| Non-large Hydro (<100MW) | Hydropower 10-100MW | 16.56million[a] | 1.5 | 0.25million | 5.0 | 0.13million |
| Solar Community | Small commercial/ETRI with tracking | 5.50million[b] | 1.7 | 0.09million | 0 | 0.00 |
| PV rooftop (individual) | Residential/ETRI commercial 0.1-2 | 6.0million[b] | 2.0 | 0.12million | 0 | 0.00 |
| PV Farm (non-individual) | Industrial/Commercial with tracking | 3.60million[b] | 1.7 | 0.06million | 0 | 0.00 |
| MySuria | Residential/ETRI commercial 0.1-2 | 6.0million[b] | 2.0 | 0.12million | 0 | 0.00 |
| LSS/USS (<20MW) | Small centralized/ETRI without tracking | 2.95million[b] | 1.7 | 0.05million | 0 | 0.00 |
| LSS/USS (>20MW) | Large centralized/ETRI without tracking | 2.85million[b] | 1.7 | 0.05million | 0 | 0.00 |
| NEM | Industrial/Commercial with tracking | 3.60million[b] | 1.7 | 0.06million | 0 | 0.00 |
| SELCO | Large commercial/ETRI residential | 4.0million[b] | 2.5 | 0.10million | 0 | 0.00 |
| Biomass | Biomass Grate Furnace | 12.92million[b] | 2.2 | 0.28million | 3.5 | 0.08million |
| Biogas | Anaerobic digestion | 15.68million[b] | 4.1 | 0.64million | 3.1 | 0.08million |

Note: Currency conversion rate at 4.93 Euro/RM; ETRI is the Energy Technology Reference Indicator (European Commission, 2014).
Note of sources: [a]Capital cost (European Commission, 2014), [b]capital cost (SEDA & IEA, 2018), [a]fixed O&M cost (European Commission, 2014) and [d]variable O&M cost (European Commission, 2014).

Regarding the capital investment cost, it is mentioned in a government report on the slow development of RE in earlier stages due to the high RE system cost compared to non-RE power systems (KeTTHA, 2011). However, it is illustrated in Table 4.5 that the cost of renewable energy generation mainly on solar power has lower capital cost compared to coal fired power plants and large hydropower and some PV categories are even lower compared to the least non-renewable capital cost by natural gas power plants. This is justified as the solar generation cost has been forecasted to decrease below the price of coal generation due to the government targets on energy mix (Abdullah et al., 2019). Other than this, the Solar Energy Industries Association also reported on the rapid falls in solar PV installation cost due to the big scale manufacturing and improvement of technology with new materials (SEIA, 2021)

### 4.1.3 Generation Demand Projection

The electricity consumption by sectors in Malaysia was 48.7%, 29.8%, 20.7% 0.4% and 0.3% contributed by industry, commercial, residential, agriculture and transport sectors respectively in year 2017 as shown in Table 4.6 (Energy Commission, 2017). Electricity demand projection is performed by considering the compound annual growth rate (CAGR) for 2018 to 2020 is 1.9% and 2020 to 2030 is 1.2% based on the electricity consumption in year 2017 (Energy Commission, 2019c). Since the CARG is different for 2018 to 2025, CARG of 1.9% will be used to project electricity demand for year 2020 and CARG of 1.2% project electricity demand for year 2025 based on the projected 2020 demand. The calculated projected demand for year 2025 based on the Compound Annual Growth Rate (CAGR) is shown as in Table 4.6 by using the equation (10) as below. It is shown that the projected electricity demand in year 2025 is calculated to be 164,574.87 GWh/year.

$$CAGR = \left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1$$

$$EV = (CAGR + 1)^n * BV \quad (10)$$

where

$EV$ = projected electricity demand for a period of n years (MWh).

$BV$ = beginning value of the electricity demand (MWh).

$n$ = number of years

Table 4.6: The calculated projected electricity consumption by sector in year 2025.

| **Electricity consumption by sector in Malaysia** | **2017 (GWh)** | **2020 (GWh)** | **2025 (GWh)** |
|---|---|---|---|
| Industrial | 71,417.00 | 75,565.60 | 80,209.67 |
| Commercial | 43,724.00 | 46,263.92 | 49,107.18 |
| Residential | 30,340.00 | 32,102.45 | 34,075.38 |
| Transportation | 469.00 | 496.24 | 526.74 |
| Agriculture | 584.00 | 617.92 | 655.90 |
| Total | 146,534.00 | 155,046.14 | 164,574.87 |

## 4.2 Optimal Solution and Discussion

This project presents the electricity optimization model on two case studies which are (1) projected business as usual capacity mix in Malaysia in 2025 and (2) sustainability factors as consideration for the projected capacity mix in Malaysia in Y2025. Based on the definition of renewable energy by the past Minister of Energy, Science, Technology, Environment and Climate Change (MESTECC), the large hydropower system with capacity greater or equal to 100MW are excluded from the RE category list due to the environmental impact caused during development of large hydropower compared to non-large hydro (Yeo, 2018). Therefore, the non-renewable energy resources category comprises of coal, natural gas and large hydropower while the renewable energy category includes the non-large hydropower, solar photovoltaic (Community Solar, Individual Solar, Industrial Solar, MySuria, NEM, LSS and SelCo), biomass and biogas.

Based on the updated data reported, the installed power plant capacity in Malaysia at the end of 2017 was 34,182.9 MW while the available capacity for generation was 29,218.4 MW (Energy Commission, 2017). The trend of the installed capacity mix was dominated by natural gas (43.6%) followed by coal (30.9%) large hydropower (17.9%), diesel (4.1%) and remaining 3.5% by renewable power plants. The optimization model for both Case Study 1 and Case Study 2 are solved as Linear Programming (LP) problems and the feasible solution is discussed in the following.

### 4.2.1 Case Study 1: Projection of Business as Usual Capacity Mix in Malaysia in 2025

Case Study 1 with projection business as usual case study would like to illustrate the scenario of typical development planning where the least cost model is being prioritized and renewable energy power systems are not being emphasized. The objective function for this case study is described by equation (3) with capital cost included for development of new power plants from year 2018 to 2025 with BAU as consideration calculated by multiplication of the capital cost with difference of optimal capacity from lower bound supply capacity discussed in Table 4.1 and Table 4.3. Case Study 1 includes the supply (Equation (4) and Equation (5)), demand (Equation (6)) and non-negativity constraint (Equation (8) and Equation (9)) discussed in Section 3.3. The model is solved by taking the optimal capacity for EOY2025 as the decision variables. The Microsoft Excel Solver engine will vary the optimal capacity until the feasible solution that provides the least cost model is solved. Projected solutions obtained for Case Study 1 are presented in Table 4.7, Figure 4.1, and Table 4.8.

Table 4.7: Data and results for Case Study 1 (BAU 2025).

| Fuel Types | DECISION VARIABLES | New Plant Capacity (CS1-LB2017) | Capacity Share (%) | SUPPLY CONSTRAINT | | Electricity generation (MWh) | Total Operating Cost (RM/year) | Total Investment Cost (RM) |
|---|---|---|---|---|---|---|---|---|
| | **Optimal Capacity (MW) for EOY2025** | | | **Lower Bound Capacity (MW)** | **Upper Bound Capacity (MW)** | | | |
| Coal | 10,444.00 | 0.00 | 29.65% | 10,444.0[b] | 13,146[a] | 43.46 million | 2,830.84 million | 0 |
| Natural Gas | 17,742.07 | 5,077.97 | 50.36% | 4,488.1[b] | 19,777.6[a] | 121.12 million | 2,729.13 million | 21,279 million |
| Large Hydro (>100MW) | 5,792.00 | 0.00 | 16.44% | 5,792.0[a] | 5,792.0[a] | 30.44 million | 1,078.45 million | 0 |
| Non-large Hydro (<100MW) | 50.30 | 0.00 | 0.14% | 50.3[d] | 601.5[c] | 0.26 million | 19.02 million | 0 |
| Solar Community | 7.81 | 0.00 | 0.02% | 7.8[d] | 11.8[c] | 0.01 million | 0.73 million | 0 |
| PV rooftop (individual) | 81.92 | 0.00 | 0.23% | 81.9[d] | 98.4[c] | 0.12 million | 9.83 million | 0 |
| PV Farm (non-individual) | 292.24 | 0.00 | 0.83% | 292.2[d] | 330.2[c] | 0.44 million | 17.89 million | 0 |
| MySuria | 0.96 | 0.00 | 0.00% | 1.0[d] | 1.0c | 0.00 million | 0.12 million | 0 |
| LSS/USS (<20MW) | 197.07 | 0.00 | 0.56% | 197.1[d] | 715.38[c] | 0.29 million | 9.88 million | 0 |
| LSS/USS (>20MW) | 492.71 | 0.00 | 1.40% | 492.71[d] | 1788.39[c] | 13.98 million | 23.87 million | 0 |
| NEM | 9.01 | 0.00 | 0.03% | 9.0[d] | 27.8[c] | 0.01 million | 0.55 million | 0 |
| SELCO | 0.00 | 0.00 | 0.00% | 0[d] | 69.3[c] | 0.00 million | 0.00 million | 0 |
| Biomass | 48.90 | 0.00 | 0.14% | 48.9[b] | 748.2[a] | 0.21 million | 17.59 million | 0 |
| Biogas | 69.94 | 0.00 | 0.20% | 69.9[d] | 222.3[c] | 0.31 million | 50.57 million | 0 |

Note: LB2017 refers to lower bound of capacity in year 2017 shown in Table 4.1 and Table 4.3.
Note on sources: [a]Installed capacity (Energy Commission, 2019b), [b]available capacity (Energy Commission, 2019b), [c]approved capacity (SEDA, 2018) and [d]commercial operation capacity (SEDA, 2018).

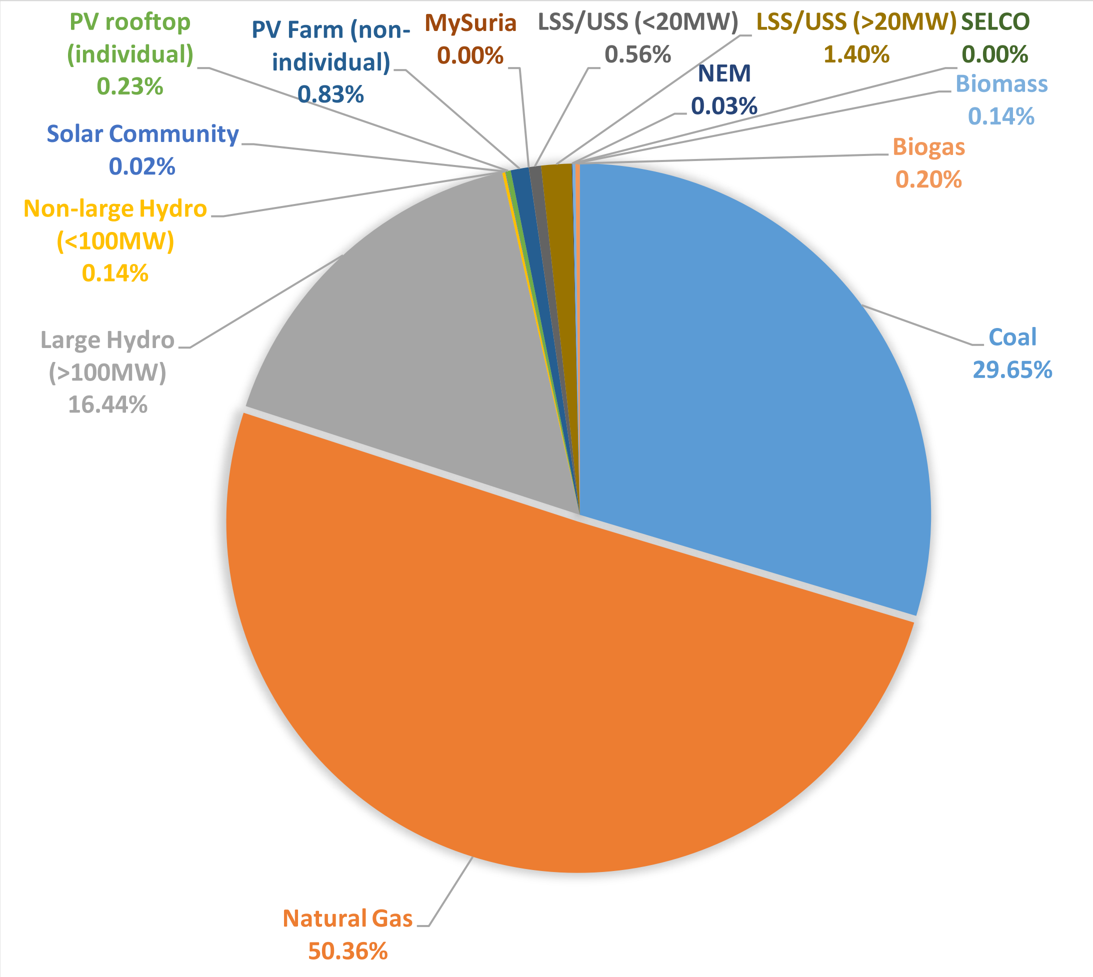


Figure 4.1: Electricity capacity mix of Case Study 1 (BAU 2025).

Table 4.8: Optimal solution of Case Study 1 (BAU) based on Table 4.7.

| Properties | Value |
|---|---|
| Total Optimal Capacity (MW) | 35.23 x $10^3$ MW |
| Total Electricity Generated (GWh) | 164.57 x $10^3$ GWh |
| Allocation percent of RE mix (%) | 3.55% |
| Objective Minimum Total Cost | 28.07 billion RM<br>(Operating cost: 6.79 billion RM/year)<br>(Investment cost: 21 billion RM) |

Based on Table 4.7 and Figure 4.1, it is illustrated that the projected optimal capacity of the power system is dominated by natural gas with 50.36% followed with non-renewable coal (29.65%), large hydropower (16.44%) and RE (3.55%). In this case study, the electricity supply is still dominated by fossil fuel power (80.01%) with an increase of 5.5% compared to 2017 lower bound data discussed earlier in Table 4.1 and Table 4.3. This increase of 5.5% mainly contributed by the optimal development of 5,078 MW natural gas power plants compared to 2017. This is justified as the overall cost of the natural gas category to meet the electricity demand constraint is lowest among other categories. Since business as usual model emphasized cost effectiveness of electricity generation, it shows that the overall cost of natural gas to generate 1 MWh of energy is even cheaper than the overall cost of LSS (> 20 MW), LSS(<20MW), NEM, PV farm and SELCO PV although the capital cost of these system are cheaper. This is validated as it is reported that gas-based power plants are the most economical attractive options in business as usual condition (Almansoori & Betancourt-Torcat, 2015). The objective function obtained in Table 4.7 shows that optimal capacity required to meet the electricity demand constraint of 164.57 x $10^3$ GWh is 35.23 x $10^3$ MW with the total new investment cost of RM 21.28 billion for the natural gas category.

### 4.2.2 Case Study 2: Sustainability Factor as Consideration for Projected Capacity Mix in Malaysia in 2025

Case Study 2 with consideration on sustainability factors illustrates the scenario where accelerated development of renewable energy is prioritized over the cost effectiveness of electricity generation. This case study is essential to improve the development on renewable energy and meet the national target of 20% capacity mix by 2025. Results obtained for this section will provide an economical solution for a sustainability generation development plan in the future. Case Study 2 includes the objective function described in equation (3) where the capital cost of new developed capacity is calculated by multiplication of the capital cost with difference of optimal capacity from lower bound supply capacity discussed in Table 4.1 and Table 4.3. Constraints included are the supply trend (Equation (4) and Equation (5)), demand constraint (Equation (6))20% RE mix (Equation (7)) and non-negativity constraint (Equation (8) and Equation (9)). However, the upper bound of supply constraint for Equation (5) is not included to eliminate the RE expansion restriction. The Microsoft Excel Solver engine will vary the decision variables based on the constraints until the feasible solution that provides the least cost model is solved. The solutions obtained for Case Study 2 are presented in Table 4.9, Figure 4.2, and Table 4.10.

Table 4.9: Data and results for Case Study 2 (RE 2025).

| Fuel Types | DECISION VARIABLES | New Plant Capacity (CS2-LB2017) | Capacity Share (%) | SUPPLY CONSTRAINT | | Electricity generation (MWh) | Total Operating Cost (RM/year) | Total Investment Cost (RM) |
|---|---|---|---|---|---|---|---|---|
| | Optimal Capacity (MW) for EOY2025 | | | Lower Bound Capacity (MW) | Upper Bound Capacity (MW) | | | |
| Coal | 10,444.00 | 0 | 26.14% | 10,444.0[b] | 13,146[a] | 43.46 million | 2,830.84 million | 0 |
| Natural Gas | 15,724.99 | 3,060.89 | 39.36% | 4,488.1[b] | 19,777.6[a] | 98.41 million | 2,418.86 million | 12,827 million |
| Large Hydro (>100MW) | 5,792.00 | 0 | 14.50% | 5,792.0[a] | 5,792.0[a] | 30.44 million | 1,078.45 million | 0 |
| Non-large Hydro (<100MW) | 50.30 | 0 | 0.13% | 50.3[d] | 601.5[c] | 0.26 million | 19.02 million | 0 |
| Solar Community | 7.81 | 0 | 0.02% | 7.8[d] | 11.8[c] | 0.01 million | 0.73 million | 0 |
| PV rooftop (individual) | 81.92 | 0 | 0.21% | 81.9[d] | 98.4[c] | 0.12 million | 9.83 million | 0 |
| PV Farm (non-individual) | 292.24 | 0 | 0.73% | 292.2[d] | 330.2[c] | 0.44 million | 17.89 million | 0 |
| MySuria | 0.96 | 0 | 0.00% | 1.0[d] | 1.0c | 0.00 million | 0.12 million | 0 |
| LSS/USS (<20MW) | 197.07 | 0 | 0.49% | 197.1[d] | 715.38[c] | 0.29 million | 9.88 million | 0 |
| LSS/USS (>20MW) | 7,232.10 | 6,739.39 | 18.10% | 492.71[d] | 1788.39[c] | 36.69 million | 350.40 million | 19,207 million |
| NEM | 9.01 | 0 | 0.02% | 9.0[d] | 27.8[c] | 0.01 million | 0.55 million | 0 |
| SELCO | 0 | 0 | 0.00% | 0[d] | 69.3[c] | 0.00 million | 0.00 million | 0 |
| Biomass | 48.90 | 0 | 0.12% | 48.9[b] | 748.2[a] | 0.21 million | 17.59 million | 0 |
| Biogas | 69.94 | 0 | 0.18% | 69.9[d] | 222.3[c] | 0.31 million | 50.57 million | 0 |

Note: LB2017 refers to lower bound of capacity in year 2017 shown in Table 4.1 and Table 4.3.
Note on sources: [a]Installed capacity (Energy Commission, 2019b), [b]available capacity (Energy Commission, 2019b), [c]approved capacity (SEDA, 2018) and [d]commercial operation capacity (SEDA, 2018).

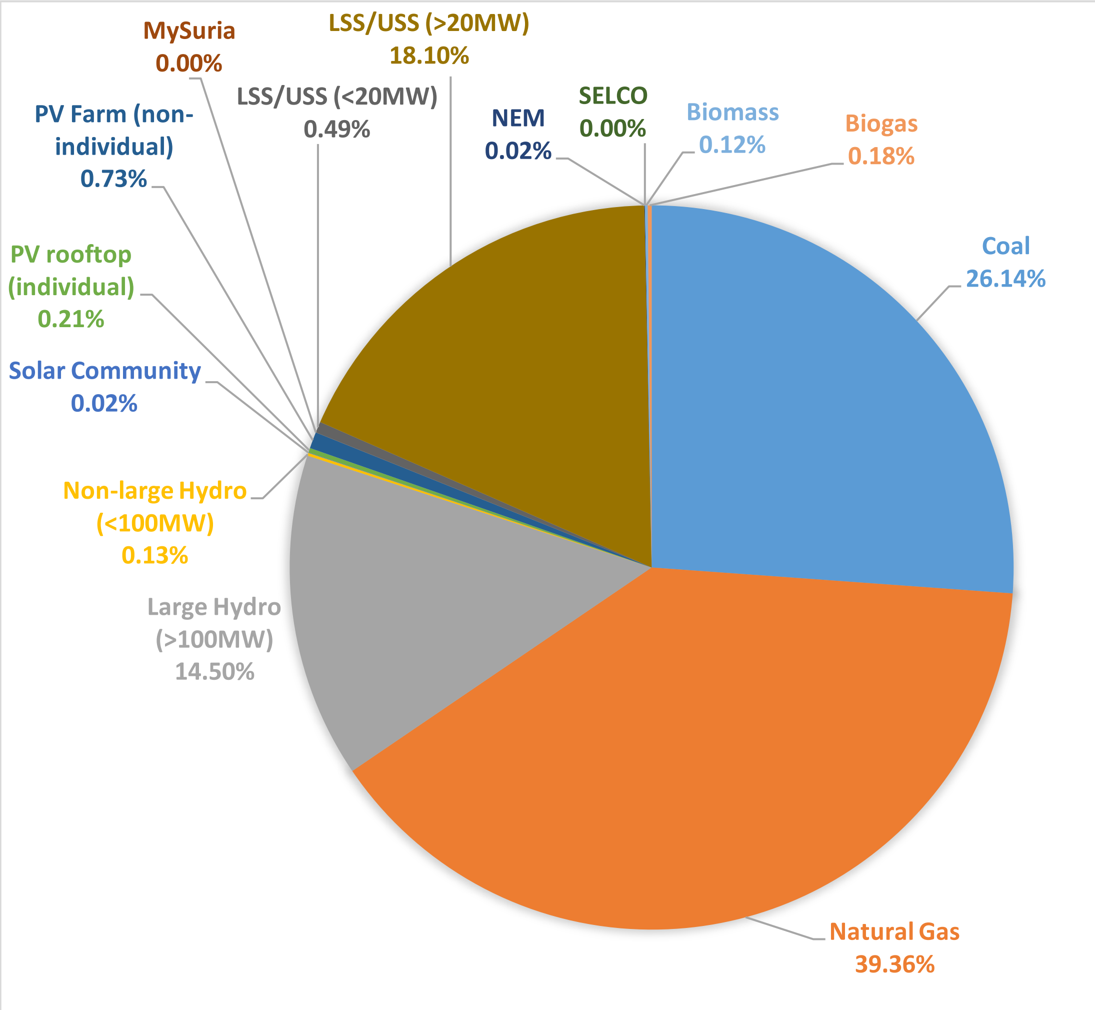


Figure 4.2: Electricity capacity mix of Case Study 2 (RE 2025)

Table 4.10: Optimal solutions for Case Study 2 (RE) based on Table 4.9.

| **Properties** | **Value** |
|---|---|
| Total Optimal Capacity (MW) | 39.91 x $10^3$ MW |
| Total Electricity Generated (GWh) | 164.57x $10^3$ GWh |
| Allocation percent of RE mix (%) | 20.00% |
| Objective Minimum Total Cost | 38.84 billion RM<br>(Operating cost: 6.80 billion RM/year)<br>(Investment cost: 32 billion RM) |

Figure 4.2 shows the feasible solution obtained for Case Study 2 optimization model. The share of electricity capacity mix in this scenario is still dominated by natural gas (39.36%), followed by coal (26.14%), renewable power (20.00%) and large hydropower (14.50%). It is noticed that capacity mix ranking in Case Study 2 differs from Case Study 1 in terms of the share ranking of hydro and renewable energy capacity. The increasing share of renewable energy over the hydropower share is mainly due to the accelerated RE capacity to achieve the 20% national capacity target constraint. In addition, the capacity development demonstrated higher emphasis on the renewable energy as LSS (>20MW) category that shows new development of 6,739.4 MW compared to natural gas of 3,060.89 MW. This statement can be explained since the sustainability generation expansion prefers to reduce dependency on fossil fuel power over least cost optimization model. It is observed that the renewable energy category in Case study 2 is dominated by LSS greater than 20 MW (18.1%), followed by PV farm (0.49%), LSS (<20MW) (0.49%) and other RE generation as the model prioritized on the low cost of LSS (>20MW) system. The optimal solution generated mainly on RE category is considered valid as the preferred RE in Peninsular Malaysia is solar power while in Sabah is non-large hydropower (Energy Commission, 2019a). The tropical climatic conditions in Malaysia are favorable for solar power development with abundant average daily solar irradiation of 15 $MJ/m^2$ (Oh, Pang, & Chua, 2010) and limitless solar potential generation capacity (KeTTHA, 2011); (Oh et al., 2010).

From the non-RE perspective, it is perceived that the percentage of fossil fuel power has decreased from 75.4% (2017) to 65.5% (CS2) which is considered progressive as the government would like to reduce the dependency on fossil fuel power. However, it is reported that the RE still act as the complementary role to the fossil fuels power due to the output intermittency, location and technology advancement in the current development plan. It is not an easy barrier for the government to abandon the dependence on these resources within a short transition period (Oh et al., 2018). Therefore, the continuous long-term planning for the electricity generation system has to revise from time to time.

To achieve an electricity demand constraint of 164.57 x $10^3$ GWh, the total optimal capacity of power system required is 39.95 x $10^3$ MW (greater than CS1). Total investment cost on new natural gas and LSS (>20 MW) capacity is approximately RM 32 billion with annual operational cost of RM 6.80 billion. Comparing the optimal solution obtained from Table 4.7 (CS1) and Table 4.9 (CS2), the capacity development that meets the electricity demand costs less in the model compared to the RE model. This can be explained as the business as usual model develops the least cost natural gas power model only while CS2 develops LSS (>20MW) to meet the national target and natural gas development to meet the generation demand. Based on the ASEAN energy project, the expected total investment ahead Malaysia 2025 RE capacity target from government, public private partnerships and private financing is estimated to be approximately RM 33 billion (US$8 billion) (Vakulchuk, Chan, Kresnawan, & Merdekawati, 2020). This shows that the estimated investment cost obtained from the optimization model is validated as the error percent from RM 33 billion is 2.93%.

### 4.2.3 Comparison of Case Study 1 and Case Study 2.

The optimal capacity obtained from Case Study 1 (Table 4.7) and Case Study 2 (Table 4.9) are compared in Figure 4.3. Based on Figure 4.3, it is also observed that the distinction between Case Study 1 and Case Study 2 falls under the natural gas and LSS (>20 MW) category only. With respect to lower bound of 2017 data shown in Tale 4.1 and Table 4.3, it is illustrated that Case Study 1 developed greater capacity for non-renewable natural gas category compared to Case Study 2 in year 2025 while the LSS renewable energy developed greater capacity in Case Study 2 instead. However, Case Study 2 shows greater increase in overall generation capacity compared to Case Study 1. This statement indicates that the renewable LSS (>20MW) required higher power plant capacity to generate equal amounts of electricity compared to natural gas due to its low capacity factor discussed in Table 4.4. Solar power system has a low capacity factor mainly due to its limitation of no energy generation during nighttime. Hence, more research and development (R&D) efforts are required to better utilize the abundant solar energy during the daytime.

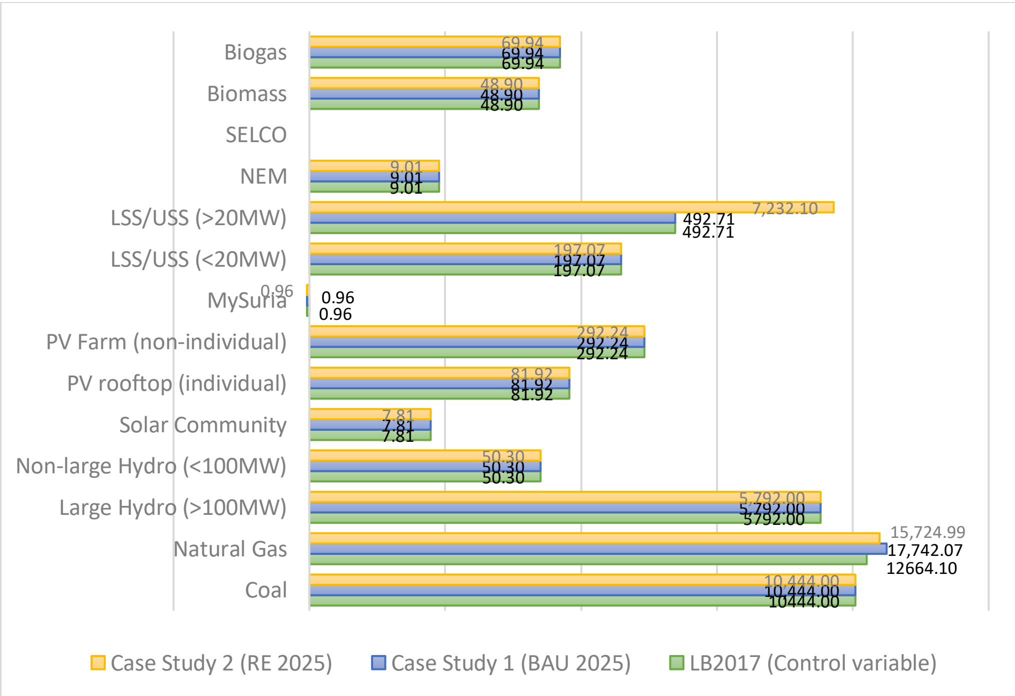


Figure 4.3: Comparison of Optimal Capacity for Case Study 1 and Case Study 2.

Note: The x-axis of Figure 4.3 is illustrated as logarithm form; LB2017 refers to lower bound capacity in year 2017 shown in Table 4.1 and Table 4.3.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In conclusion, the current model defines the importance of an optimal electricity generation model to ensure 20% of RE capacity target, reduction of 45% carbon dioxide target as well as to meet the rising electricity demand. Numbers of published papers are reviewed to study the methods used in developing the optimal electricity planning model during the earlier stage of the project. By using the knowledge gained from the literature, two case studies have been successfully developed and feasible solutions are obtained. Results obtained from the solution shows that to meet the national demand of 164.57x $10^3$ GWh, business as usual condition should place more emphasis on the natural gas power system while for sustainability factor as consideration, renewable solar energy should be prioritized as well. For a long-term sustainable development, Malaysia government has to place more emphasis on LSS greater than 20MW category and continuously explore new technologies to improvise the low capacity factor of solar system and ensure the intermittent generation from solar PV will not jeopardize the overall supply system (Energy Commission, March 2021). However, to ensure diversification of fuel mix and generation system balancing, other renewable sources like biogas, biomass and hydropower should be appropriately developed and considered for the future electricity optimization model. New generation systems like the hydrogen fuel cells, ocean thermal energy conversion (OTEC) and other advanced technologies for the renewable energy should be studied and developed to compensate the depleting fossil fuels resources in the future. This will be an important step to make a headway to carbon free economy in the future.

## 5.2 Recommendation

Other than the 20% RE mix generation in 2025, Malaysia government has another national target on the 45% GHG emission reduction with respect to 2005 baseline. This aspect can be included in the future work to check on the annual carbon dioxide emission from the electricity generation sector. The GHG emission aspect is significant to be studied due to its detrimental environmental impacts and the treatment cost required. Based on the GHG emission rate shown in Figure 5.1, the total carbon dioxide emission for the power generation sector can be estimated and affect the development decision on the power plant capacity.

| | $CO_2$ Emissions Factor (kg $CO_2$/Btu) | Heat Rate (Btu/kWh) | Emission rate (kg $CO_2$/MWh) |
|---|---|---|---|
| **Coal, steam generator** | 95.3 | 10,080 | 960.6 |
| **Petroleum, steam generator** | 73.2 | 10,156 | 743.4 |
| **Natural Gas, combustion turbine** | 53.1 | 11,378 | 604.2 |
| **Natural gas, combined cycle** | 53.1 | 7,658 | 406.6 |

Figure 5.1: Carbon dioxide emissions from electricity generation sector (Department of Energy, 2016b).

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# APPENDICES

## APPENDIX A: Gantt Chart of FYP

| No | Details/Week | Final Year Project | | | | | | | | | | | | FYP2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 1 | Selection of Project Title | ■ | ■ | | | | | | | | | | | |
| 2 | Weekly progress update session with SV | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | |
| 3 | Literature Review | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| 4 | Data collection | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 5 | Development of problem statement and research objectives | | | ■ | ■ | | | | | | | | | |
| 6 | Development of objective function and constraints | | | | ■ | ■ | ■ | | | | | | | |
| 7 | Submission of Progress Assessment I | | | | | ■ | | | | | | | | |
| 8 | Development of superstructure model | | | | | | ■ | ■ | ■ | ■ | | | | |
| 9 | Proposal Defense | | | | | | ■ | | | | | | | |
| 10 | Model configuration using Excel Solver | | | | | | | ■ | ■ | ■ | | | | |
| 11 | Submission of Progress Assessment II | | | | | | | | | ■ | | | | |
| 12 | Submission of Interim Report | | | | | | | | | | ■ | | | |
| 13 | Preliminary optimal solution | | | | | | | | | | | | | ■ |
| 14 | Finalize the optimal solution | | | | | | | | | | | | | ■ |
| 15 | Discussion on the optimal solution | | | | | | | | | | | | | ■ |
| 16 | Submission of softbound | | | | | | | | | | | | | ■ |
| 17 | Final Year Project Viva | | | | | | | | | | | | | ■ |
| 18 | Submission of hardbound | | | | | | | | | | | | | ■ |

## APPENDIX B: Capacity Data Collected

| Updated date | | | 31/12/2017 | 31/12/2017 | 31/12/2018 | 31/12/2018 | Lower Bound Capacity (MW) | Upper Bound Capacity (MW) |
|---|---|---|---|---|---|---|---|---|
| Energy Sources | | Area | Installed capacity (MW) | Available capacity (MW) | Approved Capacity (MW) | Commercial Operation Capacity (MW) | | |
| Non-RE | Coal | Peninsular Malaysia | 10,066.0 | 10,066 | n.r | n.r | | |
| | | Malaysia | 11,146.0 | 10,444 | n.r | n.r | 10,444.0 | 11,146.0 |
| | Natural Gas | Peninsular Malaysia | 12,681.6 | 11,129.7 | n.r | n.r | | |
| | | Malaysia | 14,896.6 | 12,664.1 | n.r | n.r | 12,664.1 | 14,896.6 |
| | Large Hydro (>100MW) | Peninsular Malaysia | 2,340.0 | 2514.8 (PM), 5797.9 (MALAYSIA) | n.r | n.r | | |
| | | Malaysia | 5,792.0 | | n.r | n.r | 5,792.0 | 5,792.0 |
| RE | Non-large Hydro (<100MW) | Peninsular Malaysia | 214.1 | | n.r | n.r | | |
| | | Malaysia | 303.7 | | 601.48 | 50.30 | 50.3 | 601.5 |
| | Community | Malaysia | n.r | n.r | 11.80 | 7.81 | 7.81 | 11.80 |
| | PV rooftop (individual) | Malaysia | n.r | n.r | 98.4 | 81.92 | 81.92 | 98.43 |
| | PV Farm (non-individual) | Malaysia | n.r | n.r | 330.2 | 292.24 | 292.24 | 330.16 |
| | MySuria | Malaysia | n.r | n.r | 0.96 | 0.99 | 0.96 | 0.99 |
| | LSS/USS | Malaysia | 2,503.76 | n.r | n.r | 689.8 | 689.78 | 2503.764 |
| | NEM | Malaysia | n.r | n.r | 27.81 | 9.01 | 9.01 | 27.81 |
| | SELCO | Malaysia | n.r | n.r | n.r | n.r | 0 | 69.27 |
| | Biomass | Peninsular Malaysia | 403.20 | 0.00 | n.r | n.r | | |
| | | Malaysia | 748.20 | 48.90 | 400.64 | 95.55 | 48.90 | 748.20 |
| | Biogas | Peninsular Malaysia | 51.10 | n.r | n.r | n.r | | |
| | | Malaysia | 70.40 | n.r | 222.29 | 69.94 | 69.94 | 222.29 |

Note on sources: Installed capacity (Energy Commission, 2019b), available capacity (Energy Commission, 2019b), approved capacity (SEDA, 2018) and commercial operation capacity (SEDA, 2018).