Department of Mechanical and Aerospace Engineering

PENINSULAR MALAYSIA

FUTURE RENEWABLE ENERGY SYSTEM

Author: Noraini Binti Md Zamri

Supervisor: Dr Paul Gerard Tuohy

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Copyright Declaration

Abstract

Peninsular Malaysia is selected as the case study as there is a concern on the energy security as the domestic energy demand continuously rising while the domestic fossil fuel resources have been declining. In 2014, Malaysia contributed the third highest Carbon Dioxide (CO_2) emissions in South East Asia (Data.worldbank.org, 2019). Based from these two factors, this thesis will investigate the potential to move from 73.8% power generation energy sources from fossil fuel to a more sustainable renewable energy system i.e. wind, biomass, solar and hydro. This project will investigate the possibility of a hybrid combination between solar and fossil fuel and also the potential of moving into 100% renewable energy system as the main power generation for the incremental demand in peninsular Malaysia. This is to reduce the risk of energy shortage and improve the environment condition in the countries.

The case study will be divided into two phases (year 2030 and year 2040) to analyse the different combination of renewable system as well as hybrid power generation system. Hybrid Optimisation of Model with Multiple Energy Resources (HOMER) software will be used as a tool to simulate the different scenario for both phases. Prior to the simulation, the demand was downloaded from Malaysia Energy Information Handbook (MEIH) and the current as well as future demand for the next 20 years was forecasted based from growth factor published by Energy Commission Malaysia. Simultaneously, the input for renewable resources as well as cost data was gathered from several sources reliable energy sources such as U.S. Energy Information Administration (EIA) and International Renewable Energy Agency (IRENA).

The result was summarised into four shortlisted option with variable renewable fraction ranges from 70% to 100%. However, due to the geographical limitation in Malaysia, the required area for renewable development, hybrid development option was recommended. Future studies are required to further improve the possibility to maximise the renewable energy generation in Malaysia region.

Acknowledgements

I would to take this opportunity to thank Dr Paul Tuohy for all his support in writing this thesis. This study would have not been possible without the transparency and information access from the numerous national bodies of Malaysia, allowing this research to materialise in its desired forms. I would like to thank all the staff at the University of Strathclyde.

Finally, and most importantly, I want to express my gratitude to my family for their never-ending support

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Glossary

AC	Alternative current
CCGT	Combined Cycle Gas Turbine
CEIC	Census and Economic Information Centre Governmental
CO2	CO2 – Carbon dioxide
CSP	Concentrated Solar Panel
DC	Direct current
DLs	Distribution Licensees
DNI	Direct Normal Irradiation
EIA	U.S. Energy Information Administration
EMS	Energy Management System
FITs	Feed-in Tariffs
FSPV	Floating Solar Photovoltaic
GHI	Global Horizontal Irradiance
GW	Gigawatt
HOMER	Hybrid Optimisation of Model with Multiple Energy Resources
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
kW	Kilowatt
kWh	Kilowatt-hours
Li-ion	Lithium ion
LNG	Liquid Natural Gas
LSSPV	Large Scale Solar PV

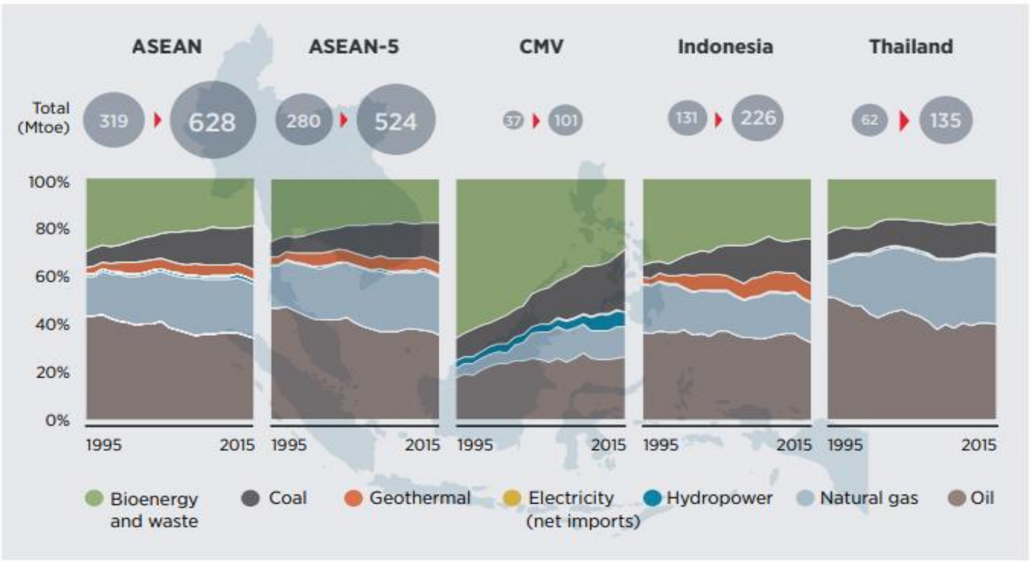
m/2	Meter per second
MEIH	Malaysia Energy Information Hub
MoU	Memorandum of Understanding
MSW	Municipal Solid Wastes
Mtoe	Metric Tonne Oil Equivalent
MW	Megawatt
MWh	Megawatt-hours
NASA	National Aeronautics and Space Administration
NEM	Net Energy Metering
NGG	Natural gas generator
NPC	Net present cost ($)
O&M	Operation & Maintenance
OCGT	Open Cycle Gas Turbine
POME	Palm Oil Mill Effluent
PV	Photovoltaic
PV	Present Value
RES	Renewable Energy Sources
RF	Renewable Fraction
RGT	Regasification Terminal
SCADA	Supervisory Control and Data Acquisition
SEDA	Sustainable Energy Development Authority
SO_2	Sulphur Dioxide
TEPS	Total Primary Energy Supply

1. Introduction

1.1. Background

Energy is an essential factor in everyday human life. As industry expands to cater for the population growth, there is an increase in energy demand. According to REN21, in 2018, global energy demand had a significant increase of 2.3%, due to strong global economic growth (3.7%) and to a rise in heating and cooling demand in some regions (Report, 2019). Current energy resources are mainly from fossil fuel particularly from coal and hydrocarbon extracted from the underground reservoir. Fossil fuel accounted for an estimated of 79.7% of total final global energy consumption in 2017 an estimated to be reduced to 73.8% by end of year 2018 (Report, 2019). As the fossil fuel is a finite energy resources and contributed to the increase in greenhouse gas emission, each country is researching into a sustainable and clean energy resource.

In Southeast Asia, total primary energy supply (TPES) has reached 628 Mtoe in 2015 with oil as the main sources (34%) while natural gas and coal contributed 22% and 18% respectively (IRENA.org, 2019). Figure 1 demonstrate the breakdown TPES by energy sources in Southeast Asia. Crude oil is largely used in the transportation sector, while the natural gas and coal are the main source used in the power generation system.



Source: Based on IEA, 2017c.
Note: The ASEAN figures do not include Lao PDR due to non-availability of data. ASEAN = Association of Southeast Asian Nations; CMV = Cambodia, Myanmar and Viet Nam. ASEAN-5 comprises Indonesia, Malaysia, the Philippines, Singapore and Thailand.

Figure 1: Total primary energy supply by source, 1995-2015 (IRENA.org, 2019)

In this thesis, peninsular Malaysia is selected as the case study as there is a concern on the energy security since the domestic energy demand continuously rising while the domestic fossil fuel resources have been declining. Referring to Figure 2, in year 2040, Malaysia is estimated to import energy as the energy self-sufficiency is predicted to be less than 60% (IRENA.org, 2019).

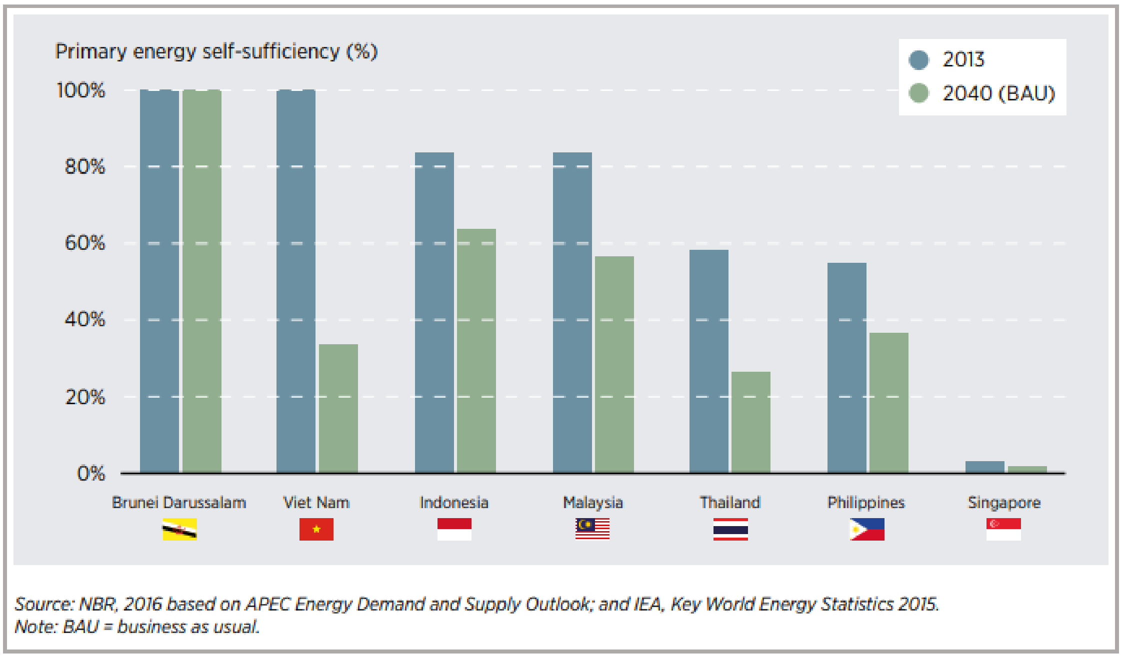


Figure 2: Primary energy from domestic resources in selected Southeast Asian (IRENA.org, 2019)

In addition, it was recorded that in 2014, Malaysia contributed the third highest Carbon Dioxide (CO_2) emissions (metric tons per capita) in South East Asia (Data.worldbank.org, 2019). In view of these two factors, it will be beneficial for investigate the potential renewable energy system as a balance to the primary energy sources in Malaysia.

Malaysia consists two main land area which is east Malaysia (Borneo) and West Malaysia (peninsular Malaysia). This focus of this study is on peninsular Malaysia as the major cities and the highest demand requirement is located in this region. Figure 3 shows the location of the peninsular Malaysia which is south of Thailand.

Figure 3: Map of Malaysia (Freeworldmaps.net, 2019)

1.2. Project Aim

The aim of this project to analyse the possibility of peninsular Malaysia to move from 73.8% power generation energy sources from fossil fuel to a more sustainable renewable energy system i.e. wind, biomass, solar and hydro. The project will investigate the possibility of a hybrid combination between solar and fossil fuel and also the potential of moving into 100% renewable energy system as the main power generation for the incremental demand in peninsular Malaysia. This is to reduce the risk of energy shortage and improve the environment condition in the countries. The main objective is to recommend the most optimum renewable supply combination in the peninsular Malaysia.

1.3. Scope

This study scope covers the electrical energy system in Peninsular Malaysia. There will be several hybrid scenarios and the potential of having 100% renewable as the primary energy sources for the incremental demand. In addition, this study will touch briefly on existing electricity network and the impact of the recommendation scenario towards Malaysia Renewable Energy plan. However, transportation system energy requirement is excluded from the main study and might be addresses in the future works.

1.4. Methodology

A structured methodology is developed to perform this research as per Figure 4. The demand and weather sources were gathered from published articles as well as information gathered from several agencies in Malaysia. The data acquired will be analysed and interpolate and entered the modelling software. Detail explanation on the methodology will be explain in the next section.

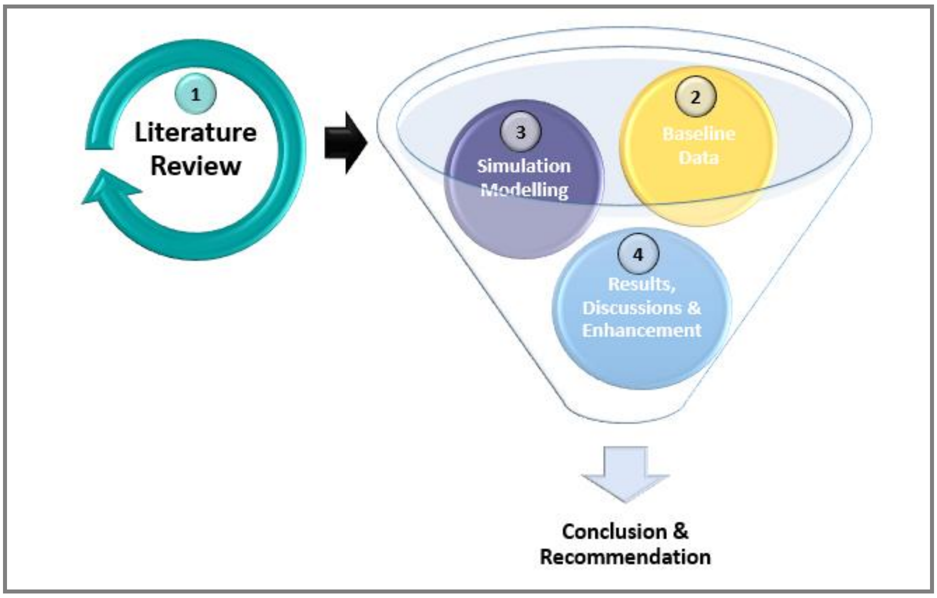


Figure 4: Research methodology

1.4.1. Step 1: Detail Literature Review

The literature review is to establish the current power generation system in Peninsular Malaysia. In this section, the existing power generation system, electricity infrastructure and the Malaysia future plan on the power generation system will be explained as to understand each infrastructure capabilities and limitation.

1.4.2. Step 2: Establishment of Baseline Input for Modelling

In this section, the baseline data for this project is generated by analysing daily demand profile and as well as the available renewable energy resources. The demand profile, weather data and the seasonal impact throughout the year will be analysed and concluded with a baseline for this project. In addition, the type of renewable system that was selected to be used will be deliberated in this section.

1.4.3. Step 3: Simulation Modelling for All Scenarios

In this section, a software was selected to simulate the several project scenarios as to meet the project objectives. The demand and supply scenario will be evaluated with an energy modelling software as per below:

- Hybrid Optimisation of Model with Multiple Energy Resources (HOMER) Pro is a modelling software that was developed to simulate optimum microgrid design that includes the economics of the project (Homerenergy.com, 2019).
- EnergyPLAN is developed by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. The software is able to simulate the operation of total energy system including the electricity and transportation system (EnergyPLAN, 2019).

HOMER is selected as this software able to simulate hybrid combination design and providing emissions data for each scenario.

1.4.4. Step 4: Results and Discussions

In this section, the advantages and disadvantages of each scenario from the hybrid combination will be analysed and discussed. The identified strength and weaknesses will be registered to ensure this will be covered in the future works.

1.4.5. Step 5: Conclusion and Recommendation

Based on the discussion section, the best combination will be summarised and the optimum option for sustainable energy system for peninsular Malaysia will be proposed. In addition, due to HOMER limitation, this section will discuss the best possible location to install the renewable energy system while considering the impact towards the communities as well as the existing power generation system.

1.4.6. Step 6: Discussion on Potential Future Work

In this step, potential improvement on the recommended option will be identified and proposed. This will provide some idea to those that would like to further study in depth on further optimisation of the feasible renewable energy system in Peninsular Malaysia.

2. Detail Literature Review

There are four (4) sections in this literature review that will illustrate an overall background knowledge on energy system in Peninsular Malaysia including the infrastructure as well as the previous study conducted on potential renewable energy in Malaysia. These topics will be deliberated and will be analysed and set as a foundation to understand Malaysia' energy systems.

2.1. Electricity Energy Production

Peninsular had utilised a diversified electricity generation fuel mix to base on the Figure 5. The Figure demonstrated that in 2017, coal makes up the bulk of the electricity fuel mix (TNB, 2017).

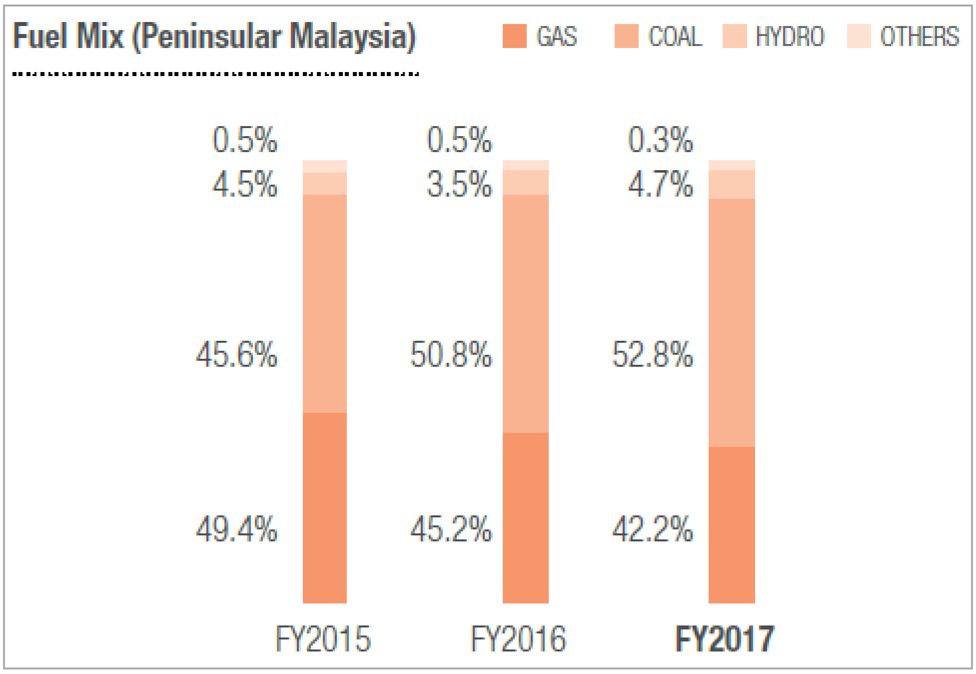


Figure 5: Fuel mix breakdown in peninsular Malaysia (TNB, 2017)

Based from this information, it can be said that Malaysia are highly dependent on fossil fuel as a main source to generate electricity. Almost half of the generated electricity is used for industrial used followed by Commercial (29.8%) and residential (20.7%) accordingly (Malaysia Energy Information Hub (MEIH), 2019). Figure 6 depicted the electricity consumption in 2017. Based on this, the major reduction in fossil fuel materialised if the industrial sector transfers the electricity source from the national grid to generating their own renewable energy system.

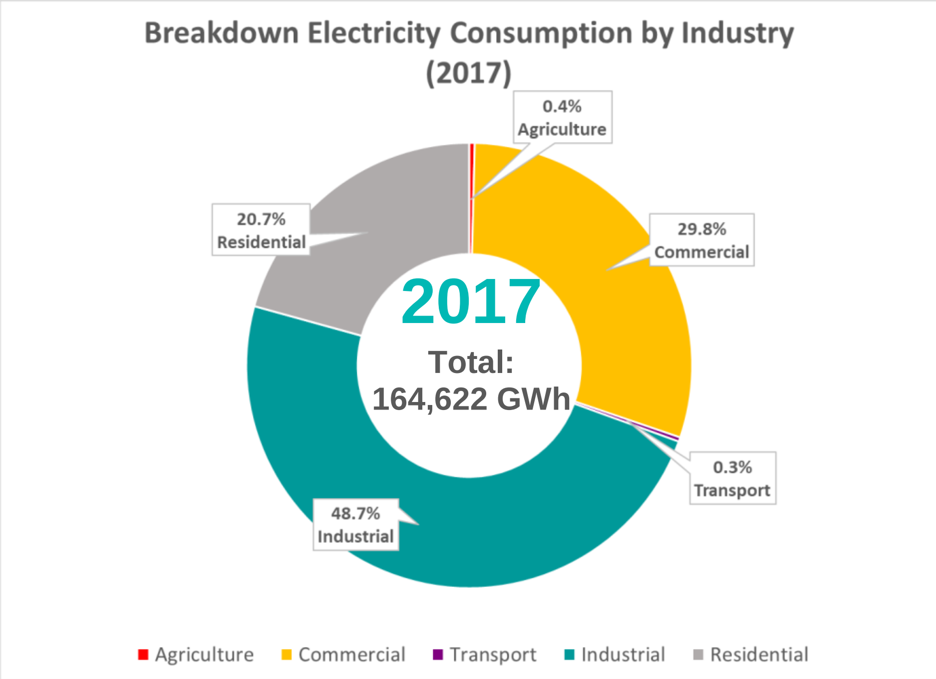


Figure 6: Electricity consumption in Malaysia by industry

There are two major power generation plant in Malaysia which are thermal power stations and renewable power generation plant. This will be further explained in the next section.

2.1.1. Thermal Power Stations

In order to maintain system security and reliability the power generation plant produced 10% more than the forecasted demand. As of 2016, 22,919 MW power was generated in peninsular and the breakdown of the installed plant capacity is shown in Figure 7 (St.gov.my, 2017).

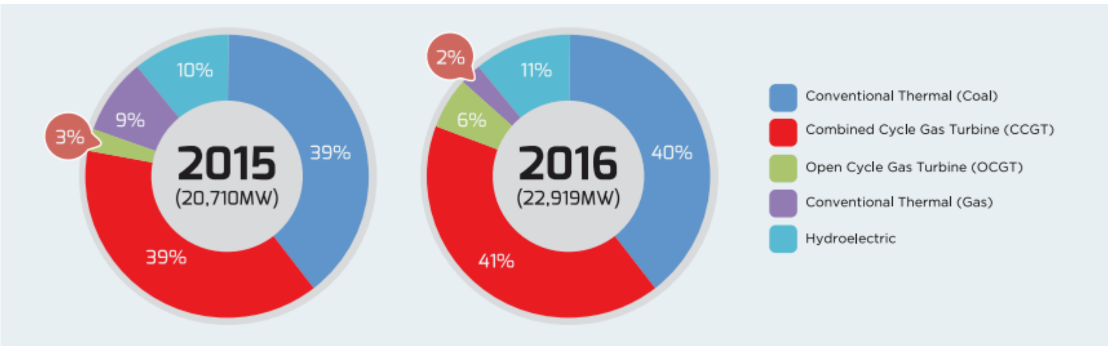


Figure 7: Installed capacity by plant type in peninsular Malaysia (St.gov.my, 2017)

Figure 7, indicated that approximately 48% from the plants are using open cycle gas turbine or conventional thermal (gas or coal). Due to this, Energy Commission is in the process to decommission the inefficient and ageing Open Cycle Gas Turbine (OCGT) plants and substituted with a higher efficiency and cost-effective Combined Cycle Gas Turbine (CCGT) plants (TNB, 2019). The primary resources of the thermal plant are coal and natural gas as these resources is domestically available.

2.1.1.1. Hydrocarbon Resources

a. Coal

There is an increase of coal utilisation from 8.3% in 1996 to 42.5% in 2016 as depicted in Figure 8 (Malaysia Energy Statistic Handbook (2017), 2018).

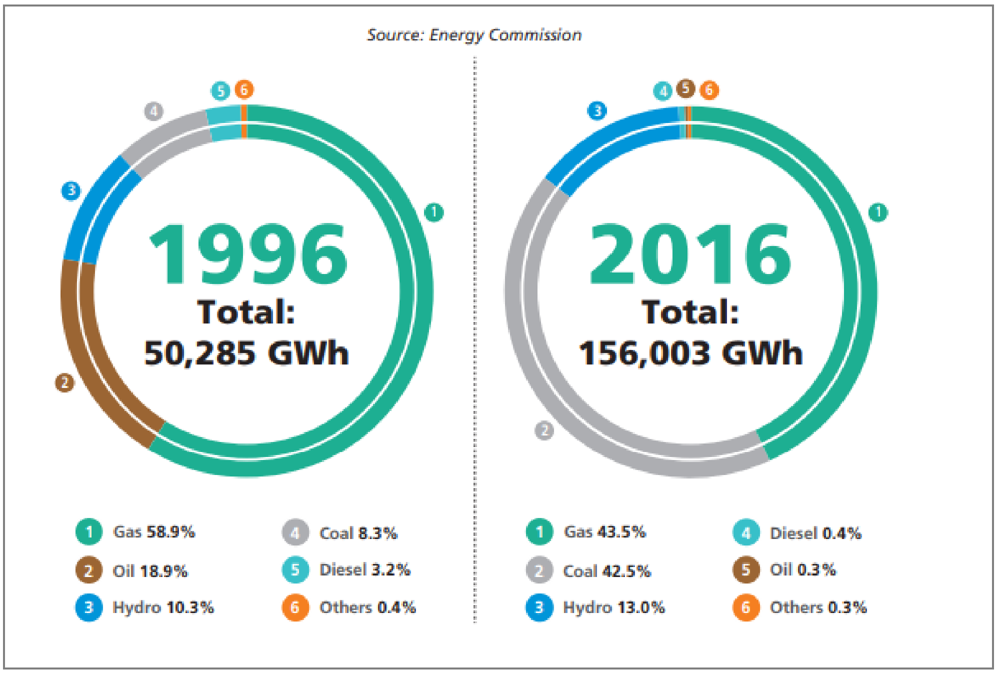


Figure 8: Fuel mix resources breakdown (Malaysia Energy Statistic Handbook (2017), 2018)

The increase in coal in Malaysia's fuel mix is due to coal competitive price and the ability to provide a balanced fuel mix in the system (How Clean Energy Affects Energy Supply, 2018). In addition, variation in fuel mix provides a better flexibility for electricity generation supply to the national grid as the coal power plant can be operated as a base load for the country. This plant can be considered as non-dispatchable due to the operation requirement that will take hours or days to shutdown and switch on again.

The Malaysian had invested on utilises ultra-supercritical steam generation technology at the latest coal-fired power plant in Perak, this overall power plant complex contributed up to 20% of peninsular Malaysia's total generation capacity (TNB, 2019). This is to meet the country target to reduce emission as the technology provide higher efficiency plant that led to reduction in coal consumption, improved operation flexibility and subsequently reduced emissions.

Based from the peninsular Malaysia Electricity Supply Industry Outlook 2017, in the next five (5) years, there will be new coal power plants as the gas supply is expected to decrease 12% approximately in the subsequent 8 years (St.gov.my, 2017). In view of this, there will be an increase in coal consumption that will lead to an increase in CO_2 emission. As published by Energy Information Administration (EIA), coal emits between 200 to 230 pounds of CO_2 per million British thermal units (Btu) as compare to natural gas, which emits 117 pounds of CO_2 per million Btu (EIA.gov, 2019).

Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (subbituminous)	214.3
Diesel fuel and heating oil	161.3
Gasoline (without ethanol)	157.2
Propane	139.0
Natural gas	117.0

Figure 9: Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuels (EIA.gov, 2019)

This created an opportunity for renewable energy power plant to be built in place of the potential new coal power plant. The new renewable energy plant will aid the country to reduce the CO_2 gas emission greatly. This opportunity will be further analysed and discussed in Chapter 5.

b. Natural Gas Resources

Referring to Figure 8, natural gas plant contributed nearly half of the power generation in Malaysia. This is mainly due to the availability of natural gas resources domestically. Based on the last twelve (12) years trending of natural gas reserve in peninsular Malaysia, there is a concern as the reserve has been declining steadily since 2014 (Malaysia Energy Information Hub (MEIH), 2019). In 2013, the government built Liquid Natural Gas (LNG) regasification terminal (RGT) in Melaka to strengthen the gas supply capacity by 500 mmscfd. In addition, the government has constructed a new 490 mmscfd RGT in Johor as to ensure continuous security of supply of natural gas for power sector (St.gov.my, 2017). However, the LNG price is higher as compared to natural gas. This created an opportunity for renewable energy power system to reinforce the electricity system in peninsular Malaysia as the production of natural gas resources depleting.

2.1.2. Renewable Energy Sources (RES)

As stated in the 11th Malaysia Plan, the Malaysian Government's target to achieve 2,080MW of renewable energy installed capacity by the year 2020 (TNB, 2019). One of the main reasons is to reduce the fossil fuel dependencies. In addition, by 2025, the government aim is to install up to 20% of renewable energy system as compare to three percent (3%) in year 2017 (How Clean Energy Affects Energy Supply, 2018).

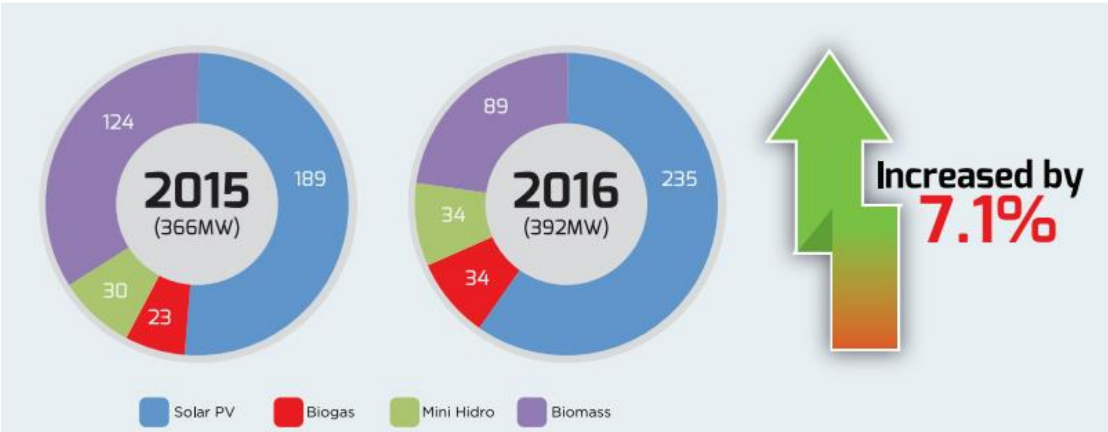


Figure 10: Renewable energy capacity mix in peninsular Malaysia (2015 vs 2016) (St.gov.my, 2017)

Figure 10 depicts that there is has been a steady increase in renewable energy capacity in peninsular Malaysia since 2015 and a total licensed capacity of 392MW was installed mainly from solar PV (235MW).

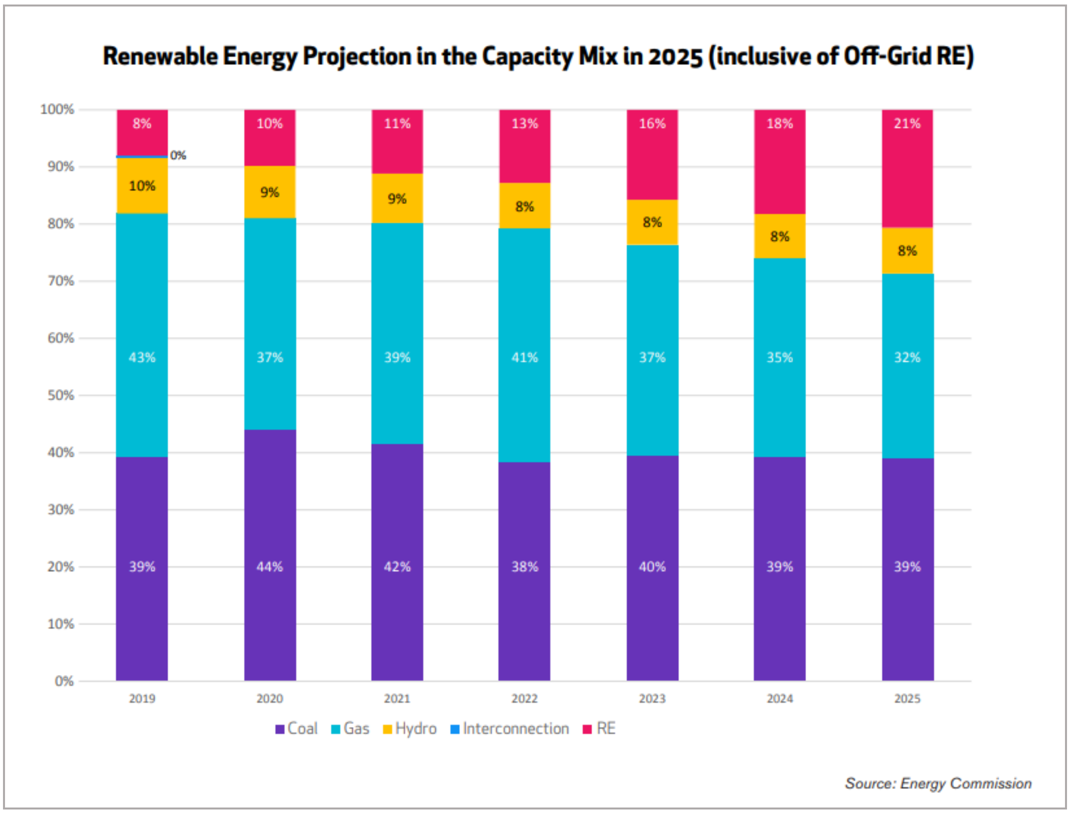


Figure 11: Renewable energy projection in the capacity mix in 2025 - inclusive off-grid renewable (Sustainably Powering a Nation, 2019)

The government plan to increase the renewable energy source in the electricity capacity mix is demonstrated in Figure 11. With the additional renewable energy power, the coal and gas power plant will be reduced from 86 % as per Figure 8 to 71% as per Figure 11. Several projects and plan were introduced since 2017 as to meet the national target.

In 2011, Sustainable Energy Development Authority (SEDA) Malaysia was formed to administer and manage the implementation of any new mechanism or programme on renewable energy. One of the programmes introduced by the government was Feed-in-Tariff (FiT) programme. This programme is similar to United Kingdom (UK) FiT programme where the Distribution Licensees (DLs) will buy the electricity produced from renewable resources from companies and individuals. This programme has increase people interest and led to 7,367 FiT projects in Peninsular Malaysia with an installed capacity of 379.4MW as of July 2017 (St.gov.my, 2017).

In addition to FiT, in 2016, the government has also launch Net Energy Metering (NEM) programme where resident that had installed rooftop solar PV system can supply any excess energy to the electricity supply utilities. The government target to achieve

500MW installed capacity by year 2020 from this programme (St.gov.my, 2017). As to promote this programme to the consumer, SEDA has established a NEM calculator which help the consumer to approximate the cost as well as the payback period for the investment on rooftop solar PV. This calculator was programmed to three (3) types of residential house as shown in Figure 12.

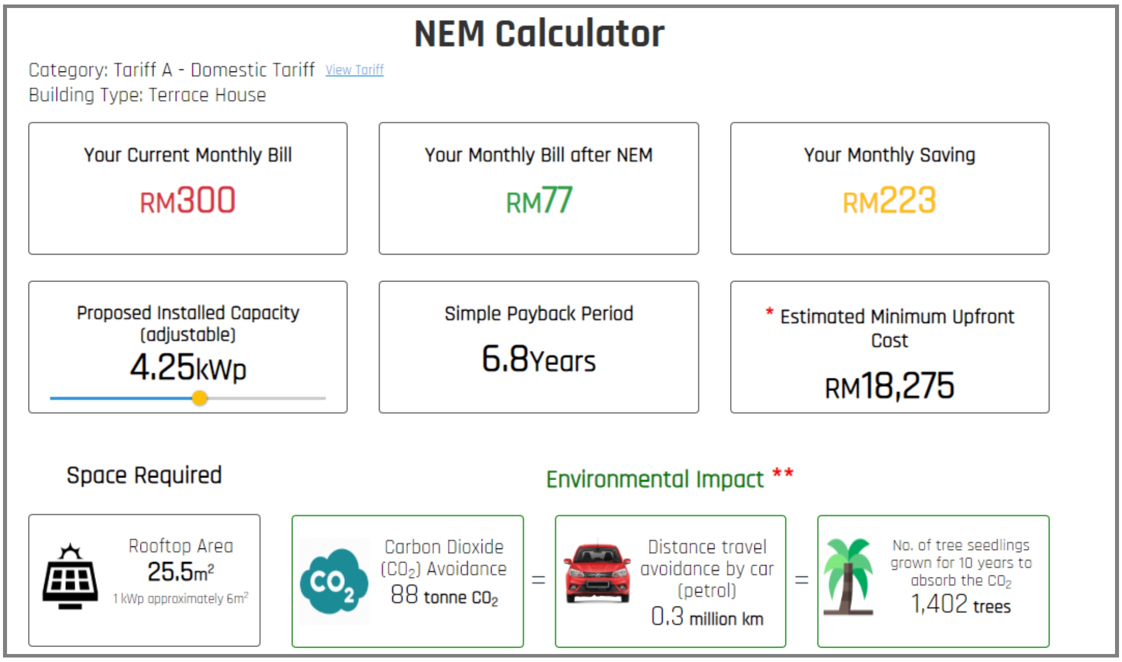


Figure 12: Net Energy Metering (NEM) Calculator (seda.gov.my, 2019)

Based from these two programmes, the government has encouraged consumers to installed renewable energy for their home as well as office buildings. There are several additional renewable energy projects in solar, biomass and hydro that will further explain in the next section.

2.1.2.1. Solar

As Malaysia is situated close to the Equator, the country has an abundance of sunlight which provides an opportunity for solar energy generation. However, as any other renewable energy, solar power has its limitations as the electricity can only be generated during the day. Solar energy effectiveness will be around 5 to 6 hours during dry season. In addition, for a large capacity solar photovoltaic plants to be connected to the power supply system, the energy and capacity input drops due to the weather condition needs to be considered to ensure a stabilise system. (How Clean Energy Affects Energy Supply, 2018).

In 2017, the government has embarked on first floating solar photovoltaic (FSPV) system with a capacity of 108kwp, covering 1,000m2 on a 50-hectare lake (St.gov.my, 2017). In addition to this, the government had invited private sector to invest on Large Scale Solar PV (LSSPV) plants to supply and sell energy to the utilities under long term power purchase agreements with a target capacity of 1,000MW by 2020 with annual capacity capped at 200MW (St.gov.my, 2017). Figure 13 shows the LSS location and capacity awarded in 2017.

Figure 13: LSS location and capacity awarded (St.gov.my, 2017)

In addition to solar PV farm, Malaysia has a potential to develop concentrated solar panel (CSP) in certain part of the country. Referring to Figure 14, in northern peninsular Malaysia, the average direct normal irradiation (DNI) value can be as high as 3.6kWh/m2 daily.

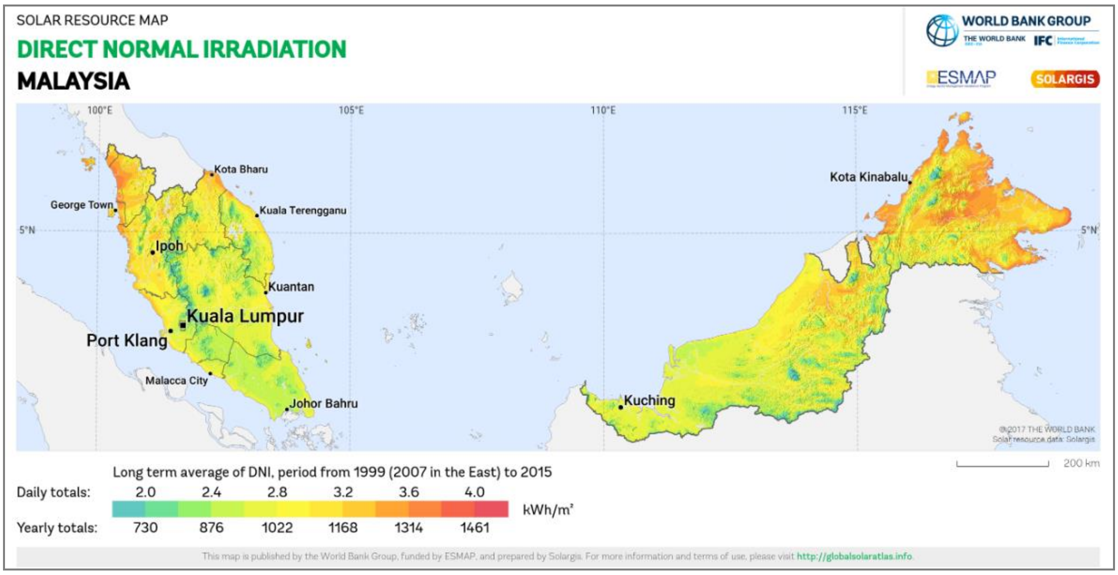


Figure 14: Map of direct normal irradiation in Malaysia (Solargis.com, 2017)

According to Affandi et al. (2015), the yearly average irradiation in Malaysia is between 834 kWh/m^2 up to 1246 kWh/m^2. Table 1 listed the range of yearly irradiation for several cities in Malaysia.

Table 1: Yearly irradiation data for selected cities in Malaysia (Affandi et al., 2015)

Cities in Malaysia	DNI [kWh/m^2]
George Town	1246
Kota Kinabalu	1192
Kota Bahru	1107
Senai	1045
Kuantan	1013
Durian Tunggal	973
Tawau	969
Sitiawan	949
Subang	932
Kuching	834

Based from another study, in order to be economically viable, CSP technology requires DNI of at least 1900 to 2000 kWh/m2/year (Affandi et al., 2013). However, Malaysia's neighbouring country, Thailand, is the first country in Southeast Asia that had installed 5MW CSP plant in 2012 even though the country DNI is between 1350 to 1500 kWh/m2/year (Affandi et al., 2013).

Even though there is a potential for CSP in Malaysia, the government need to revaluate current FIT scheme as the current scheme is dedicated to solar PV, Mini Hydro, Biomass and Biogas. Due to this, solar energy in Malaysia is focused on the photovoltaic panel to generate electricity.

2.1.2.2. Bio-energy (Biomass and Biogas)

Approximately 14% of the energy used in Malaysia are contributed by Biomass, which is equivalent to 340 million barrel of oil (boe) (Chuah et al., 2006). In Malaysia, 168 million tonnes of biomass, including agriculture waste and municipal waste was produced annually. According to Tun et al., (2019), there are around 83 million dry tons of biomass produced in 2012 and by 2020, the amount is expected to rise up to 100 million dry tons. Based from this value, the estimated value of 29,000 MW power potential to be generated from biomass (Tun et al., 2019). Table 2 listed the new biomass plant plan to be installed in 2017.

Table 2: New biomass plant in 2017 (Malaysia Energy Information Hub, 2019)

No.	Biogas (2017 - 2033)	Capacity (MW)
1	Advance Project Management Sdn. Bhd.	2.40
2	Betatechnic Sdn. Bhd.	1.20
3	Felda Palm Industries Sdn. Bhd.	2.40
4	Future Biomass Gasification Sdn. Bhd.	2.40
5	Gan Teng Siew Realty Sdn. Bhd.	1.56
6	Glt Renewable Sdn. Bhd.	2.20
7	Kim Loong Power Sdn. Bhd.	2.40
8	Metro Havana Sdn. Bhd.	1.56
	TOTAL	**16.12**

Palm Oil

There are approximately 4 million hectares of land under oil palm plantation in Malaysia that has a potential to produce around 58 million tons of palm oil mill effluent (POME) annually which has a potential to generate an estimated of 15 billion m^3 of biogas (Zafar, 2019). A large quantity (around 60%) of waste in the form of palm fibers and shells were produced after the extraction of the palm oil are utilized as the boiler fuel in the mill to generate steam and electricity

Rice Husk

Another agricultural biomass potential is rice husk which is suitable for biomass cogeneration. However, the production of this resources as biomass fuel is not as massive as the POME. One of the rice husk biomass plant installed in Malaysia is in Perlis which generates 10 MW power and able to meet the demands of 30,000 households (Zafar, 2019).

Municipal Solid Wastes (MSW)

In Malaysia, incineration plant one of the options to manage the MSW due to the unavailability of space for new landfills. This incineration will be able to produce electricity and at the same time managed the issue on the increase of MSW. However, due to a high moisture content of approximately 55%, the incineration plant has become a challenging option (Kathirvale et al., 2004).

In summary, biogas and biomass in Malaysia are constrained by resource availability and are only suitable for small capacity. (How Clean Energy Affects Energy Supply, 2018). On the other hands, the resource for Biomass can be stored and easily transported from East Malaysia to peninsular Malaysia as compared to other renewable resources i.e hydro. East Malaysia has significant amount of agricultural biomass and wood waste resources available for immediate exploitation. However, cost and consistencies of this supply is still a concern for this industry in peninsular Malaysia.

2.1.2.3. Hydropower and Wave Energy

a) Hydropower

According to Energy Commission, several small hydro power plant will be on stream post 2020 will be among the last in peninsular Malaysia as most of the hydro resources has been tapped (St.gov.my, 2017). Based from this, the contribution of hydro in electricity fuel mix will reduce from 5% to 4% from 2018 to 2022 (St.gov.my, 2017). The reduction is due to the increase in other generation to cater the increase in demand while there will be no new hydro power plant in the future.

In Malaysia, for hydro power plant that generated more than 100MW for hydro will not be counted towards renewable energy (Sustainably Powering a Nation, 2019). Currently there are approximately 2,529MW hydro power plant installed in Malaysia (St.gov.my, 2017). In addition, Table 3 listed the additional new hydro power plant plan to be installed in 2017.

Table 3: New hydro power plant to be installed in 2017 (MEIH, 2019)

No.	Hydro (2017 - 2038)	Capacity (MW)
1	Contour Mechanism Sdn. Bhd.	10.57
2	Trident Cartel Sdn. Bhd.	9.88
	TOTAL	**20.45**

In summary, hydro energy from river was fully exploited in peninsular Malaysia. Based from this observation, new hydro power is excluded from this study.

b) Wave Energy

In peninsular Malaysia there is a potential wave energy particularly during the rainy season from November to March. As the wind speed during this season is significantly high, this produces high energy waves. Referring to a study by Mohd Nasir et al., (2016), there are several locations in east coast of peninsular Malaysia that has a potential to generate wave energy. Figure 15 demonstrated the areas that have the potential to generate energy of more than 10 kW which is the ideal power to generate wave energy.

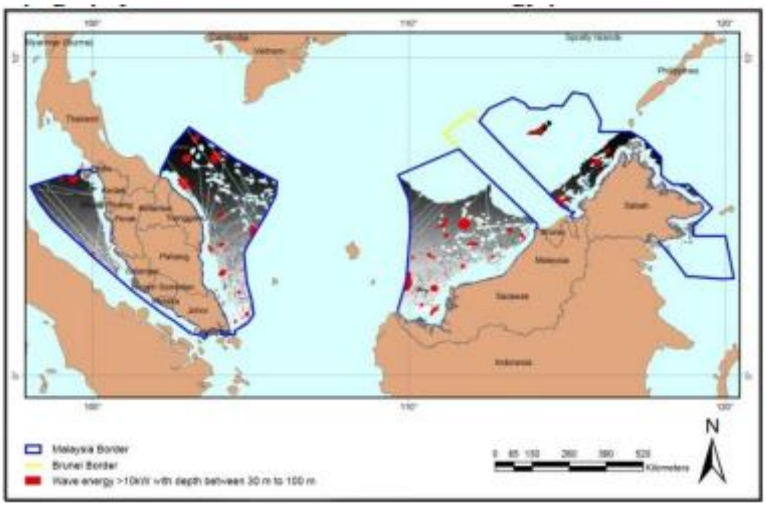


Figure 15: Location for wave power of more than 10kW (Mohd Nasir et al., 2016)

The study concludes that there are between 2.8 kW/m to 8.6 kW/m of an average annual wave energy that can be generated in Malaysian territorial waters (Mohd Nasir et al., 2016). In addition, Figure 16 indicates the seasonal impact of average wave power at East coast Malaysia where the highest energy density occurring during the rainy season that associated with frequent storms and high winds (AM et al., 2010).

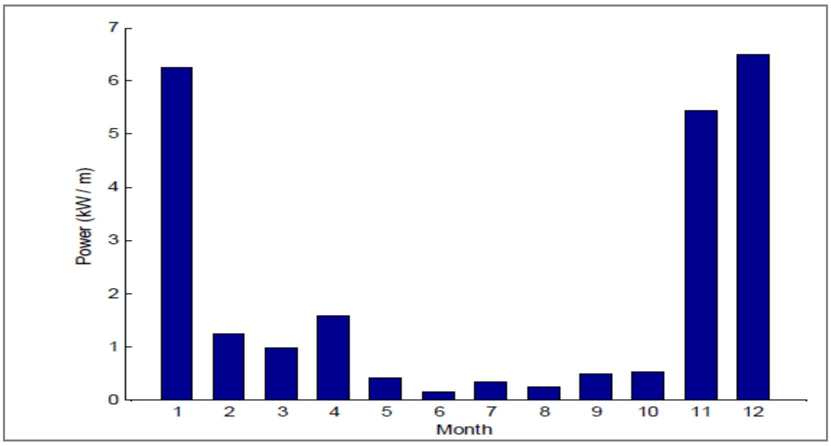


Figure 16: Average wave power at east coast Peninsular Malaysia (AM et al., 2010)

From this data, it can be said that the east coast Peninsular Malaysia has a potential source of low wave power. However, the potential energy generated is inconsistent throughout the year and low as compare to other countries. Additional research is required to improve wave energy conversion technologies and harness a lower wave power.

2.1.2.4. Wind Energy

Based from 2003 study, peninsular Malaysia has potential wind energy that can be harness further. The average offshore wind speed in peninsular Malaysia is within a range of 2.0 m/s to 4.1 m/s (Sopian, Othman and Wirsat, 1995). This is consistent with the information on wind potential map for Malaysia at 80 meters onshore from IRENA (2019) as illustrated in Figure 17.

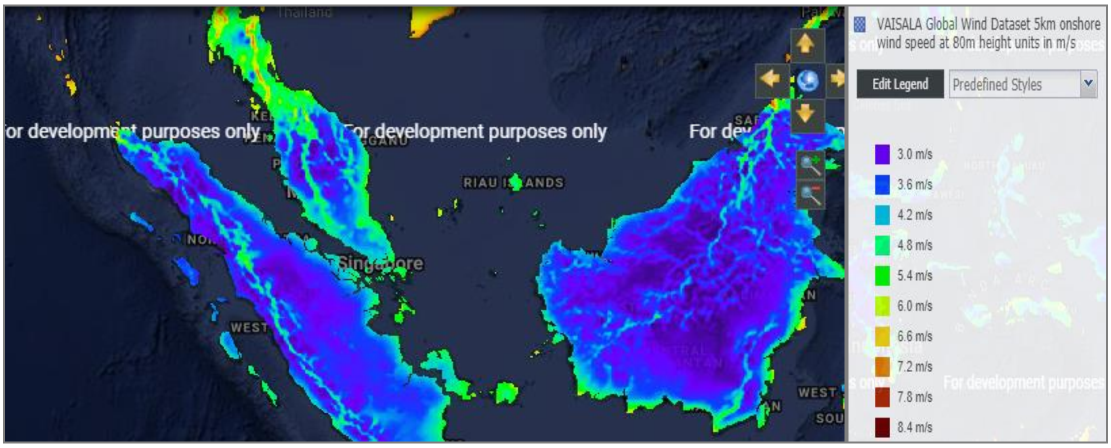


Figure 17: Wind potential map for Malaysia at 80 meters onshore (IRENA,2019)

In another study, it was indicated that east coast peninsular Malaysia at the South China Sea has the highest energy resource available in the months of November to February, which coincide with northeast monsoon season (Chiang et al., 2003). In 2007, there were 2 unit of 100kW wind turbine was installed in Perhentian Island at the east coast of Peninsular Malaysia as a part of a hybrid power plant consist solar PV and diesel. However, the turbine is longer in operation due to improper maintenance from the operator (Sovacool and Drupady, 2016).

Similar to wave and CSP, there are potential to harness power from wind turbine, however, government need to relook at existing renewable energy scheme and includes other source of renewable energy particularly wind energy.

2.2. Energy Demand

Based from Energy Commission forecast analysis, as shown in Figure 18, the peak demand is expected to grow by 1.99% annually for 2016 to 2025, while 1.62% annually for 2016 to 2035 (St.gov.my, 2017). This forecast has included the impact of socio demographic, technical and historical electricity demand trend. This forecast will be the basis for this study to analysis future potential for renewable energy.

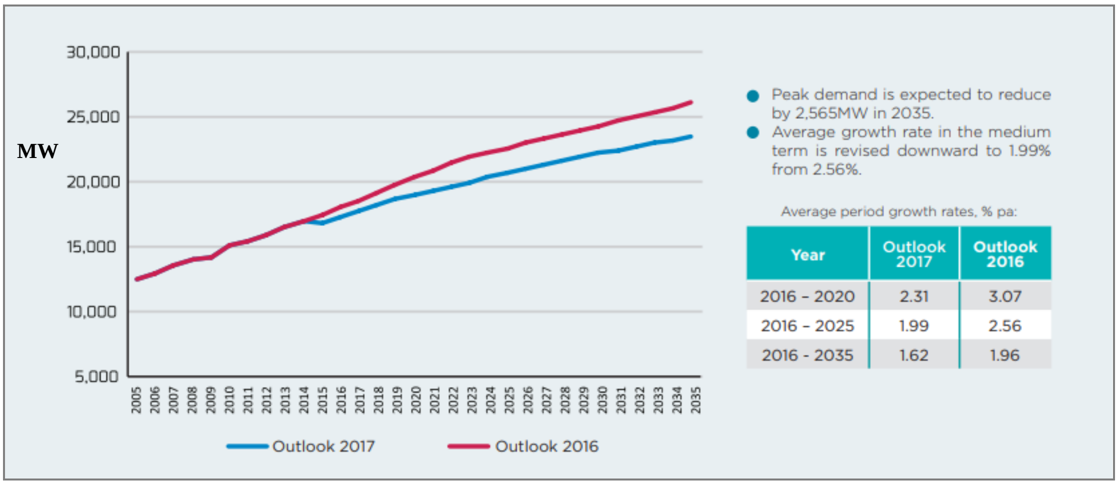


Figure 18: Peak demand forecast for peninsular Malaysia (St.gov.my, 2017)

Based from the information in Malaysia Statistic Handbook, Figure 19 was plotted to show monthly trend for energy consumption in Malaysia.

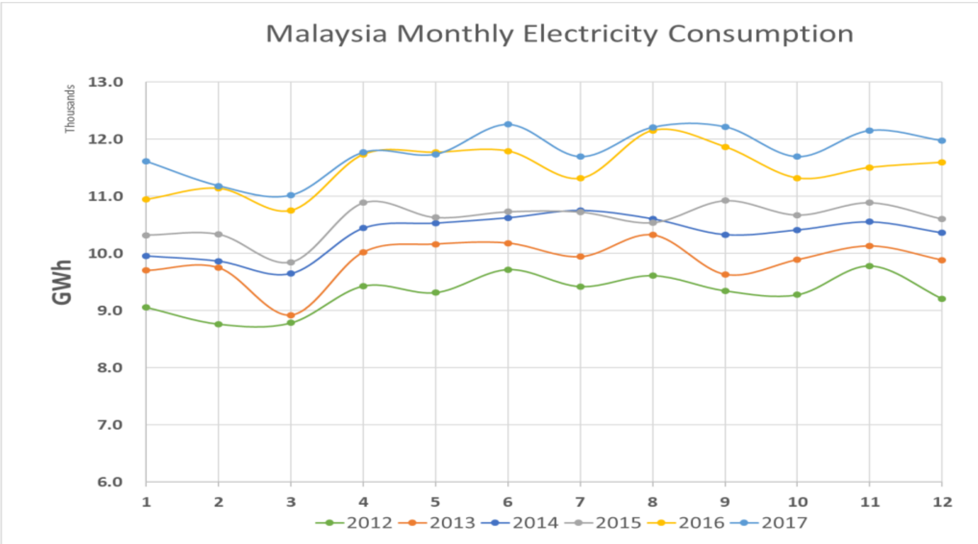


Figure 19: Malaysia monthly electricity consumption by year

As demonstrated by Figure 19, the peak season in Malaysia started to pick up in April and maintained at peak until September. This duration in Malaysia is considered as dry season while the duration between September to March is considered a rainy season. This is consistent with a study conducted in South of Thailand which is at the northern border of Peninsular Malaysia. As shown in Figure 20 below, the summer season is between March through to June, wet season is between June to October, and finally the winter season is from November to February (Damrongsri, 2018). The changes of demand during each season will be incorporated in the model simulation for this study.

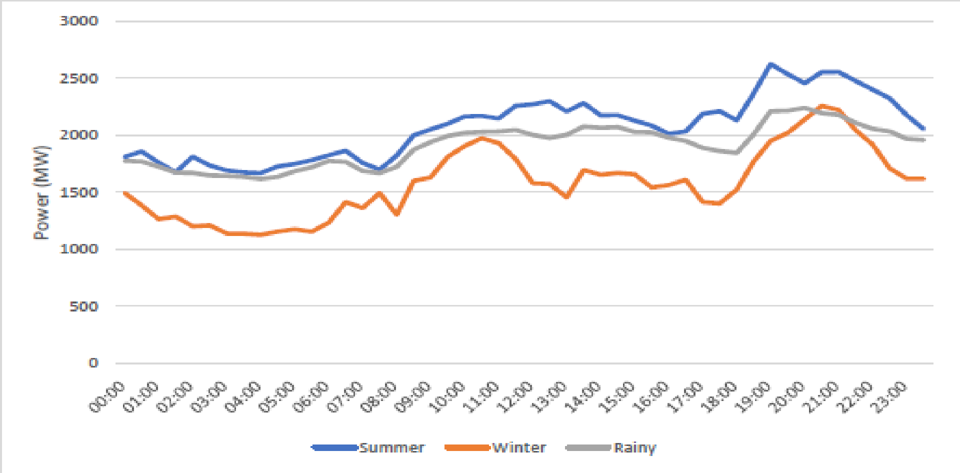


Figure 20: 2017 South Thailand daily demand profile by season (Damrongsri, 2018)

Due to unavailability of hourly demand profile for Malaysia, the profile for south Thailand was used as reference for residential demand trending to be used in HOMER model.

2.3. Electricity Infrastructure

In view of the Malaysia target to increase the renewable energy resources, the Energy Commission had invested in Energy Management System/Supervisory Control and Data Acquisition (EMS/SCADA) system at grid and distribution level. In addition, a new weather forecasting technology is currently develop to improve the predictability and accuracy of the power generated from solar and potentially wind in the future (St.gov.my, 2017).

2.3.1. Domestic Interconnection

Based from the latest forecast, there will be an increased up to 20,989 MW in 2026. As the exsiting power plant will be expired within the next 10 years, new power plants are required. This leads to several 500kV transmission projects, involving new lines and substations to be constructed. These 500kV grid will be connected to the main tranmission line and become the backbone of Peninsular Malaysia's transmission system. This created a possibility of having multilateral electricity trading via the ASEAN Power Grid. (St.gov.my, 2017).

2.3.2. International Interconnection

2.3.2.1. Lao PDR, Thailand and Malaysia (LTM)

Regional interconnection is essential for system cost reduction and to improve supply security for the country. In view of this, Malaysian government had signed Memorandum of Understanding (MoU) with the Governments of Lao PDR, Thailand and Singapore during the 34th ASEAN Ministers on Energy Meeting to buy up to 100MW of power from Lao PDR through the Thailand power grid (St.gov.my, 2017). This initiative was established to manage the power trading between borders through existing transmission network. In view of this, there is an opportunity for Malaysia to sell excess power to the border countries once there is an access of electricity in Malaysia. This is similar electricity arrangement between UK and european countries.

2.4. Summary

In summary, peninsular Malaysia has an abundant renewable resource inland as well as offshore. Thus far, there are still several renewable resources in peninsular Malaysia such as wind, CSP and wave energy that is waiting to be harnessed fully. On the other hand, the hydro energy from river sources had fully exploited in peninsular Malaysia. The Malaysian government has also established renewable energy policy as to encourage the consumer to switch to renewable power system as the primary electricity supply and the grid system will be the secondary supply.

However, the steps taken by the consumer is not sufficient to address the overall incremental electricity demand as forecasted until year 2040. Other renewable power generation will be required such as wind farm, biogas generator, solar farm or wave power generation to address the shortage.

In addition, the electricity infrastructure in peninsular Malaysia is well established and will be able to cater additional power generated by the renewable energy system. The government has started to invest on weather forecasting technology and high technology control system at grid and distribution level as to address the inconsistencies of power generated by the renewable energy sources.

3. Establishment of Baseline Input Data

As summarised in the literature review section, peninsular Malaysia has a significant renewable energy resources that has yet to be tapped. In view from this information, a baseline input data will be established to decide the type of renewable energy technology to be used in the modelling as to meet the incremental demand for year 2030 and 2040. The following section will breakdown each renewable energy resource, technology component and identify important parameters relevant to simulations.

3.1. HOMER Simulation Software

As mentioned previously, HOMER software is program developed to simulate optimum microgrid design that includes the economics as well as the environmental aspects such as carbon dioxide (CO_2) and sulphur dioxide (SO_2) emissions of the project (Homerenergy.com, 2019). This is one of the efficient tools to evaluate power system analysis with variety of renewable energy resource with a certain limitation that need to take into consideration during modelling.

As the aim of this project is to evaluate the best power system option for future Peninsular Malaysia taken into consideration of renewable fraction (RF), the net present cost (NPC) and percentage of the carbon dioxide (% CO_2) emission reduction. The renewable fraction is defined as the fraction of the energy delivered to the load that originated from renewable energy resources (HOMER, 2019). This can is shown as per the equation below:

$$f_{ren} = 1 - \frac{E_{nonren} + H_{nonren}}{E_{served} + H_{served}}$$

Equation 1: Renewable fraction (RF)

Where:

- E_{nonren} = non-renewable energy production and grid import [kWh/year]
- H_{nonren} = non-renewable thermal production [kWh/yr]
- E_{served} = total energy served to the load [kWh/year]
- H_{served} = total thermal load served [kWh/yr]

Based from this equation, for system architecture that only consist of renewable energy component, the RF will be 100%. Even though the RF is at 100%, there is a possibility that the system is unable to meet 100% of the electricity demand. This will be further deliberated in Chapter 5 (Scenario Results and Discussions).

The next factor that will be taken into consideration is the NPC. NPC is the present value of all the installation, operation and maintenance cost of the component during the project lifetime minus the present value of all the revenue it earns over its lifetime (HOMER, 2019). This is explained in Equation 2 below:

$$NPC = \Sigma\, PV_{cost} - \Sigma\, PV_{revenue}$$

Equation 2: Net present cost (NPC)

Where:

- $\Sigma\, PV_{cost}$ = Present value cost of the component during the project lifetime
- $\Sigma\, PV_{revenue}$ = Present value of revenue

Referring to the equation, total NPC is the sum of total discounted cash flows in each year of the project lifetime. A lower NPC value will improve the project worth.

In addition to RF and NPC, the reduction of CO2 emission as compared to the base model will be evaluated compared between all the scenarios. This is to measure the effective of the proposed renewable power system against base model which is conventional gas generator system. This can is shown as per Equation 3 below:

$$\%\ CO_2\ reduction = 1 - \frac{CO_2\ emission\ of\ proposed\ scenario\ (kg/year)}{CO_2\ emission\ of\ base\ model\ (kg/year)}$$

Equation 3: Percentage CO_2 reduction

In summary, all the above factor will be simulated in HOMER and the result from the simulation will be further discuss in Chapter 5.

3.2. General Project Input

At the start of the modelling, project assumption and constraints were set as this condition will directly influence the result. The nominal discount rate is set at 10% while the expected inflation rate for Malaysia is at 1% (IRENA & ACE (2016) and Bnm.gov.my, 2019). After a calculation by HOMER, the real discount rate used in HOMER is 8.91%. Listed in Table 4 are the project economics input for this analysis.

Table 4: Economics basis

Economics Basis	Value	Unit
Nominal Discount Rate	10	%
Expected Inflation Rate	1	%
Project Lifetime	25	years

3.3. Peninsular Malaysia Energy Demand

Energy commission Malaysia has established MEIH to provide statistic and energy information to the public. In addition to MEIH, Malaysia's monthly electricity consumption and generation data is publicly available in Census and Economic Information Centre Governmental (CEIC) Data website. Based from these two sources, the historical energy demand and monthly consumption for peninsular Malaysia can be plot and analysed. In addition, the demand was forecasted to be increase 1.99% annually for 2016 to 2035 (St.gov.my, 2017). Based from the equation below, the future demand for peninsular Malaysia was represented in Figure 21.

$$Future\ demand_{2030} = (Current\ demand_{2016} \times 1.0199^{14}) - Current\ demand$$

$$Future\ demand_{2040} = (Current\ demand_{2016} \times 1.0199^{24}) - Current\ demand$$

Equation 4: Future demand forecast

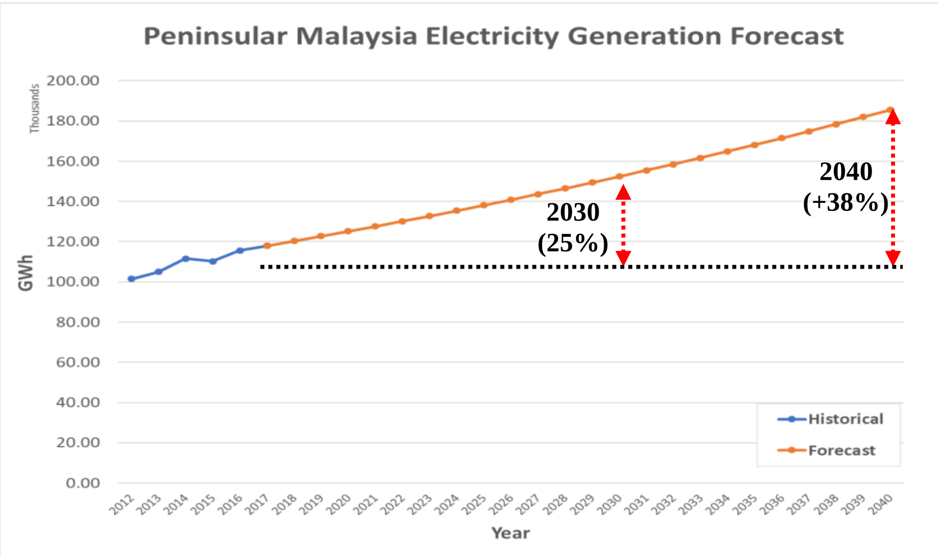


Figure 21: Electricity demand forecast for peninsular Malaysia

It can be seen that the 2030 incremental demand contributed up to 25% from overall peninsular Malaysia demand. Meanwhile, in 2040, the demand has reach around 185,564 GWh which is an increase of 60% from year 2016 and contributed up to 38% from the overall demand of that year.

Due to the unavailability of monthly and hourly demand data, the yearly demand was breakdown by categories as per the Table 5 below (MEIH, 2018).

Table 5: Breakdown by components

Year	**Final Electricity Consumption (GWh)**				
	Agriculture	**Commercial**	**Transport**	**Industrial**	**Residential**
2017	581.50	43,752.06	453.57	71,466.35	30,354.30
Breakdown	0.40%	29.84%	0.31%	48.75%	20.70%

Based from the historical trend of the monthly demand in CEIC for peninsular Malaysia. the seasonal trend for year 2030 and 2040 was represented in Figure 22.

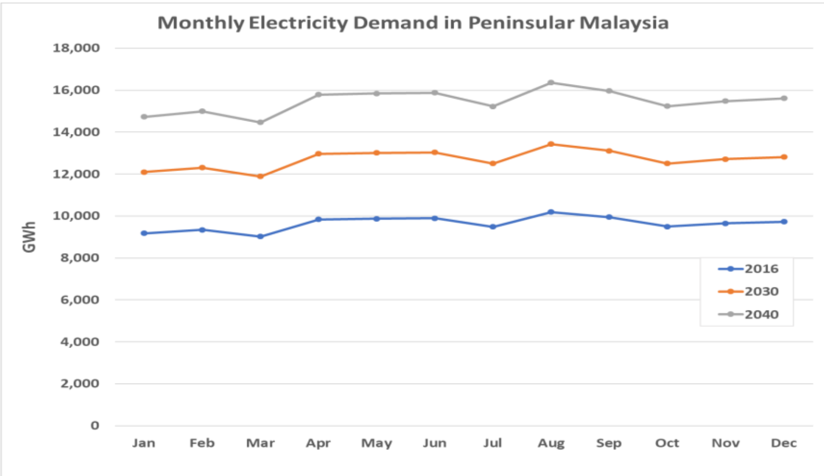


Figure 22: Monthly electricity demand trends in peninsular Malaysia

It can be seen that during dry season between April to September the demand had increase and the demand start to decline in October. Based from the demand breakdown in Table 5 and the monthly trends, the daily demand was established. This daily demand that was prorated utilising HOMER trends for residential, commercial and industrial. Figure 23 represent the hourly demand distribution for dry and rainy season that was entered in HOMER for this study.

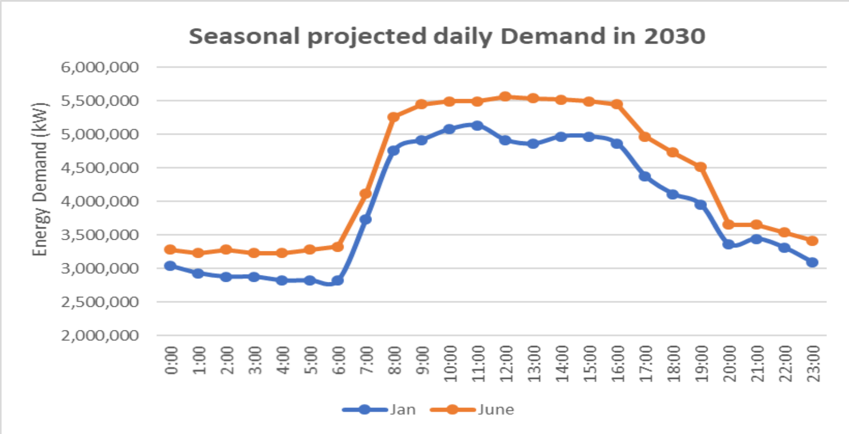


Figure 23: Hourly electricity demand trends in dry and rainy season

It seems that both seasons has a similar pattern, which the demand start to increase up at 0700 hours and reach it peak demand between 0800 to 1700 hours. The demand significantly at 2000 hours and maintain at 3.25 GW between 2300 hours and 0600 hours which is the time where less activities occurs and most of the people are asleep. In dry season, the demand peak at 5.5 GW in the afternoon while the demand slightly lower during winter which is at 5GW.

In addition, it can be seen from Figure 24 that the monthly demand is directly correspond to the average temperature in the country. This is due to the fact that, the requirement to cool down the building has increase to offset the outside high temperature particularly in the industrial area where certain machinery is required to be between certain temperature to avoid any failure.

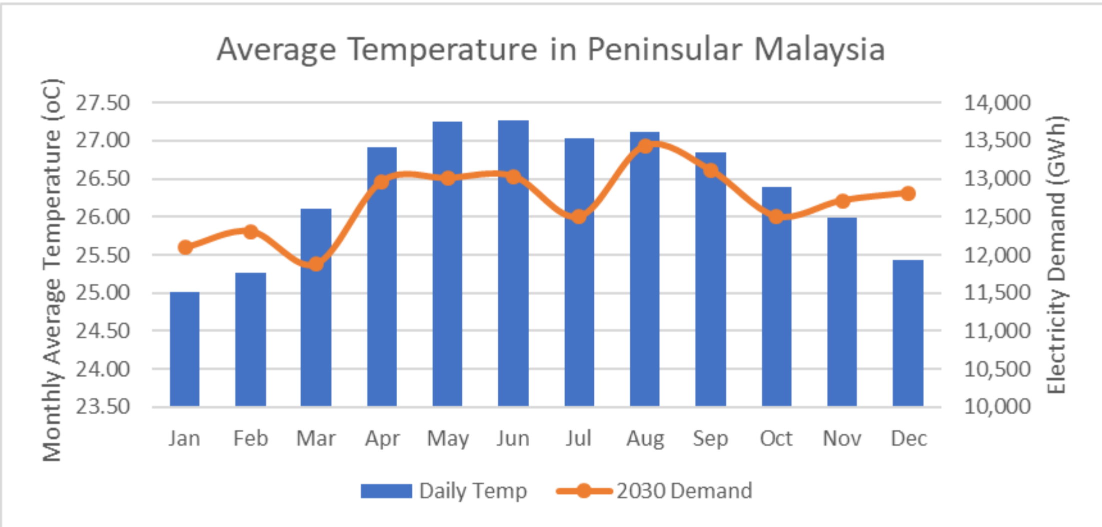


Figure 24: Relationship between average temperature and electricity demand

3.4. Simulation Modelling Resource and Component

3.4.1. Natural Gas Generator (NGG)

Standalone NGG was used as a base model in this thesis. As peninsular Malaysia has a well-established gas and LNG infrastructure, gas power generation will be the first choice by the government. In addition, gas power generation system is dispatchable and able to manoeuvre the generation system quickly to match the demand.

In this simulation, generic gas turbine (size your own) was selected and sized according to the requirement. The technical detail of the turbine was referred to Jenbacher Type 6 Gas Engines a manufacturing from GE that use natural gas for fuel. Four different NGG capacities were simulated to find the optimum size for the scenario.

The capital cost of NGG plant in year 2016 was USD 978 per kW and O&M cost is USD 0.004 per kWh (U.S. Energy Information Administration (EIA), 2016). The discount factor of 8.91% was applied to get NGG present value for year 2018. The new capital cost is at USD 1,160 per kW and the O&M is USD 0.06 per operation hour (for 10GW).

In this study, the replacement cost is set to be 90% from the capital cost which is at USD 1,044 per kW. This is due to the fact that, for NGG plant, the main replacement will be the gas engine and driver. However, by end of design life, major rejuvenation normally take place to ensure that the plant can operated smoothly. Specification and properties and this turbine are stated below in Table 6.

Table 6:NGG specification and properties

Characteristic	Value	Unit
Type	Jenbacher Type 6 Gas Engines	
Fuel	Natural Gas	
Capacity	5, 10, 8.5 and 17	GW
Capital cost	1,160	$/kW
Replacement cost	1,044	
O&M	0.06	$/operate hour
Lifetime	25	years
Fuel price	0.3	$/m^3
Fuel curve slope	0.253	m^3/hour/kW
CO_2 Emission	6.42	g/m^3 fuel

3.4.2. Wind Resource and Components

a) Wind Resources

Due to unavailability of the latest wind speed data from Malaysian Meteorological Department, wind speed from NASA Surface Meteorology and Solar Energy database was utilised in the simulation. The wind speed use is above 50 m from the surface of the earth (HOMER, 2019). Two wind data were evaluated prior to selection for the simulation as per illustrated in Figure 25.

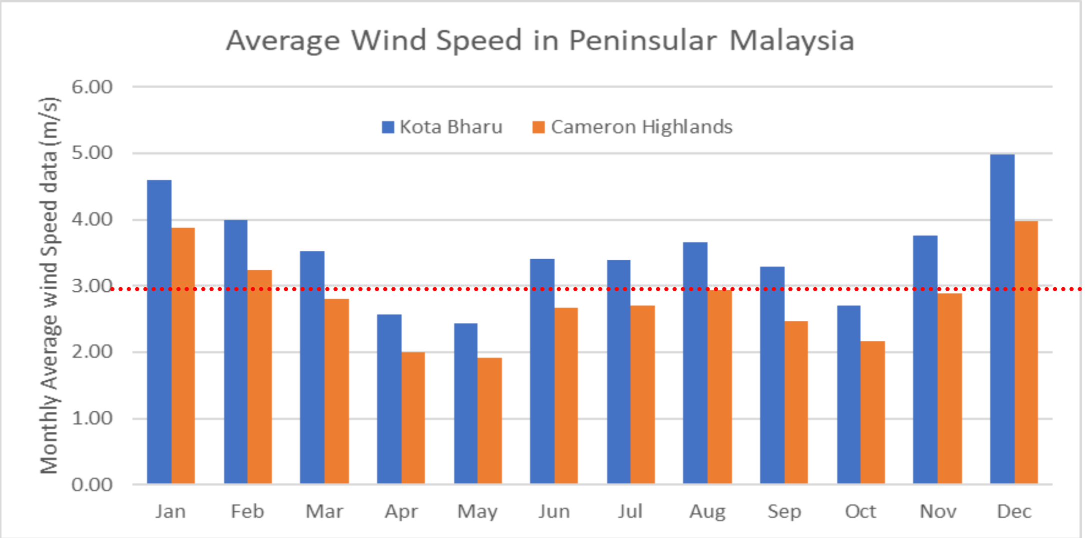


Figure 25: Average wind speed in selected location at peninsular Malaysia

As shown, wind speed profile at Cameron Highland is lower than the wind speed at Kota Bharu. In addition, Cameron highland is located on the mountainous area which is surrounded by rainforest, while Kota Bharu was at the east coast of peninsular Malaysia. Based from there two factors, wind data at Kota Bharu was selected for this simulation. In addition, as peninsular Malaysia has a limited land area for wind farm, in this simulation, the wind farm was assumed as an offshore development.

b) Wind Turbine Components

Based on IRENA (2019) report, the latest wind turbine size that has been installed offshore was at 9 MW rated capacity. Installing a high MW capacity turbine is advantageous for offshore wind farm as this will reduced the number of wind turbine required to achieve the same amount of power generated for the wind farm. However, there is concern as the higher the rated capacity, the rotor diameter will increase accordingly and subsequently the overall height of the wind turbine will increase. This will require a stronger offshore based structure and an increase in cost. However, in 2018 several offshore wind turbines between 3.5 MW and 8.8 MW were installed (IRENA, 2019). In this analysis, Enercon E-126 was selected as this wind turbine has the highest capacity in HOMER.

In addition, the global weighted-average installed costs of offshore wind turbine capital costs have declined over the last 8 years. The 2018 offshore wind turbine capital cost estimated around USD 4,353/kW (IRENA, 2019). As Enercon E-126 has the capacity of 7.5 MW, the capital cost for the wind turbine was set at USD 32,648. The operation and maintenance (O&M) is estimated at 39.7 USD/kWyr which is around 0.005 $/operate hour (U.S. Energy Information Administration (EIA), 2016). This wind turbine has the hub height of 135 m and the cut in wind speed is at 3 m/s which able to lower than 80% of peninsular Malaysia wind speed (Bauer, 2019). Specification of this type of wind turbine is shown below in Table 7 and the power curve is illustrated in Figure 26.

Table 7:Wind turbine specification and properties

Characteristic	Value	Unit
Type	Enercon E-126	
Capacity	7.5	MW
Capital cost	4,350	$/kW
Replacement cost	3,915	$/kW
O&M	0.005	$/operate hour
Hub height	135	m
Lifetime	25	years

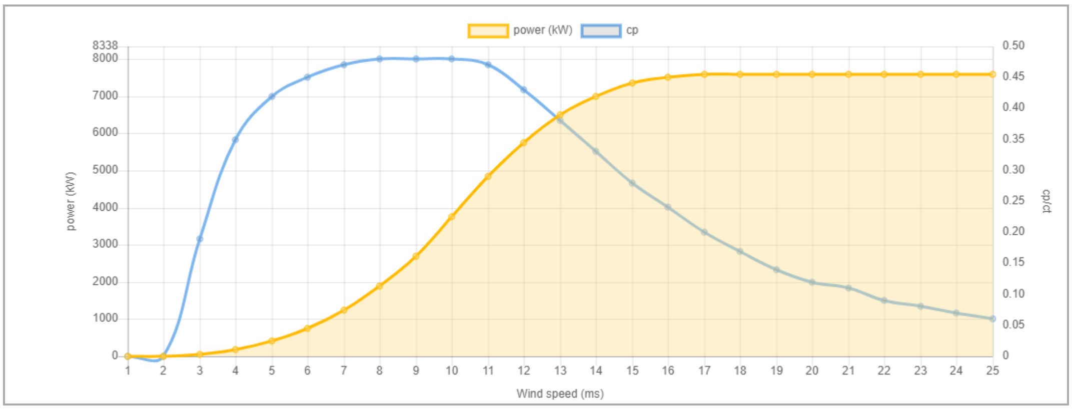


Figure 26: Power curve of Enercon E-126

3.4.3. Solar Resources and Components

a) Solar Resources

Similar to wind speed data, global solar irradiation (GHI) and clearness index from NASA Surface Meteorology and Solar Energy database were utilised in the simulation. The data is an average value over 22 years from July 1983 to June 2005 (HOMER, 2019). The monthly GHI profile is illustrated in Figure 27.

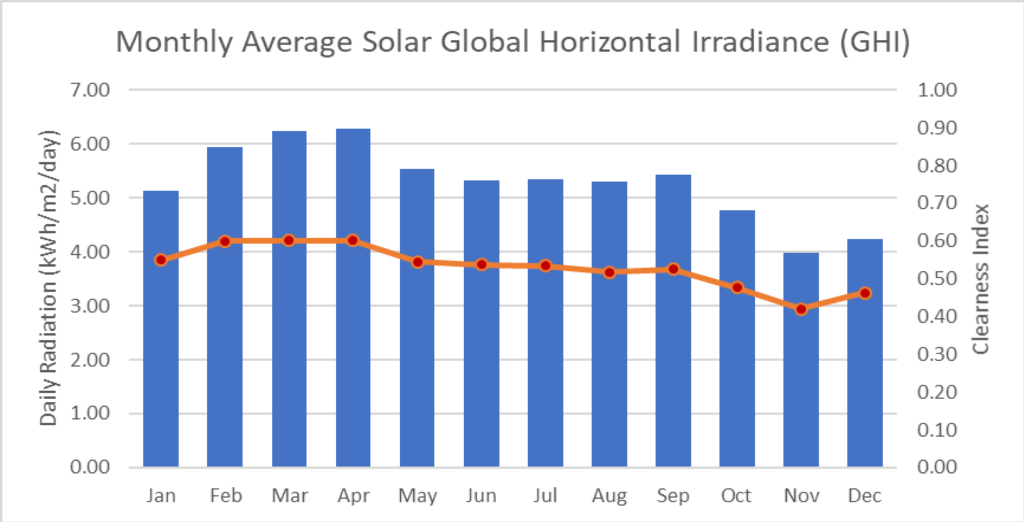


Figure 27: Monthly solar global horizontal irradiation (GHI) in peninsular Malaysia

Clearness index is essential as it is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth (HOMER, 2019). These two data are required to calculate solar panel PV array output. As shown, the trends of GHI and clearness index are similar as a higher radiation indicate clear sky permit more solar radiation to be in contact with solar PV as compared to overcast sky.

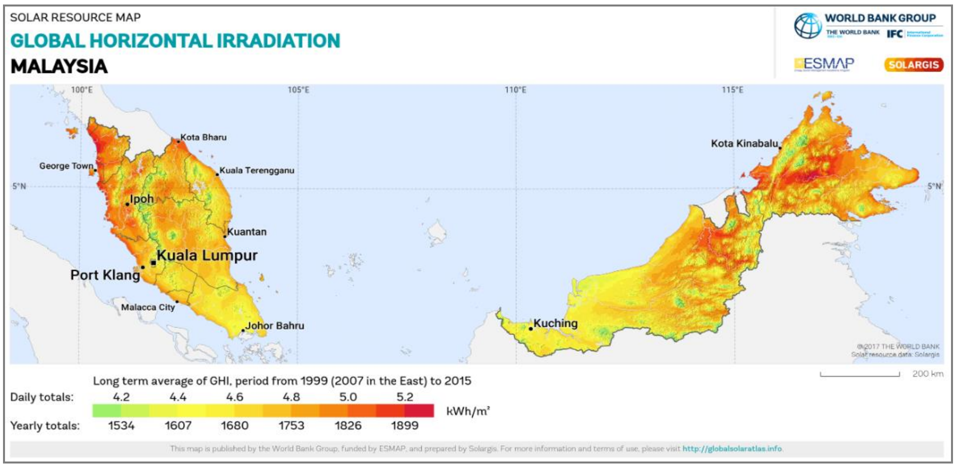


Figure 28: Solar resource map on GHI (Solargis.com, 2017)

The data from HOMER was benchmarked with solar resource map as per Figure 28. It can be seen that the range of the GHI in peninsular Malaysia is between 4.4 $kWh/m^2/day$ and 5.2 $kWh/m^2/day$ which consistent with the data from HOMER. In view of this, the GHI data from HOMER was utilised for the simulation.

b) Solar Energy Component

For this simulation generic flat plate PV panel is selected as the solar PV components. In 2018, the global weighted-average total installed cost for utility-scale solar PV projects was at 2018 USD 1,210 per kW and O&M cost are at USD 23.4 per year (IRENA, 2019). The replacement cost for solar PV is set at 90% from the capital cost. Table 8 below listed out the solar PV specification for this study.

Table 8: Generic flat plate PV specification

Characteristic	Value	Unit
Type	Generic Solar PV	
Capacity	1	kW
Capital cost	1,210	$/kW
Replacement cost	1,089	$/kW
O&M	23.4	$/year
Panel Efficiency	17	%
Lifetime	25	years

3.4.4. Biogas Resources and Components

a) Biomass Resources

As mentioned in Chapter 2, Malaysia produces a high amount of biomass annually and currently there are several small-scale biomass plants in Malaysia. However, most of the biomass in Malaysia is from POME and there is a concern as palm oil is associated is non environmentally friendly plant. However, for this study, POME was used as a sample and it is advisable to study the potential of utilising other high energy biomass to replace POME. In term of area, when palm oil plantation to be replace, certain land area can be used to construct biogas generation plant.

b) Biogas Generation Plant Component

As there are several system configuration and demand profile, the capacity of biogas generation plants was varied to optimize power system. As for the cost analysis input, the global weighted-average of total installed costs for biogas generation plant is around USD 2,100/kW in 2018. IRENA (2019). Meanwhile, the replacement cost is assumed at 90% of the capital cost. The specification for biogas generation plant are tabled below in Table 9.

Table 9: Specification for biogas generation plant

Specification	Value	Unit
Type	Generic Biomass	
Fuel	POME	MW
Capacity	1.0, 1.5	GW
Capital cost	2,100	$/kW
Replacement cost	1,890	$/kW
O&M	0.013	$/operation hour
Efficiency	30	%
Lifetime	25	years
Fuel price	1	$/kg
Fuel resource	39,925	tons/day
Fuel curve slope	2	kg/hour/kW
CO_2 Emission	2	g/kg fuel

3.4.5. Power Storage Technologies

As the renewable resource is inconsistent throughout the year, a power storage is required to ensure that the power supply will be interrupted. This will help to balance the power generation system, and avoid a sudden shutdown. In this study, battery was selected to be further studied. Battery is concept is utilising the reversible chemical reaction to store and release energy.

a) Lead Acid Battery

Lead acid battery is a matured technology and has a low total installed cost. In addition, this battery has a high round trip efficiency between 70% to 90% (IRENA, 2017). On the other hands, lead-acid battery has a poor cycle life and performance is low at high ambient temperature and required thermal management system. In this case, this is not suitable for Malaysia weather.

b) Lithium Ion (Li-ion) Battery

On the other hand, compared to other batteries, Li-ion batteries have high specific energy, high energy and power density (IRENA, 2017). In addition, these batteries have an exceptional round-trip efficiency and relatively long lifespan lifetime and a low self-discharging rate. Based from the comparison made, Li-ion battery was selected for this simulation. In IRENA (2016) report, the estimated capital cost for utility scale application is between USD 200 to USD 1,260/kWh. For this study, the replacement cost is the same as the capital cost. The specification for Li-Ion battery are tabled below in Table 10.

Table 10: Specification for Li-Ion battery

Specification	Value	Unit
Type	Generic 100kWh Li-Ion	
Capacity	100	kWh
Capital cost	20,000	unit
Replacement cost	20,000	$/kW
O&M	1,162	$/year
Efficiency	90	%
Lifetime	15	years

3.4.6. Converter

In this power generation model, converter required as this device helps to converts direct current (DC) to alternative current (AC) and inversely. Batteries and solar PV will be on DC side, while other power generation systems (wind, hydro and etc) will be on AC side, this generation system requires converter connect these two systems. The cost for converter was refer to ABB solar inverter price which is at USD 255 per kW (Solar Experts, 2019). The replacement cost is set at 90% from the capital cost. Table 11 listed the specification of the converter that was used in this study.

Table 11: Specification of converter

Characteristic	Value	Unit
Type	Generic Converter	
Capacity	1	kW
Capital cost	255	$/kW
Replacement cost	230	$/kW
O&M	0	$/year
Efficiency	90	%
Lifetime	15	years

3.5. Project Constrains and Challenges

There are several constraint and assumption that was set to ensure that the model is consistent the result is based on the best available data at the moment. Below is the summary of assumption made in this study.

- **Data availability**: Due to unavailability of the latest demand and weather data, the demand base year is set at 2016 and the weather data is from NASA Surface Meteorology and Solar Energy database.
- **Biomass Source:** assumption that the biomass production of 168 million tonnes was produced annually is applicable until year 2040. In addition, Biomass source will be interchangeable between (agriculture waste and municipal waste)

4. Potential of Renewable Energy Systems

Based from the literature review in Chapter 2, Peninsular Malaysia has an abundant renewable resource inland as well as offshore. As most of the energy system will take at least 5 to 8 years to be constructed and in operation, this study will evaluate the future renewable energy system in Malaysia in 2 phases. The first phase is to evaluate year 2030 incremental electricity demand and the second stage is to evaluate year 2040 incremental electricity demand. As mentioned in Chapter 3, the incremental demand in 2030 has increase up to 30% from year 2016, while in year 2040 the demand has increased approximately up to 60% from 2016 demand. Scenarios for each year were evaluated and analysed in the next section.

4.1. Malaysia Future Electricity Scenarios

As mentioned in previous section, several scenarios were evaluated for year 2030 and 2040. This evaluation is to recommend the optimum option for Peninsular Malaysia future electricity system. Table 12 represent all scenarios that were evaluated.

Table 12: List of scenarios for phase 1 and phase 2 development

Phases	Base Case	100% Renewable Fraction (RF)	Hybrid
		Scenario 1	**Scenario 2**
1 (Year 2030)	**Resource:** Natural Gas Generator (100%)	1.Lowest NPC 2.Lowest CO_2 3.Optimum number of wind turbine and biogas **Resources:** Combination of Biogas Generator, Wind Turbine and/or Solar PV	1.Lowest NPC 2.Half of NGG base capacity 3.Optimum number of wind turbine **Resources:** Combination of NGG, Biogas Generator, Wind Turbine and/or Solar PV
2 (Year 2040)	**Resource:** Natural Gas Generator (100%)	1.Lowest NPC 2.Lowest CO_2 3.Optimum number of wind turbine and Biogas **Resources:** Combination of Biogas Generator, Wind Turbine and/or Solar PV	1.Lowest NPC 2.Half of NGG base capacity 3.Optimum number of wind turbine **Resources:** Combination of NGG, Biogas Generator, Wind Turbine and/or Solar PV

Optimization was carried out by varying renewable power system, design capacity of NGC, and type of energy storage for each scenario. In addition, for one of the hybrid cases, the NGG design capacity was set to be half of the base case. This is to check the percentage of RF factor with the lowest NPC.

All the scenarios will be evaluated based on the Net Present Cost (NPC), stability, capacity shortage (%/year), emission level and practicality. The next chapter will discuss the scenario system architecture and the results including financial as well as the technical aspects.

5. Scenario Results and Discussions

Once the project inputs were established, all the scenarios were simulated in HOMER and the result were tabled out and compared. The results will be discussed in the next section.

5.1. Phase 1 (Year 2030)

As explained in section 4.1, the Phase 1 evaluation will be focusing on 2030 renewable energy power system to address the incremental power demand. The discussion will be in 3 section as to address base case, 100% renewable fraction and hybrid options.

5.1.1. 2030 Base Case Model

The 2030 base case model result will be the based data to compare with all the scenario for year 2030. As mentioned, the total incremental power demand for year 2030 is 36,735 GWh, an average of 100.73 GWh/day which will required approximately 10GW power generation system. The base case for phase 1 is a non-renewable system, that consist of one natural gas generation (NGG) system with 10 GW capacity. Figure 29 represented the system architecture for the base case.

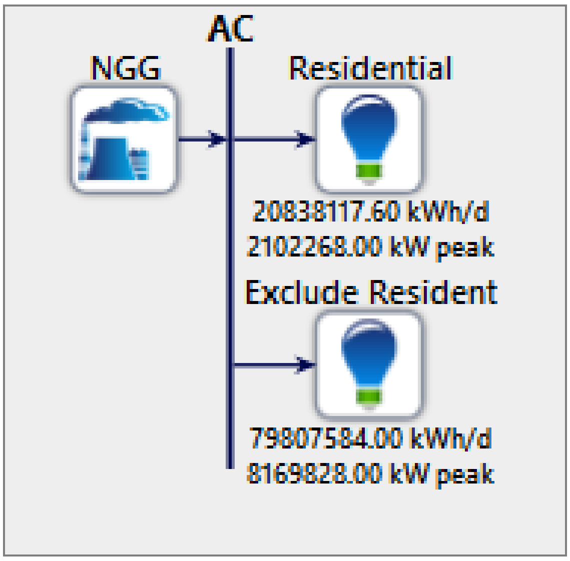


Figure 29: System architecture for base case 2030

a) 2030 Base Model Results

The result for this model has been tabled out in Table 13 below.

Table 13: The results of base model

Characteristic	Value	Unit
Renewable Fraction	0	(%)
CO_2 emissions	29,176,932,161	(kg/year)
NPC	78.07	USD Billion
Initial capital cost	11.68	USD Billion
Capacity shortage	0.07	(%/year)
Excess electricity	0.736	(%/year)

b) 2030 Base Model Discussion

As approximately 50% of peninsular Malaysia current power generation system is from natural gas, NGG was selected to be the base case. As to meet the required demand, 10 GWh NGG plant was model as this will capacity will be resulted in annual capacity shortage of less than 0.1%. Referring to Figure 30, the peak unmet electricity load for year 2030 is slightly exceed the capacity by 60kW, this will not be a major concern as this only happen for an hour and this system will be connected to the existing electricity grid system that will be able to stabilised a sudden peak.

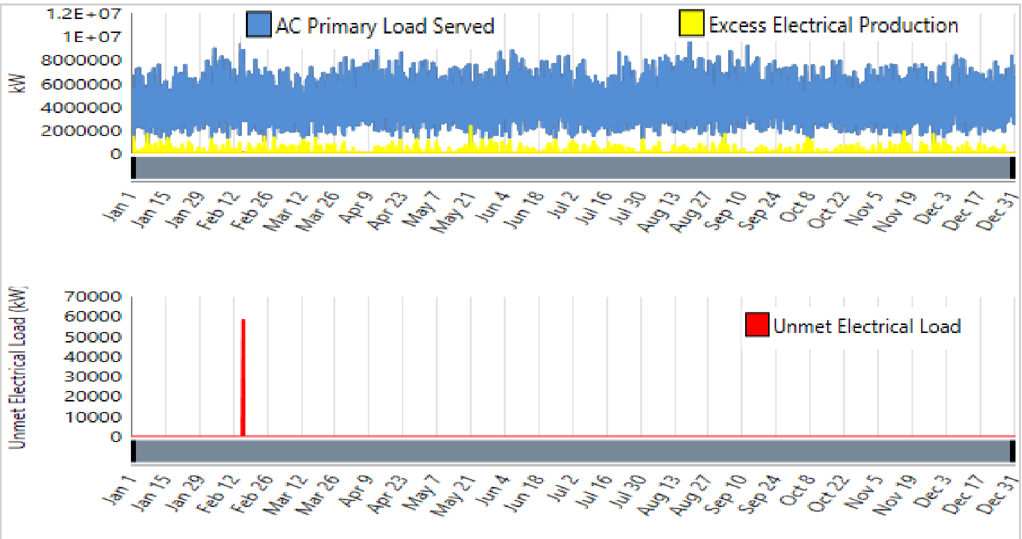


Figure 30: Forecasted electricity demand for year 2030

As NGG is a dispatchable system, this system is flexible and able to adjust the power generation to meet the changes in demands. Due to this, the excess electricity and unmet electricity can be kept at the minimum which is at 0.74% and 0.07% per year respectively. In addition, the initial cost of USD 11.7 billion, for this system are reasonable and there will be minor investment required for infrastructure as existing gas network in peninsular Malaysia is well established.

On the other hands, this power generation system produces a significant amount of CO_2 as the main energy source is natural gas. In this model, the NGG plant produces 29.18 billion kg/year of CO2 emissions. This huge emission will deter the project as several environmental impact assessment needs to be conducted and the mitigation plan need to be in place prior the start of the project. In addition, this system will have a long-term effect on global warming.

5.1.2. 2030 Scenario 1: 100% Renewable Fraction

In this scenario, NGG was excluded from the simulation as to investigate the possibility of 100% generation from renewable energy system. The system architecture for this scenario consist of wind turbine, solar PV and biogas generator. In addition, an energy storage system and converter included as to manage the inconsistencies of power generation from both solar PV as well as wind turbines. Figure 31 illustrated the system architecture for 100% RF.

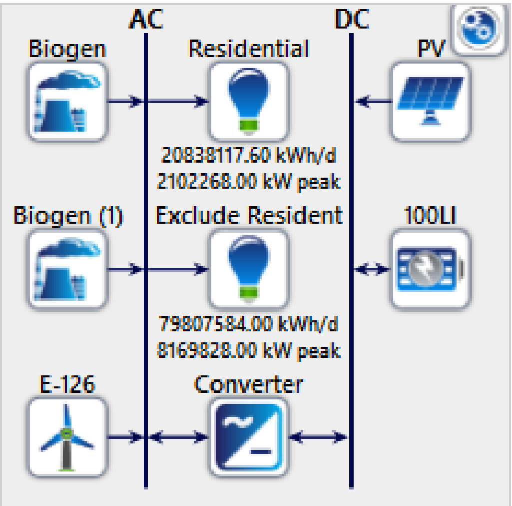


Figure 31: System architecture for scenario 1 for 2030

Three cases were simulated for this scenario. Table 14 listed the component details for each case in this scenario.

Table 14: System Components Details (Scenario 1 for 2030)

Components (2030)	**Quantity**		
	Case 1	**Case 2**	**Case 3**
	Lowest NPC	**Lowest CO_2**	**Optimum**
Biogas (1.5 GW)	2	0	1
Wind Turbine (7.5 MW)	39,712	10,770	435
Solar PV (1 kW)	22,526,557	23,861,682	56,308,767
Li-ion Battery (100 kWh)	639,381	1,702,441	1,901,107
Converter (1 kW)	6,001,241	10,773,969	10,629,613

a) 2030 Scenario 1 Results

The result for this model has been tabled out in Table 15 and Table 16 below.

Table 15: Production breakdown for each generation system (Scenario 1 for 2030)

Components (2030)	**Case 1 (Lowest NPC)**		**Case 2 Lowest CO_2**		**Case 3 (Optimum)**	
	Production (%/year)	**Capacity Factor (%)**	**Production (%/year)**	**Capacity Factor (%)**	**Production (%/year)**	**Capacity Factor (%)**
Biogas (1.5 GW)	0.31	4.172	0	*n/a*	0.03	0.212
Unit 1	*0.24*	*3.23*	*n/a*	*n/a*	*0.03*	*0.212*
Unit 2	*0.07*	*0.942*	*n/a*	*n/a*	*n/a*	*n/a*
Wind Turbine (7.5 MW)	80	5.38	51	5.38	1.75	5.38
Solar PV (1 kW)	19.7	17.7	49	17.7	98.2	17.7

Table 16: Result for each generation system (Scenario 1 for 2030)

Characteristic (2030)	**Value**				**Unit**
	Base Case	**Case 1** Lowest NPC	**Case 2** Lowest CO_2	**Case 3** Optimum Case	
Renewable Fraction	0	100	100	100	(%)
CO_2 emissions	29,176,932	303.91	0	15.2	(Tonne/ year)
% CO2 reduction	-	*99.99*	*100*	*99.99*	*%*
NPC	78.07	63.40	99.53	156.10	USD Billion
Initial capital cost	11.68	47.75	65.72	111.87	USD Billion
**IRR against Base*		*13.2*	*3.2*	*n/a*	*%*
Capacity shortage	0.07	0.099	0.099	0.099	(%/year)
Excess electricity	0.736	78.4	48.2	54.6	(%/year)

**Internal Rate of Return (IRR)*

Typical days in dry season (22nd May) and in rainy season (28th December) are selected to demonstrate the power generation pattern for each scenario.

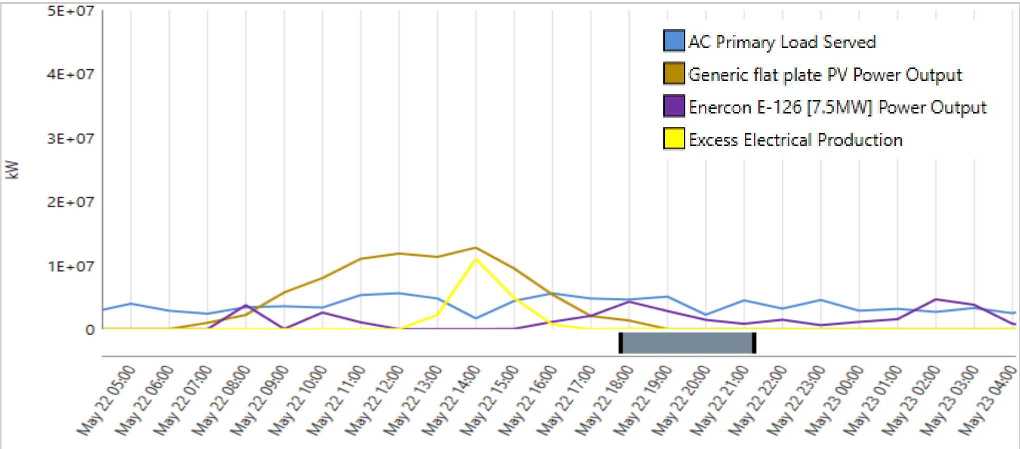


Figure 32: Power systems in dry season for Case 1

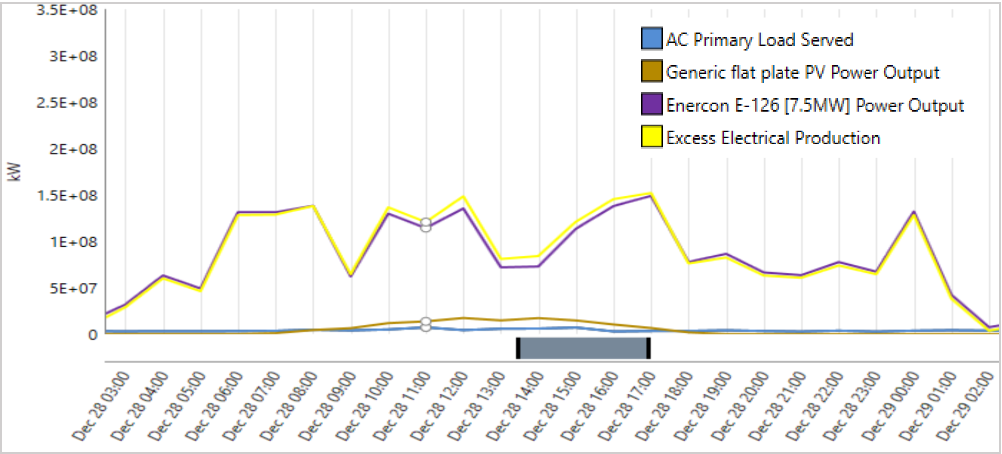


Figure 33: Power systems in rainy season for Case 1 (Scenario 1 2030)

b) 2030 Scenario 1 Discussion

Based from the result on three cases for Scenario 1, economically, Case 1 represent the best option as it has the lowest NPC value of USD 63.4 billion and the CO2% reduction is approximately at 99.99%. However, in term of excess electricity, case 1 has the highest excess electricity mainly from the wind turbine. Referring to Figure 33, it can be seen that the power generated during the rainy season is significantly high which reach up to 1.5 GW while the demand at that particular time is at 7 GW. Due to the high number of wind turbine (39,712 unit), the power generated increase accordingly as the wind blows strongly permitting wind turbines to produce higher electricity output. Meanwhile, during the dry season, the power generated by the wind turbine is lower than the power generated by the solar PV. This is illustrated in Figure 32 at section 5.1.2a.

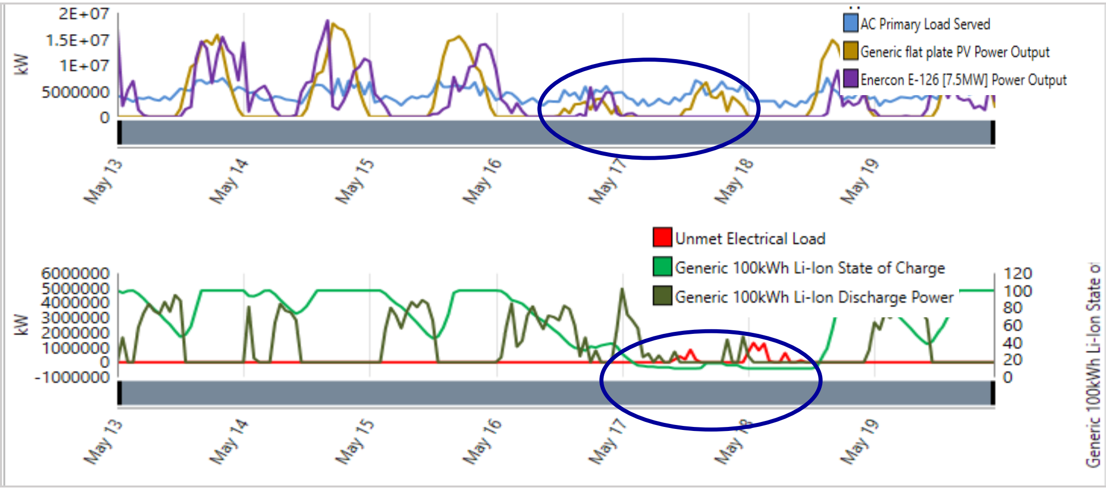


Figure 34: Unmet electrical load for Case 1 (Scenario 1 2030)

In addition, the stress point for Case 1 is on 17th May until 18th of May where the power generated is insufficient to meet the demand by 1.3 MW as shown in Figure 34. In those two days, both solar and wind resource are lower and the battery has been discharged to the maximum. Even though the total excess electricity is at 78% per year, the power is insufficient during the dry season as both solar PV and wind turbine unable to generate sufficient energy during this season. This is expected as renewable energy is known for this unpredictability. However, this electricity deficient might be able to be address by installing additional solar PV and batteries. Nevertheless, as mentioned previously, this system will be connected to the existing peninsular electricity grid. This will enable the overall system to balance the supply and demand. Biogas generator output is not included in the Figure 34 for comparison as the biogas generator produce a constant electricity monthly.

On the other hands, in term of technical feasibility, Case 3 represent a better option. Based from Table 14, the number of wind turbines required to be installed in both Case 1 and Case 2 is between 10,000 to 40,000 unit which is massive. The largest onshore wind farm is Gansu Wind Farm at China that currently in operation for 8 GW and targeting to generate 20 GW with 7,000 wind turbines by 2020 (Power Technology | Energy News and Market Analysis, 2019). Meanwhile, the largest offshore wind farm is Walney Extension which is located in England. This wind farm has a total capacity of 659 MW and consist of 87 unit of 8 MW wind turbines that require 145 km^2 area for the wind farm (Walneyextension.co.uk, 2017). In view of this, Case 3 model has constraint the number of wind turbines to 435 unit which is five times of the turbines in Walney Extension.

In addition, the biogas generator was also limited to one unit of 1.5 GW generation capacity. Referring to Bester Energy (2017), the largest biomass plant (330 acre) is Ironbridge in SevernGorge, United Kingdom with a capacity of 740MW which was closed down in 2015 (Bester.energy, 2017). Based from this information, Case 3 model has constraint the Biogas generator capacity to 1.5 GW which is twice the Ironbridge biomass plant capacity and limited to one unit as this plant will required a large land area to be constructed. This is anticipating that by 2030, the offshore wind farm technology as well as biomass generator has improved significantly and this size of both wind farm and biomass plant is technically feasible.

The reduction in number of wind turbines, resulted in an increase of Solar PV unit to 56.3 million (1 kW per unit) which contributes approximately 98% of electricity production per year. This is more than twice the solar PV number in Case 1 and 2. The optimum solar PV capacity for a terraced house in peninsular Malaysia is around 4.4kW which associated with 25.5m^2 area on the roof space (seda.gov.my, 2019). Based from this, it is feasible to install 56.3 unit of solar PV to the houses and office buildings. Even though Case 3 is technically feasible, this case has the highest NPC value of USD 156.1 billion which is twice the NPC value of the base case.

The strain point for Case 3 is in November where the power generated is insufficient to meet the demand by 2.15MW. This is illustrated in Figure 35.

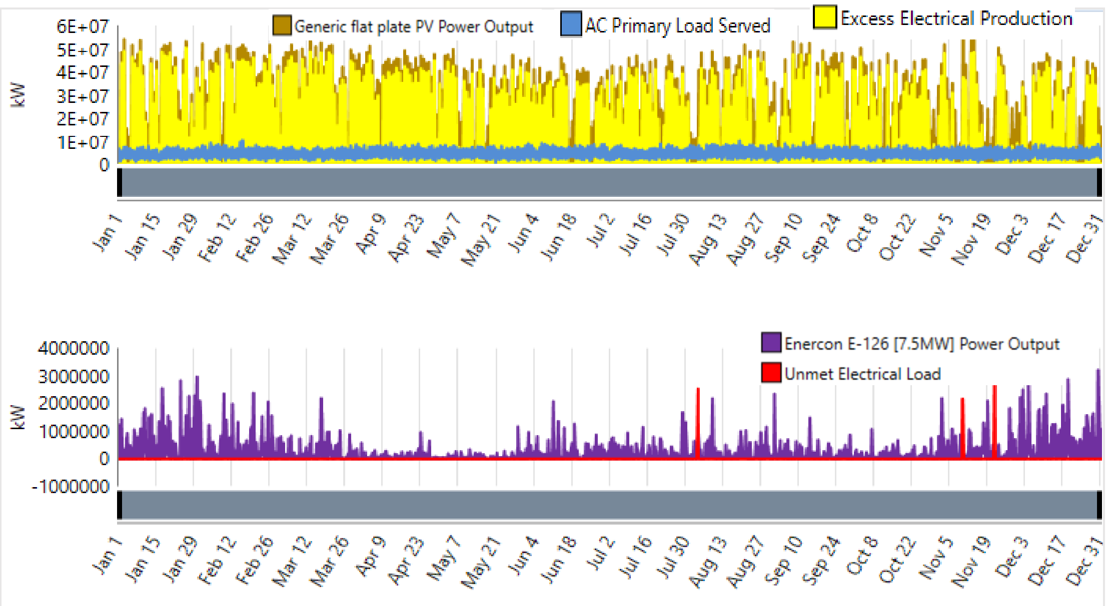


Figure 35: Electrical load for Case 3 (Scenario 1 2030)

Even though the total excess electricity is around 55% per year, the power is insufficient during this time as the number of wind turbines has been reduced for this case. The reason behind this shortage is shown in Figure 36. The electricity shortage occurs between 0500 hours until 0700 hours on 10th November where there the power from wind and solar are unavailable and both biogas generator as well as battery has been fully discharged to meet the demand prior to 0500am. Once the sun starts to rise, it can be seen that the power from the solar PV able to address the electricity shortage and the batteries have started to charge back up.

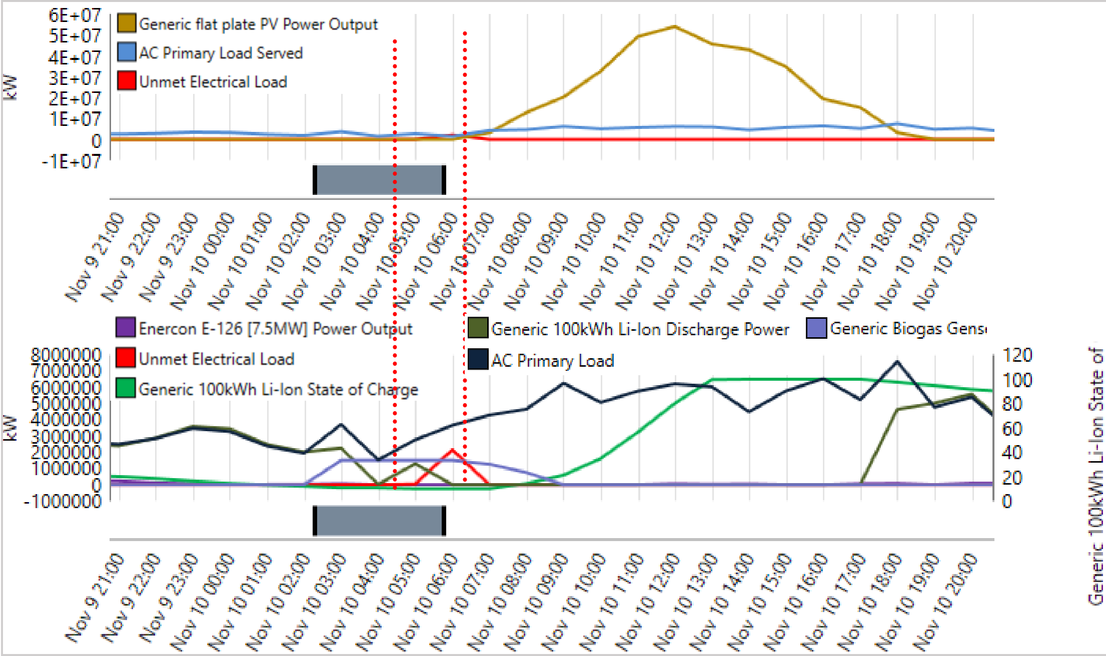


Figure 36: Unmet electrical load for Case 3 (Scenario 1 2030)

5.1.3. 2030 Scenario 2: Hybrid Model

The aim of Scenario 2 is to optimise the number of wind turbines and solar PV by combining a non-renewable power generation source. In this scenario, the capacity of NGG was varied to analyse the impact to the overall generation system. The configuration for Scenario 2 is similar to Scenario 1 with an additional NGG as shown below in Figure 37.

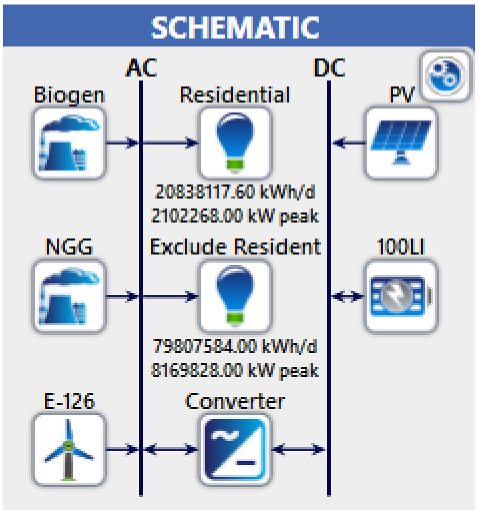


Figure 37: System architecture for scenario 2 for 2030

Three cases were simulated for this scenario. Table 17 listed the component details for each case in this scenario.

Table 17: System components details (Scenario 2 for 2030)

Components (2030)	Quantity		
	Case 1	Case 2	Case 3
	Lowest NPC	Half NGG	Optimum
NGG	1	1	1
(10GW)	1	n/a	1
(5GW)	n/a	1	n/a
Biogas (1.5 GW)	1	1	1
Wind Turbine (7.5 MW)	39,834	435	430
Solar PV (1 kW)	0	23,736,615	11,034,338
Li-ion Battery (100 kWh)	151,745	496,423	110,431
Converter (1 kW)	3,321,322	9,614,251	6,485,506

a) 2030 Scenario 2 Results

The result for this model has been tabled out in Table 18 and Table 19 below.

Table 18: Production breakdown for each generation system (Scenario 2 for 2030)

Components (2030)	Case 1 (Lowest NPC)		Case 2 Lowest CO_2		Case 3 (Optimum)	
	Production (%/year)	Capacity Factor (%)	Production (%/year)	Capacity Factor (%)	Production (%/year)	Capacity Factor (%)
NGG	5.05	8.72	10.5	10.5	50.6	22.9
Biogas (1.5 GW)	0.97	0.97	1.5	4.96	2.43	7.34
Wind Turbine (7.5 MW)	94	5.38	3.57	5.38	3.87	5.38
Solar PV (1 kW)	n/a	17.7	84.4	17.7	43.1	17.7

Table 19: Result for each case (Scenario 2 for 2030)

Characteristic (2030)	Value				Unit
	Base Case	Case 1 Lowest NPC	Case 2 Half NGG	Case 3 Optimum	
Renewable Fraction	0	78.8	87.5	45.4	(%)
CO_2 emissions	29,176,932	6,539,190	3,439,478	17,351,049	(Tonne/ year)
% CO2 reduction	-	*78*	*88*	*41*	*%*
NPC	78.07	34.62	77.5	78.15	USD Billion
Initial capital cost	11.68	18.57	53.90	31.82	USD Billion
IRR against Base		60.8	8.9	5.9	%
Capacity shortage	0.07	0	0.099	0	(%/year)
Excess electricity	0.736	75.2	8.66	4.62	(%/year)

Typical days in dry season (22nd May) and in rainy season (28th December) are selected to show the power generation pattern for each scenario.

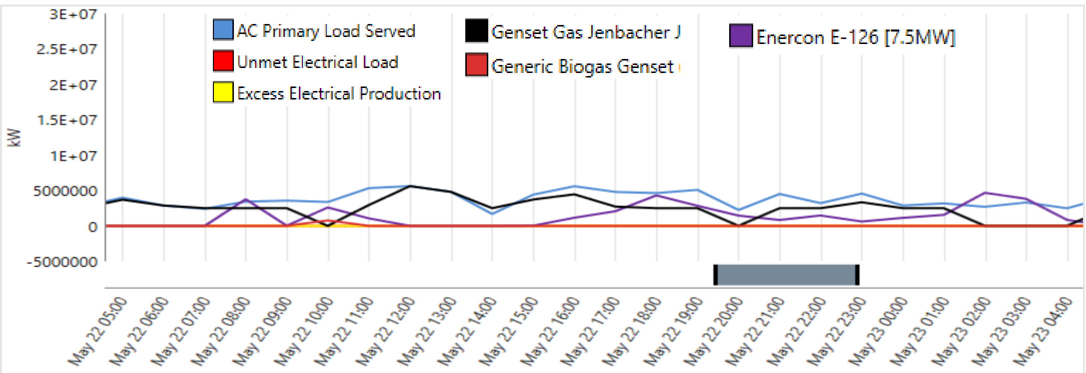


Figure 38: Power systems in dry season for Case 1 (Scenario 2 2030)

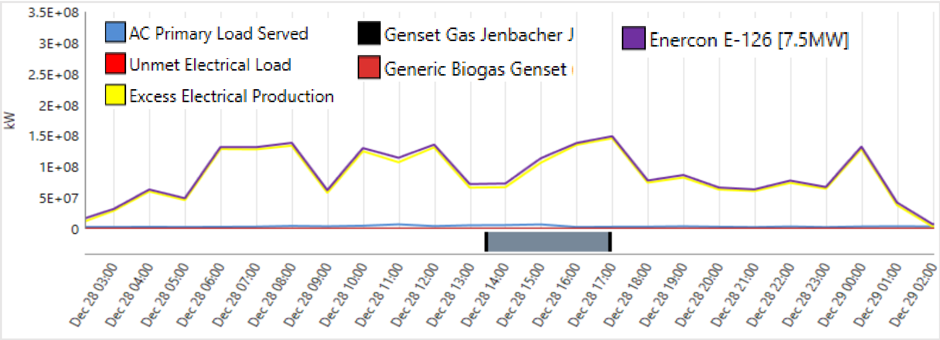


Figure 39: Power Systems in rainy season for Case 1 (Scenario 2 2030)

b) 2030 Scenario 2 Discussion

Based from the result on three cases for Scenario 2, economically, Case 1 represent the best option as it has the lowest NPC value of USD 34.6 billion and the CO2% reduction is approximately at 78%. The renewable fraction for this case is nearly 79% mainly contributed by wind turbine. However, in term of excess electricity, Case 1 has the highest excess electricity of 75.2% largely from the wind turbine that contribute up to 94% electricity production per year. Referring to Figure 39, it can be seen that the power generated during the rainy season is significantly high which reach up to 1.5×10^8 kW while the demand at that particular time is only at 8 GW. This is similar to Scenario 1, Case 1 trends. The power generated increase accordingly as the wind blows strongly permitting the 39,834 unit of wind turbines to produce higher electricity output. Meanwhile, during the dry season, the power generated by the wind turbine is lower and the NGG generator needs to pick up the load demand as illustrated in Figure 38.

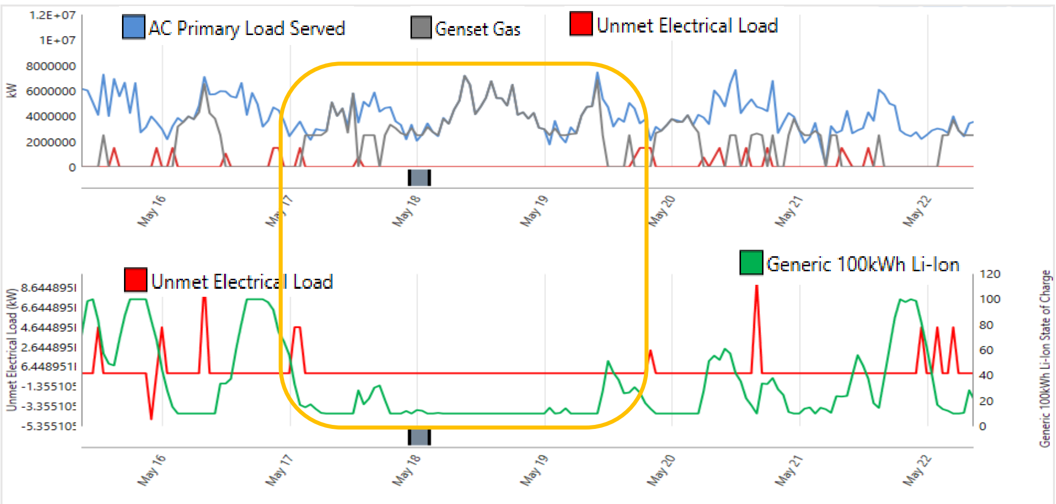


Figure 40: Unmet electrical load for Case 1 (Scenario 2 2030)

As highlighted in Figure 40, it can be seen that the unmet electrical load less than 10kW which is insignificant to the overall system. This is mainly due to the fact that 10GW NGG is in operation to match the electricity demand. Since NGG is a dispatchable system, NGG will be in operation during a higher demand to make up the shortage and decrease the power generation when the wind turbine is able to produce electricity to match the demand. In addition, NGG will start to ramp up it production when the batteries has been fully discharge. This setup helps to ensure that the system prioritise the power genrated from renewable before switching to non-renewable.

On the other hands, in term of technical feasibility, both Case 2 (87% RF) and 3 (45% RF) represent a better option. As the wind turbines is cap at 435 unit and the biogas generator is set at 1 unit of 1.5 GW, both options seem viable. In term of CO_2 percentage reduction, case 2 provide a higher value of 88% reduction compare to case 3 of 41% reduction. This is due to the size of NGG that was set to be at 5GW for case while 10GW for Case 3. In addition, in case 2, only 10% production of the year is from NGG while for case 3, 51% of the electricity production is from NGG. In both cases, the electricity capacity shortage is minimal which is less than 1% per year while the excess electricity is at 7% for Case 2 wile 5% for case 3. In term of NPC value, Case 2 has a slightly lower NPC of USD 77.5 Billion while Case 3 is at USD 78.2 Billion. In view of this, the next deliberation will be focusing on Case 2.

As mentioned in Scenario 1, the reduction in number of wind turbines in Case 2, resulted in an increase of Solar PV unit to 23.6 million (1kW per unit) which contributes approximately 84% of electricity production per year. As the number of solar PV in this case is half of the number solar PV in Scenario 1, Case 3, it is feasible to install 23.6 unit of solar PV to the houses and office buildings. It is estimated to be 5 million houses and buildings that needs to install solar PV to meet this demand.

The strain point for Case 2 is in November where the power generated is insufficient to meet the demand by 510MW. This is illustrated in Figure 41.

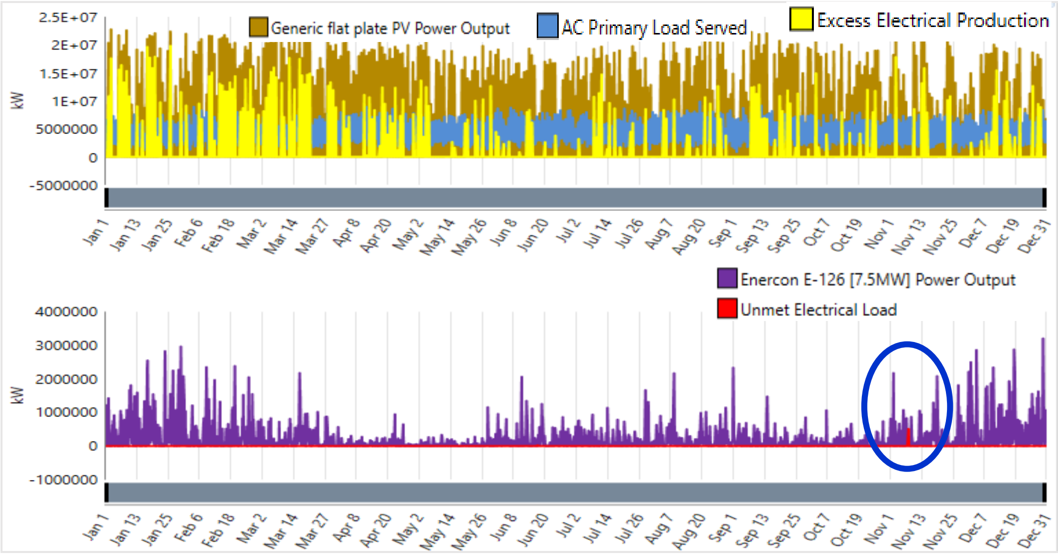


Figure 41: Electrical load for Case 2 (Scenario 2 2030)

The total excess electricity is around 7% per year, the power is insufficient during this time. As shown in Figure 42, the electricity shortage occurs between 1000 hours until 1200 hours on 8th November where there the power from wind and solar are unavailable and both biogas generator as well as NGG is operating at the highest capacity. The batteries have been fully discharged to meet the demand prior to 0700 hours. The power generated from the solar PV start to pick up at it reach 1200 hours in the afternoon. This help to dissipate the electricity shortage.

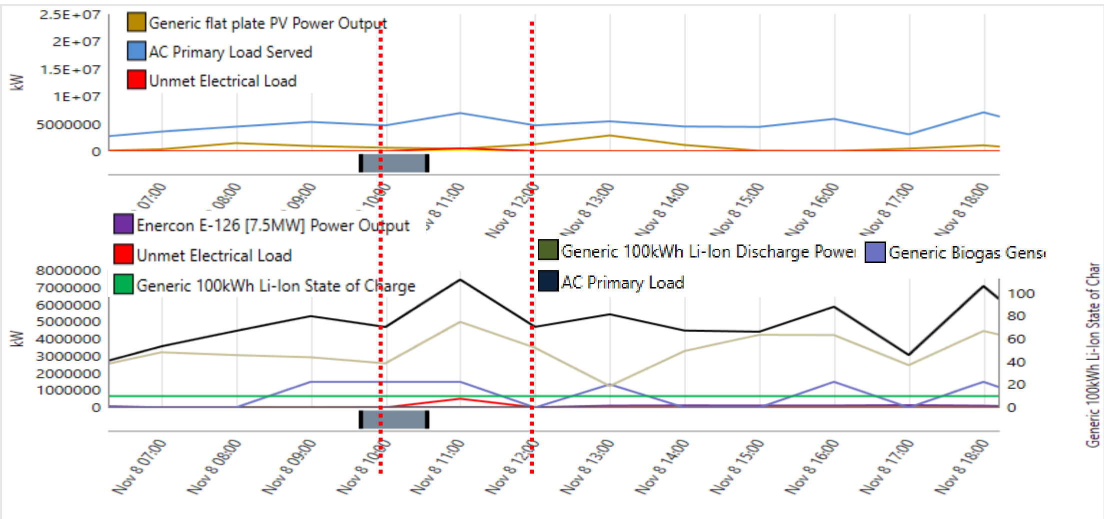


Figure 42: Unmet electrical load for Case 2 (Scenario 2 2030)

5.1.4. Summary for Phase 1

In summary, for Phase 1 future energy system in peninsular Malaysia, Scenario 2, Case 1, represent the lowest NPC value of USD 34.62 Billion. However, due to the technical feasibility of the system, Scenario 2, Case 2 will be the best option to proceed with the future renewable system. Hybrid Case 2 has the second highest RF value of 87.5% and the highest CO_2 percentage reduction of 88% as compare to the other hybrid cases. In term of NPC, hybrid Case 2 has double the hybrid Case 1 value however, hybrid Case 2 NPC of USD 77.5 billion is lower than the base case which is USD 78.1 billion. In conclusion, hybrid Case 2 the is recommended option for phase 1 energy development.

5.2. Phase 2 (Year 2040)

5.2.1. 2040 Base case

The 2040 base case model result will be the based data to compare with all the scenario for year 2040. As mentioned, the total incremental power demand for year 2040 is 69,923 GWh, an average of 191.72GWh/day which will required approximately 17GW power generation system. The base case for phase 1 is a non-renewable system, that consist of one natural gas generation (NGG) system with 17 GW capacity. Figure 43 represented the base case system architecture.

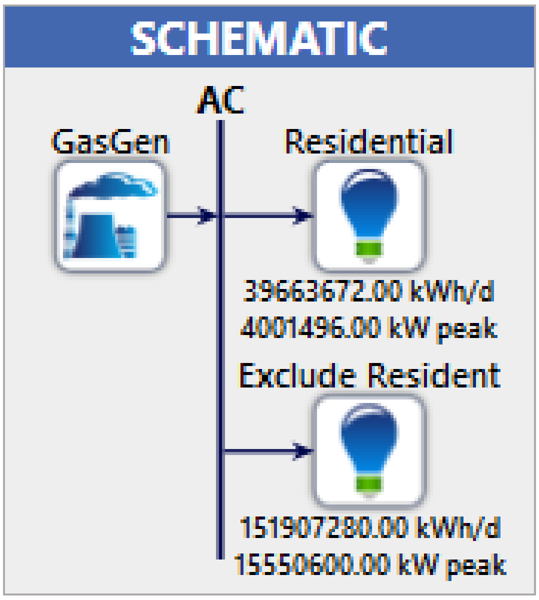


Figure 43: System architecture for base case 2040

a) 2040 Base Case Model Results

The result for this model has been tabled out in Table 20 below.

Table 20: Results of base model (2040)

Characteristic	Value	Unit
Renewable Fraction	0	(%)
CO_2 emissions	53,659,487,876	(kg/year)
NPC	138.94	USD Billion
Initial capital cost	19.72	USD Billion
Capacity shortage	0.046	(%/year)
Excess electricity	0.35	(%/year)

b) 2040 Base Case Model Discussion

As to meet the required demand in year 2040, 17 GWh NGG plant was model as this capacity will be resulted in annual capacity shortage of less than 0.1%. Referring to Figure 44, the peak unmet demand for year 2040 is slightly exceed the capacity by 2.1 MW, this will not be a major concern as this only happen for an hour at 11:00 hours on 16th February and this system will be connected to the existing electricity grid system. This grid connection will be able to stabilised a sudden peak in demand.

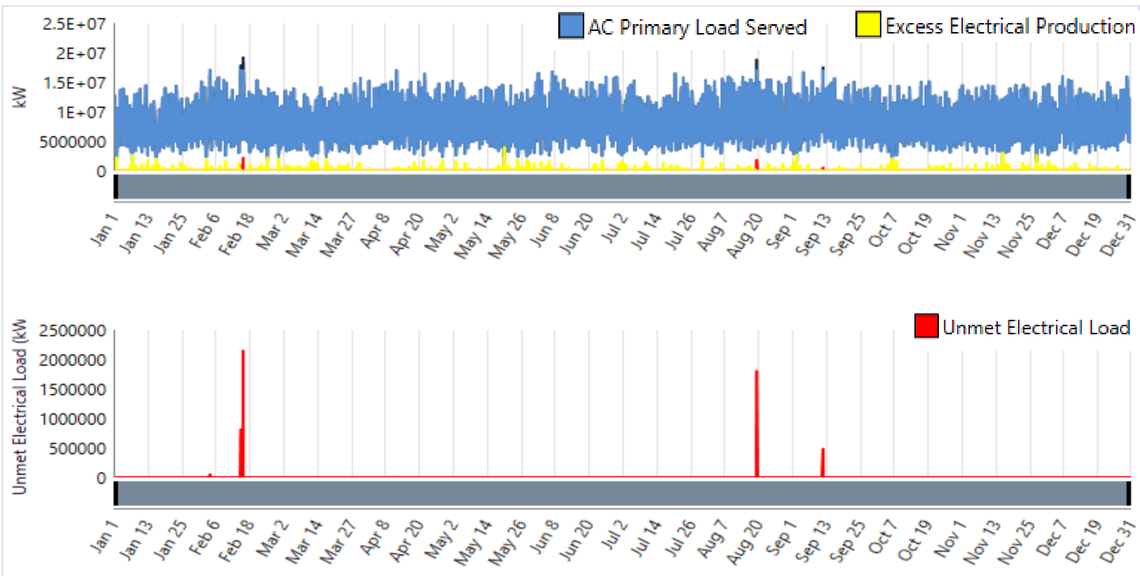


Figure 44: Forecasted electricity demand for year 2040

Similar to phase 1, NGG generation system is flexible and able to adjust the power generation to meet the changes in demands. This led to minimal excess electricity and capacity shortage is at 0.35% and 0.05% per year respectively. In addition, the system required an initial cost of USD 19.7 billion and minor investment required for infrastructure. However, NGG system produces a significant amount of CO_2 as the main fuel source is natural gas. The base case model produces 53.7 billion kg/year of CO2 emissions. This huge emission will dissuade public acceptance and subsequently impact the project timeline.

5.2.2. 2040 Scenario 1: 100% Renewable Fraction

Similar to Scenario 1 in phase 1, NGG was excluded from the simulation as to investigate the possibility of 100% generation from renewable energy system. The system architecture for this scenario consist of wind turbine, solar PV and biogas generator. In addition, an energy storage system and converter are included to manage the inconsistencies of power generation from both solar PV and wind turbines. Figure 45 illustrated the system architecture for 100% RF.

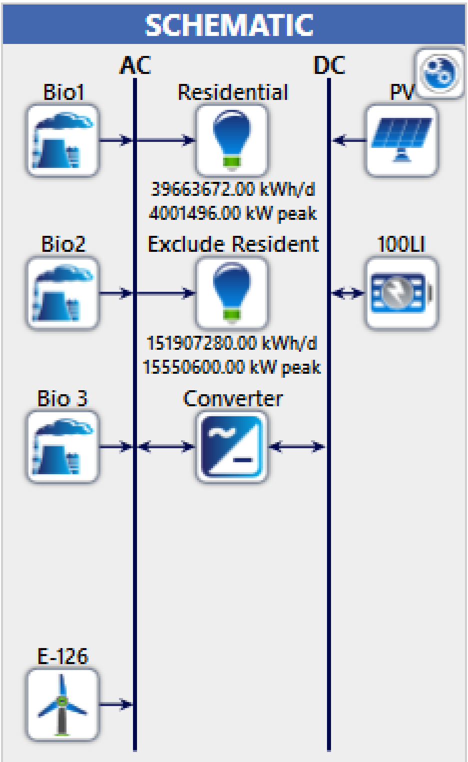


Figure 45: System architecture for scenario 1 for 2040

Three cases were simulated for this scenario. Table 21 listed the component details for each case in this scenario.

Table 21: System components details (Scenario 1 for 2040)

Components (2040)	**Quantity**		
	Case 1	**Case 2**	**Case 3**
	Lowest NPC	**Lowest CO_2**	**Optimum**
Biogas (1.5 GW)	3	0	1
Wind Turbine (7.5 MW)	74,477	75,430	869
Solar PV (1 kW)	50,000,000	50,787,430	167,350,457
Li-ion Battery (100 kWh)	1,549,771	2,507,728	2,099,774
Converter (1 kW)	16,007,187	21,206,028	18,886,706

a) 2040 Scenario 1 Results

The result for this model has been tabled out in Table 22 and Table 23 below.

Table 22: Production breakdown for each generation system (Scenario 1 for 2040)

Components (2040)	**Case 1 (Lowest NPC)**		**Case 2 Lowest CO_2**		**Case 3 (Optimum)**	
	Production (%/year)	**Capacity Factor (%)**	**Production (%/year)**	**Capacity Factor (%)**	**Production (%/year)**	**Capacity Factor (%)**
Biogas (1.5 GW)	0.042	8.72	-	-	0.01	0.257
Unit 1	*0.017*	0.46	*n/a*	*n/a*	*0.01*	0.257
Unit 2	*0.014*	0.353	*n/a*	*n/a*	*n/a*	*n/a*
Unit 3	*0.011*	0.287	*n/a*	*n/a*	*n/a*	*n/a*
Wind Turbine (7.5 MW)	77.4	5.38	77.4	5.38	1.18	5.38
Solar PV (1 kW)	22.5	17.7	22.6	17.7	98.8	17.7

Table 23: Result for each case (Scenario 1 for 2040)

Characteristic (2040)	**Value**				**Unit**
	Base Case	**Case 1**	**Case 2**	**Case 3**	
		Lowest NPC	**Lowest CO_2**	**Optimum Case**	
Renewable Fraction	0	100	100	100	(%)
CO_2 emissions	53,659,487	78.94	0	18.5	(Tonne/ year)
% CO2 reduction	-	*~100*	*100*	*~100*	*%*
NPC	138.94	141.71	171.01	325.94	USD Billion
Initial capital cost	19.72	104.90	117.343	252.31	USD Billion
**IRR against Base*	-	*8.3*	*4.3*	*n/a*	*%*
Capacity shortage	0.046	0.1	0.1	0.099	(%/year)
Excess electricity	0.35	78.8	79.1	70.8	(%/year)

**Internal Rate of Return (IRR)*

Typical days in dry season (22nd May) and in rainy season (28th December) are selected to demonstrate the power generation pattern for each scenario.

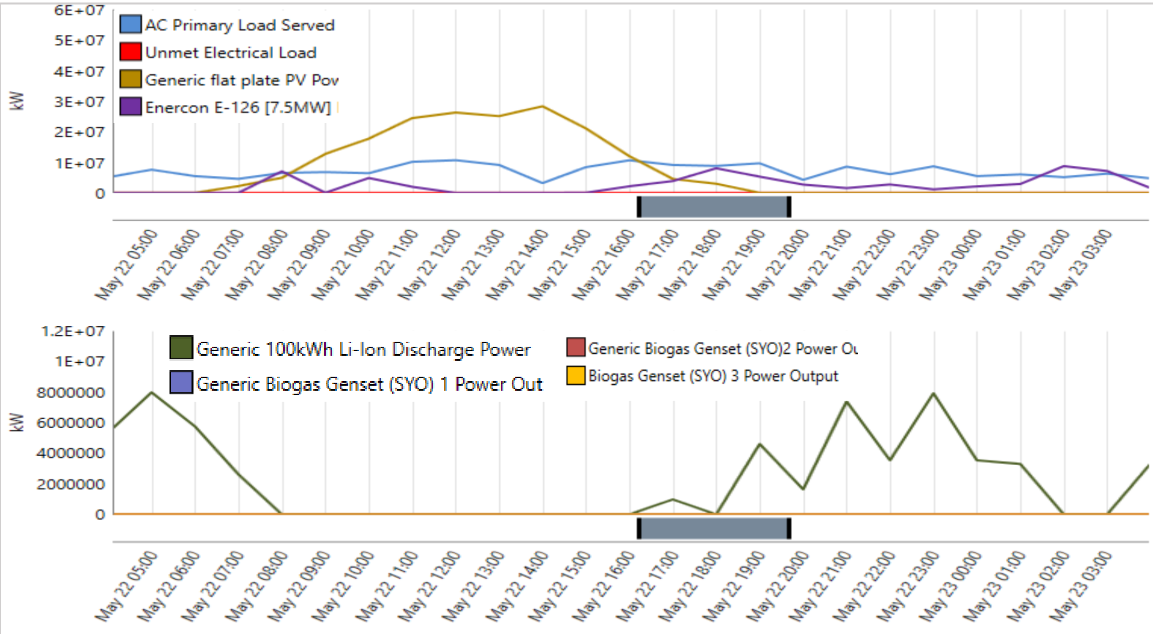


Figure 46: Power systems in dry season for Case 1 (Scenario 1 2040)

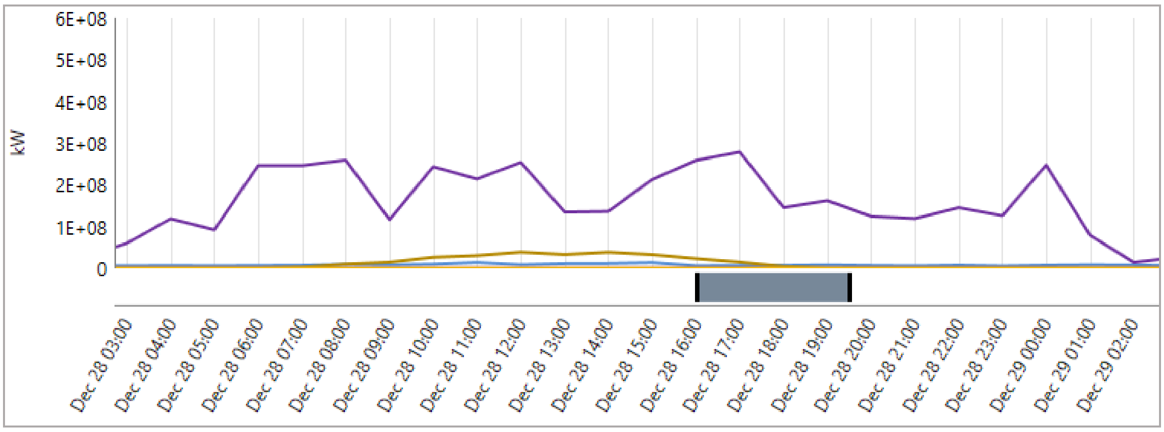


Figure 47: Power systems in rainy season for Case 1 (Scenario 1 2040)

b) 2040 Scenario 1 Discussion

Similar to phase 1, economically, Case 1 represent the best option as it has the lowest NPC value of USD 1421.71 billion and the CO2% reduction is approximately at 99.99%. However, in term of excess electricity, Case 1 has the highest excess electricity largely from wind turbine that contributed up to 77% production per year. Referring to Figure 47, the power generated by wind turbine during one of the days in rainy season is significantly high up to 253 GW at 0800 hours while the demand at that particular time is at 8GW. Due to the high number of wind turbine (74,477 unit) which is twice the number in phase 1, the power generated increase accordingly. Meanwhile, in one of the days during dry season, wind turbine generated power lower than solar PV. As mentioned in section 3, the wind speed during dry season is less than 3 m/s for two months (April and May). This significantly impacted the power generation output from wind turbine. However, power generated from solar PV and power stored in the batteries managed to handle this demand without the need to operate any of the biogas generator. This is illustrated in Figure 46.

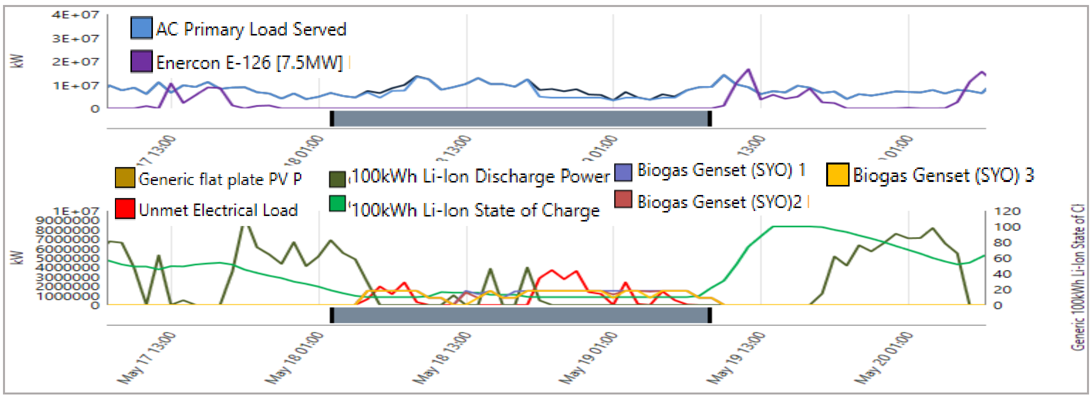


Figure 48:Unmet electrical load for Case 1 (Scenario 1 2040)

The stress point for Case 1 is on 18th May until 19th of May where the power generated is insufficient to meet the demand by 3.7 GW as shown in Figure 48. In those two days, both solar and wind resource are lower and the battery has been discharged to the maximum. Even though the three 1.5 GW biogas generator has also generated power at the particular time it is still insufficient to carter the demand. For this case, the total excess electricity is at 79% per year but that power was generated during the rainy season where most of the wind turbine will be in operation as the wind speed is constantly higher than 3 m/s. This is expected as renewable energy is known for this unpredictability and this electricity deficient might be able to be address by installing additional solar PV, batteries or through the existing peninsular electricity grid. This will enable the overall system to balance the supply and demand.

In term of technical feasibility, similar to phase 1, Case 3 represent a better option. Based from Table 21, the number of wind turbines required to be installed in both Case 1 and Case 2 is between 20,000 to 75,000 unit which is massive. As mentioned previously, the largest offshore wind farm currently consists of 87 unit of 8 MW wind turbines (Walneyextension.co.uk, 2017). As phase 2 will only be in operation in the next twenty (20) years, Case 3 model has constraint the number of wind turbines to 870 unit which is double the number from Phase 1, Case 3 option and ten times of the turbines in Walney Extension. In addition, the biogas generator was also limited to one unit of 1.5 GW generation capacity. At the moment, the assumption is by 2040, the technology on both offshore wind farm as well as biogas generation has advanced significantly and improved the area requirement as well as cost for both technologies.

Due to this, the solar PV unit is required to increase up to 167 million (1kW per unit) which contributes approximately 98% of electricity production per year. This is more than thrice the solar PV number in Case 1. This roughly required at least to install on the rooftop of 42 million houses. This need to further evaluated and other option for solar PV location need to investigated.

Even though Case 3 is technically feasible, this case has the highest NPC value of USD 298.56 billion which is more than twice the NPC value of the base case. The strain point for Case 3 is in November where the power generated is insufficient to meet the demand by 5.4 MW. This is illustrated in Figure 49.

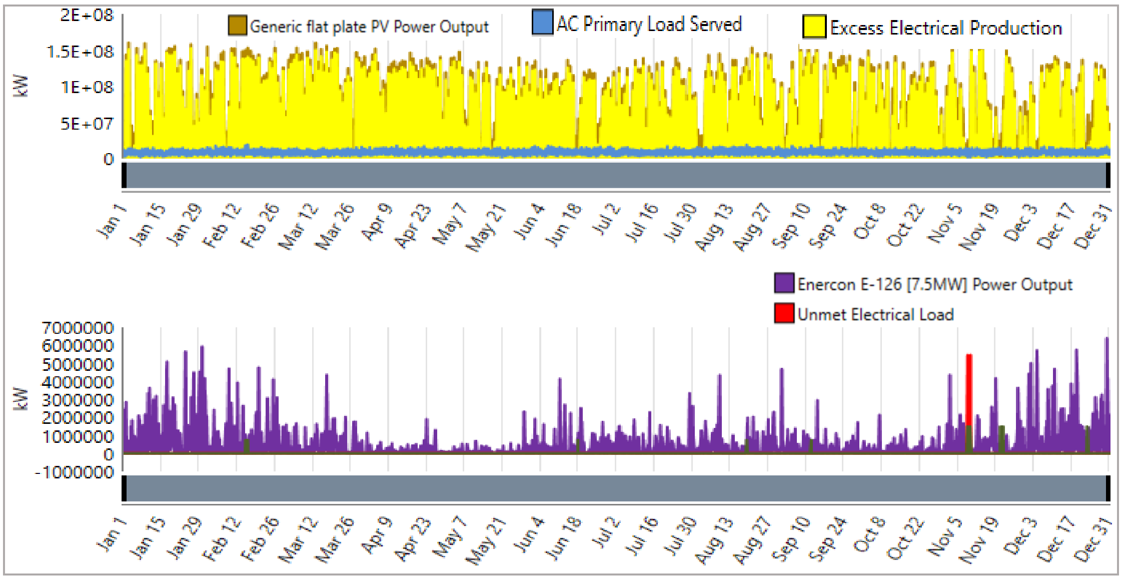


Figure 49: Demand and supply profile for Case 3 (scenario 1 2040)

As the number of wind turbine has been reduced from 70,000 unit to 870 unit, the model was unable to harness the wind energy that mostly occurs during the rainy season. Referring to Figure 50, the electricity shortage occurs between 0000 hours to 0700 hours on the 10th of November. It can be seen, once the sun starts to rise, the biogas generator begins to decline and stop operation while the battery starts to charge back up. Based from the Figure 50, the power generated from the wind is very small as to compare with the other generators.

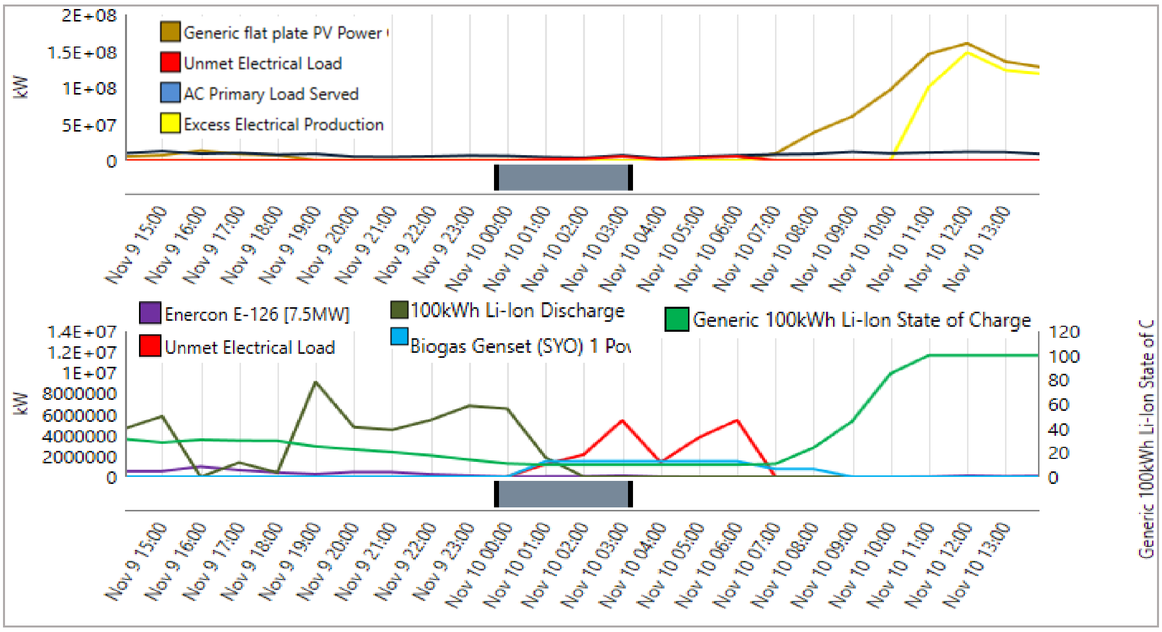


Figure 50: Unmet electrical load for Case 3 (Scenario 1 2040)

5.2.3. 2040 Scenario 2: Hybrid Model

In Scenario 2, NGG was included to optimise the number of wind turbines and solar PV. There are 2 NGG capacity evaluated in this model which is 17GW and 8.5 GW. This is to analyse the impact to the renewable system. The system architecture for Scenario 2 is similar to Scenario 1 with an additional NGG as per demonstrated in Figure 51.

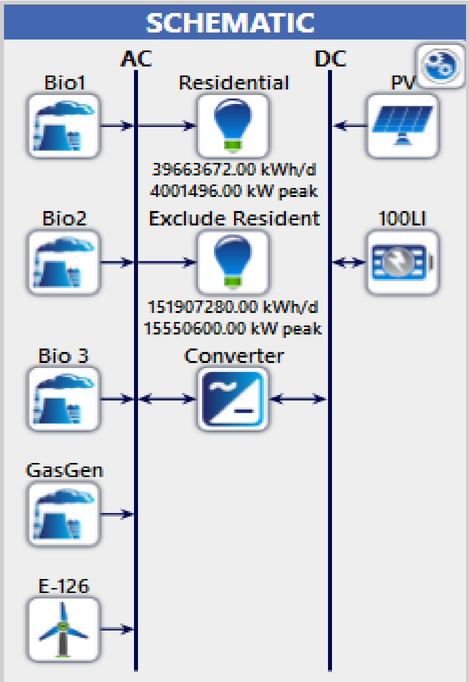


Figure 51: System architecture for scenario 2 for 2040

Three cases were simulated and the component details listed in Table 24 below.

Table 24: System components details (Scenario 2 for 2040)

Components (2040)	**Quantity**		
	Case 1	**Case 2**	**Case 3**
	Lowest NPC	**Half NGG**	**Optimum**
NGG	1	1	1
(17GW)	*n/a*	*n/a*	*1*
(8.5GW)	*n/a*	*1*	*n/a*
Biogas (1.5 GW)	-	1	1
Wind Turbine (7.5 MW)	75,822	869	869
Solar PV (1 kW)	50,000,000	80,968,661	52,000,000
Li-ion Battery (100 kWh)	266,070	1,503,288	1,156,985
Converter (1 kW)	14,092,732	11,663,925	15,319,557

a) 2040 Scenario 2 Results

The result for this model has been tabled out in Table 25 and Table 26 below.

Table 25:Production breakdown for each generation system (Scenario 2 for 2040)

Components (2030)	Case 1 (Lowest NPC)		Case 2 Lowest CO_2		Case 3 (Optimum)	
	Production (%/year)	Capacity Factor (%)	Production (%/year)	Capacity Factor (%)	Production (%/year)	Capacity Factor (%)
NGG	2.25	5.39	2.77	4.96	9.53	5.93
Biogas (1.5 GW)	0	n/a	0.61	6.16	0.25	1.76
Wind Turbine (7.5 MW)	76	5.38	2.33	5.38	3.35	5.38
Solar PV (1 kW)	21.7	17.7	94.3	17.7	86.9	17.7

Table 26: Result for each case (Scenario 2 for 2040)

Characteristic (2040)	Value				Unit
	Base Case	Case 1 Lowest NPC	Case 2 Half NGG	Case 3 Optimum	
Renewable Fraction	0	88.5	94.7	87.4	(%)
CO_2 emissions	53,659,487	7,123,565	2,938,242	7,652,643	(Tonne/ year)
% CO2 reduction	-	*87*	*95*	86	*%*
NPC	138.94	119.34	192.93	160.19	USD Billion
Initial capital cost	19.72	89.46	143.87	112.69	USD Billion
IRR against Base	-	11.9	n/a	5.9	%
Capacity shortage	0.046	0	0.096	0	(%/year)
Excess electricity	0.35	79.9	42.6	18.2	(%/year)

Typical days in dry season (22nd May) and in rainy season (28th December) are selected to show the power generation pattern for each scenario.

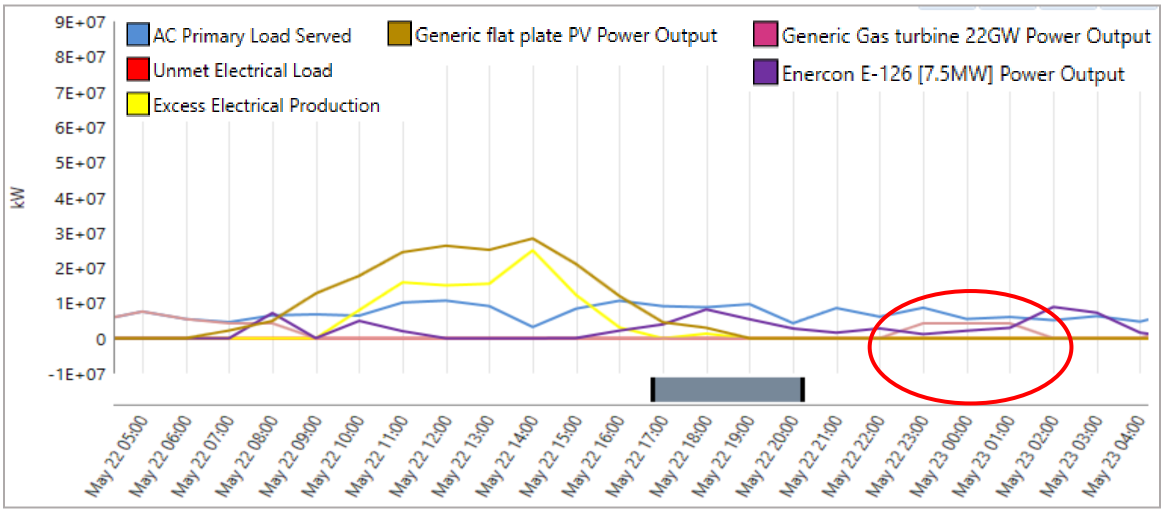


Figure 52: Power system in dry season for Case 1 (Scenario 2 2040)

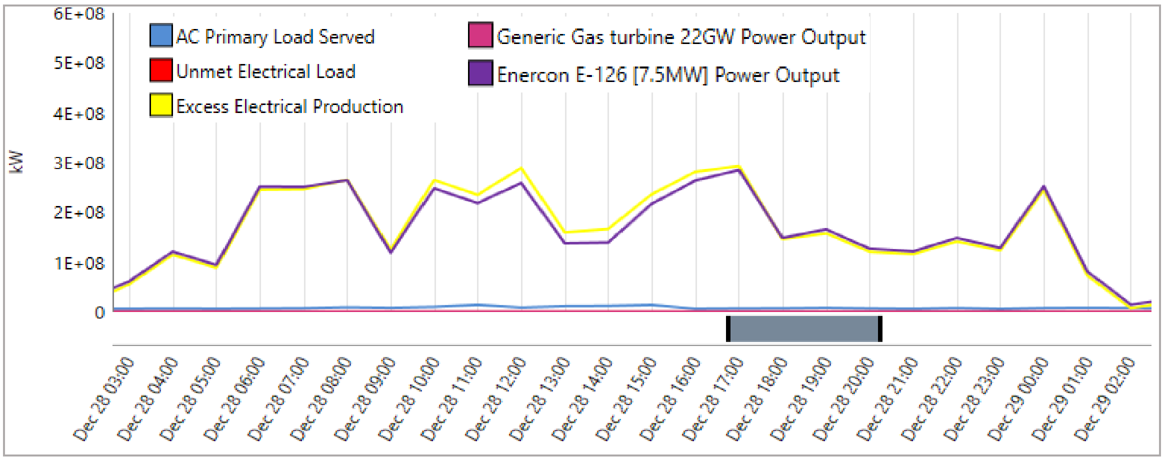


Figure 53: Power system in rainy season for Case 1 (Scenario 2 2040)

b) 2040 Scenario 2 Discussion

Similar to Phase 1, for Scenario 2, economically, Case 1 represent the best option as it has the lowest NPC value of USD 119.3 billion and the CO2% reduction is approximately at 87%. The renewable fraction for this case is nearly 88.5% mainly contributed by wind turbine that contribute up to 94% electricity production per year. However, in term of excess electricity, Case 1 has the highest excess electricity of 75.2%. Referring to Figure 53, it can be seen that the power generated during the rainy season is significantly high which reach up to 2.84 $x10^8$ kW at 1700 hours while the demand at that particular time is only at 6.3 GW. The power generated increase accordingly as the wind blows strongly permitting the 75,822 unit of wind turbines to produce higher electricity output. Meanwhile, during the dry season, the power generated by the wind turbine is lower and the NGG generator needs to pick up the load demand particularly during the night as there is no power generated from solar PVs. This is highlighted in red circle as illustrated in Figure 52.

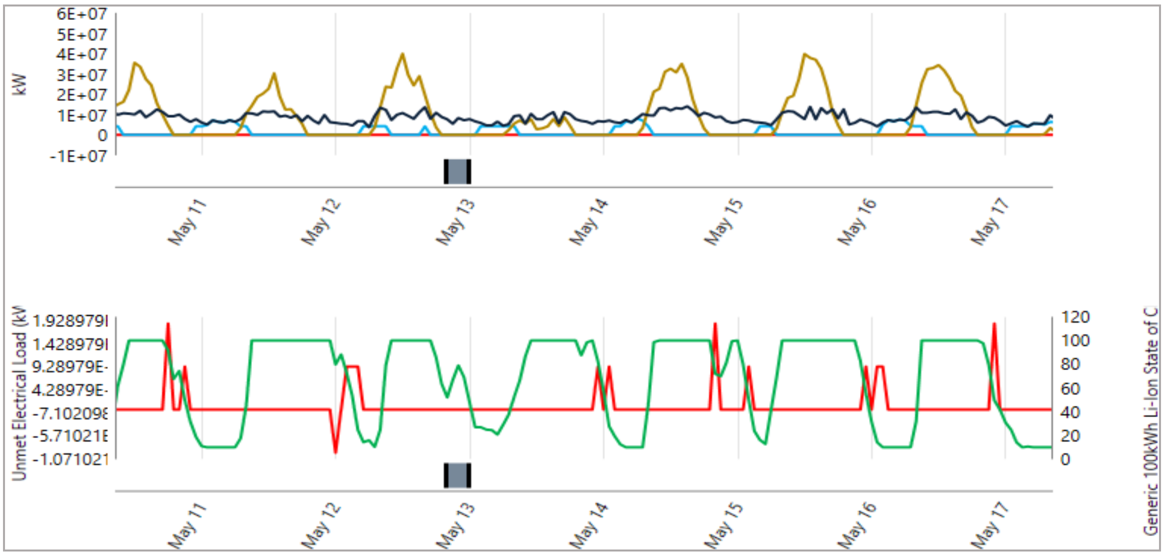


Figure 54: Unmet electrical load for case 1 (Scenario 2 2040)

Figure 54 demontrated that the the unmet electrical load less than 1kW which is very minimal and be further mitigated during the detail design. The battery state of charge is mostly at 100% except during the night time when the power from the solar PVs is not available. Once the batteries finish discharge, the NGG kick in to provide the required electricity to meet the demand. This arrangement ensure that the system prioritise the power genrated from renewable before switching to non-renewable.

In term of technical feasibility, Case 3 represent a better system. Similar to Scenario 1, the wind turbine was limited to 870 unit with 1 unit of 1.5 GW biogas generator plant. As the main power was generated by solar PV, there will be approximately 81 million solar PV (1kW unit) need to be installed. As previously mentioned, for an area of 25.5 m2 area is required to install 4.4kW solar PV. Based from this high-level estimate, approximately 20 million unit of houses and building around peninsular Malaysia that require to mount solar PVs.

In addition, 9.5% production per year is generated from NGG while 3.4% production is from wind turbines. Due this, the CO_2 emission was reduced significantly from the base cased which utilised 100% production from NGG. This arrangement resulted in 86%

CO2 emission reduction with 18.2% of excess electricity per year. In term of NPC value, Case 3 has 15% higher NPC value (USD 160.2 billion) than the base case. In view of this, for Scenario 2, Case 3 is the recommended option.

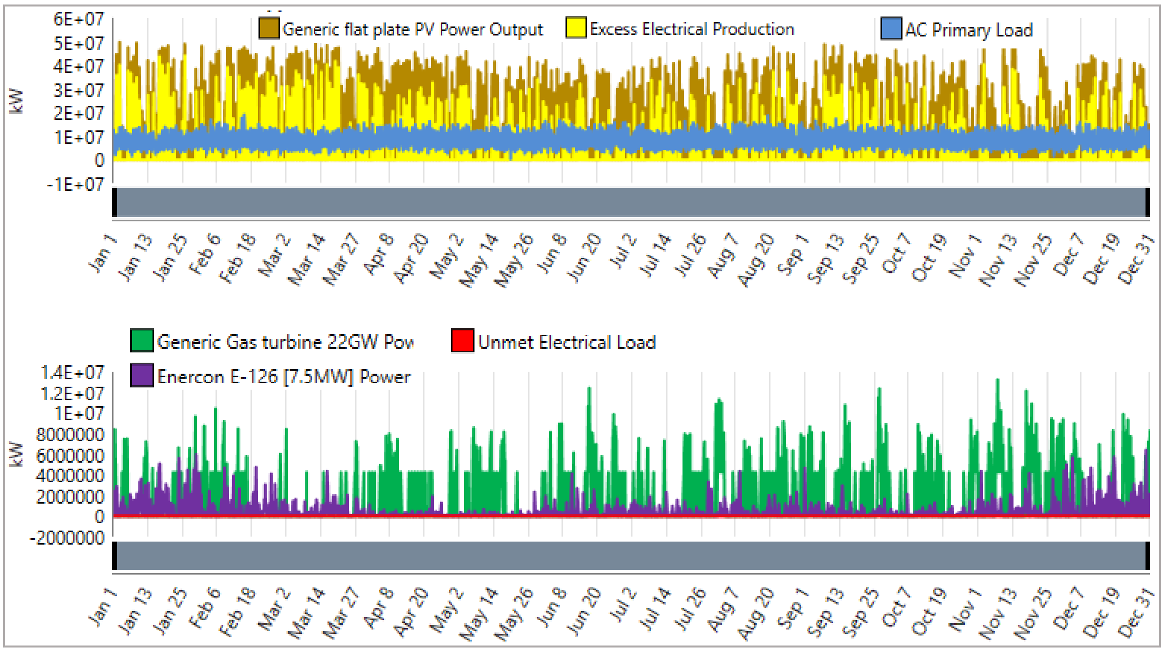


Figure 55: Unmet electrical load for Case 3 (Scenario 2 2040)

Figure 55 demontrated that the the unmet electrical load less than 1kW insignificant to the overall power system. It can be seen that majority of the power was generated by solar PV and followed by wand turbines. In the event both of the power generation source is insufficient, the generator starts to kick in. This system is quite stabilised and suffient to cater the demand for year 2040.

5.2.4. Summary for Phase 2

In summary, for Phase 2 the recommended development option is Case 3 as it is technically feasible and economically within the +/- 15% of the base case. Case 3 has the third lowest NPC value of USD 160.2 billion. In addition, hybrid Case 3 has RF value of 87.4% and CO_2 percentage reduction of 86%. The initial capital for Case 3 is at USD 112.7 billion which is significantly high. In conclusion, hybrid Case 3 the is recommended option for phase 2 energy development.

5.2.5. Overall Result Summary

Comparison of the recommended option from each scenario for both development phase was tabulated in Table 27

Table 27: Summary of overall result

Characteristic (2030)	**Phase 1**		**Phase 2**		**Unit**
	100% RF	**Hybrid**	**100% RF**	**Hybrid**	
	Optimum	**Half NGG**	**Optimum**	**Optimum**	
Renewable Fraction	100	87.5	100	87.4	(%)
CO_2 emissions	15.2	3,439,478	18.5	7,652,643	(Tonne/ year)
% CO2 reduction	*~100*	*88*	*~100*	86	*%*
NPC	156.10	77.5	325.94	160.19	USD Billion
Initial capital cost	111.87	53.90	252.31	112.69	USD Billion
**IRR against Base*	*n/a*	8.9	*n/a*	5.9	*%*
Capacity shortage	0.099	0.099	0.099	0	(%/year)
Excess electricity	54.6	8.66	70.8	18.2	(%/year)
Wind Turbines	435	430	869	869	Unit
Solar PV	56,308,767	11,034,338	50,787,430	52,000,000	Unit

Based from the comparison, hybrid combination of 17GW NGG, 1.5 GW biogas generation plant, 869 unit of 7.5 MW offshore wind turbines and 52 million unit of solar PV panels provided a technically feasible and economical viable development option. As mentioned previously, this option is technically feasible if the offshore wind turbine technology has advanced rapidly and able to optimise the number of wind turbine as well as the area required to install all the turbines.

6. Conclusion and Recommendation

This thesis evaluated the feasibility of renewable energy system to address the future demand for the next 20 years in peninsular Malaysia. Based from in depth literature reviews, peninsular Malaysia has an abundant renewable energy resources that can be harness to balance off the energy generated from fossil fuels. Several simulation cases that were conducted four cases were shortlisted to be further analysed.

Based from the result, it can be seen that scenario with a high renewable fraction (100% RF) resulted in high NPC values while hybrid scenario that consist a NGG plant will produced a lower NPC. However, the major concern is on the technical feasibility of the system architecture due to the maturity of each technologies. Below are the summarised findings based on the results.

- **Solar PV:** Provided consistent power resource through out the year as the GHI rate is varies between 4.0 to 6.3 (kWh/m2/day) and the cost per kW is significantly lower than wind turbine. However, due to the solar PV availability to absorb solar energy between 6 to 8 hours per day, battery is required and this will increase the cost significantly. In term of capacity factor, the solar PV for this simulation is at 17% which is close to the global average of 18%.

- **Wind Turbines:** Able to harness significant energy during the rainy (monsoon) season which only half of the year. In view of this, significant number of wind turbine is required during the dry season and even thought this will create a massive excess energy during rainy season. In term of capacity factor, wind turbines capacity factor is at 5.38% which is significantly lower as compared to European countries (38% to 50% in 2018) and China (23 to 34%) that is at respectively (IRENA, 2019). This represent a relatively poorer wind resource in peninsular Malaysia.

- **Batteries**: Required to store and stabilised the energy supply during the night with low wind. However, there is limitation on the number of batteries that is feasible to be installed.

- **Technical Feasibility**: Due to the low solar and energy sources in peninsular Malaysia, a large land or ocean area is required to construct the renewable development to meet 100% RF. The technical limitations that was set helps to narrow down the optimum option that required to be further developed.

In conclusion, hybrid scenario with 870 unit of wind turbines, 52,000,000 unit of solar PVs and a 1.5 GW biogas generation plant for year 2040 was recommended as the optimum option for peninsular Malaysia future renewable energy system. This proposed generation system will contribute approximately 87% renewable energy to the incremental energy demand. This resulted in 33% renewable energy from total electricity demand in 2040. This is higher than the target set by the government.

7. Future Work

There are several areas that can be look at to further improve the system architecture that was proposed in this study. Thus, the following will provide ideas on other potential study that can be carried out.

Offshore wind farm: As mentioned in Chapter 5, improvement in the next 10 years is crucial to ensure the feasibility of this option. Factors that can be analysed is as per following:

- Low cut-in wind speed - most of the available wind turbine minimum cut in wind speed is at 3m/s. With a reduction in cut in wind speed, it will improve the capacity factor of wind turbine and subsequently increases the power generated from the system.
- minimising the wake impact - In one of the previous study, there was stated that wake impact contributed up to 15% of the power losses from the whole wind farms (Barthelmie et al. 2004)

Concentrated Solar Panel (CSP): As mentioned in Chapter 2, peninsular Malaysia has a potential for development of CSP at selected area. Study on the selected site and area requirement will help to improve the renewable energy contribution in the overall power generation system.

Wave and Tidal: Similar to CSP, peninsular Malaysia has a potential to harness wave energy in selected area. Further study on the optimum site and area requirement will help to provide a healthy mix of renewable energy resources.

Electricity Grid Infrastructure: Most of the hydro energy is located in East Malaysia. Further study to investigate the feasibility of interconnection between East Malaysia and peninsular Malaysia will help to improve the overall renewable energy contribution in Malaysia as 90% of the electricity demand is in peninsular while the major hydro, wind and solar resources is located in East Malaysia.

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Appendix:

Appendix I: Demand Forecast for Peninsular Malaysia