An investigation and optimisation of electrical power generation scenarios for a sustainable Malaysia

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Abstract

The Malaysian Government has been introducing fuel diversification policies over the past decade by considering other sources of fuel such as alternative and renewable energy into the electricity mix as a measure to lengthen the oil and gas reserves against premature depletion. Since electricity consumption forms about a fifth of the total energy consumption, and directly impacts the country's economy and people's well-being, it is necessary to pay emphasis on Malaysia's intermediate to long-term power sector planning by identifying sustainable options which will enhance Malaysia's energy security and simultaneously mitigate climate change in line with the commitments set in the Paris Agreement.

This study attempts to provide a comprehensive foresight analysis in relation to the electricity generation portfolios by exploring different energy resources and technologies to meet the electricity demand through 2015 to 2050 by a modelling approach known as Malaysia TIMES Electricity Model (MYTEM). The multiple scenarios which collectively forms MYTEM were developed by deploying '**T**he **I**ntegrated **M**arket Allocation-**E**nergy Flow Optimisation Model **S**ystem' or in brief known as the TIMES model generator. The examined scenarios are business as usual (BAU), the two nuclear scenarios where one of them simulates the inclusion of the 2.0 GW nuclear power (NUC2) and the other demonstrates the nuclear expansion plan to reach cumulative nuclear power to 4.0 GW (NUC4), as well as the four renewable plus storage scenarios which were specified based on the application of 6 and 7 types of renewable technologies plus the integration of 7 and 14 days storage generation capacity respectively (RNW6S7, RNW6S14, RNW7S7, and RNW7S14).

The results indicated that by 2050, the electricity demand for Malaysia is expected to grow to 892.30 PJ from base year levels of 475.92 PJ. One of the significant findings from the renewable energy assessment revealed that based on the International Electro-technical Commission (IEC) standards, class II offshore wind turbines have great potential for grid-connected utility-scale power generation in the South China Sea since the wind speed falls within the class II velocity range from 7.5 ms^{-1} to 8.5 ms^{-1} at altitudes between 50 to 200 m. Apart from this, Malaysia has great potential to gain electricity yield from other renewable resources such as hydro, solar, geothermal, biomass, and biogas. Out of all the MYTEM scenarios, the RNW7S14 scenario would be the most feasible model for implementation from an investment perspective and the most effective model for CO_2 abatement, followed by RNW7S7, RNW6S14, and RNW6S7. The intermittency issue caused by renewables can be resolved with the integration of pumped hydro storage (PHS) system into the grid.

To conclude, MYTEM substantiated that Malaysia does not need to embrace nuclear power as other renewable-based technologies such as hydropower could generate the equivalent baseload and peak load electricity, while solar photovoltaics combined with PHS system could cater to the rise in electricity demand which occurs in the afternoon due to the increase in air-condition usage and industrial sector demand. Furthermore, MYTEM demonstrated that by 2050, 98.37% of the electricity generation portfolio could be sourced from renewable energy which simultaneously enhances Malaysia's energy security and decarbonises the environment. Ultimately, this study contributed to knowledge by providing a novel consolidated research methodological framework in modelling the reference energy system specially customised for electrical power that could be applied to other long term energy resource optimisation studies at country level.

Dedication

In the glory of the keeper of the Universe, space and time

To those dearest to my heart

My parents: Mummy Rose and Papa Werner

My husband and soulmate: Dr Mohd Ali Mohammad (Epul)

My five wonderful children: Danial, Safwan, Katrin, Nadia and Amanda

In memory of my late grandparents: Oma Johanna and Opa Helmut

And my late father in law: Mohamed Abdullah (Abah)

I wish you could witness this special moment with me

Your continuous love, support and trust in me has led me this far

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To my colleagues and friends, it has been a privilege and honour to have worked with a group of professional individuals. You all have been amazing friends that I'll surely miss, let's keep this friendship going for a lifetime.

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May all your kindness return to you in many unexpected blessing.

List of Publications

Haiges R, Wang YD, Ghoshray A, Roskilly AP. Forecasting Electricity Generation Capacity in Malaysia: An Auto Regressive Integrated Moving Average Approach. Energy Procedia. May 2017, 105:3471-8. (DOI: 10.1016/j.egypro.2017.03.795)

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Nomenclature

List of symbols

A	Area (m^2)
ACT	Generated electricity (PJ)
b	Coefficient to the independent variables
c	The intercept or constant
CdTe	Cadmium Telluride
CH_4	Methane
CIGS	Copper Indium Gallium Selenide
CO_2	Carbon Dioxide
Cs	Caesium
ºC	Celsius
€	Euro
E	Energy (J)
E_p	Electricity output (kWh)
F	Cash flow
FIXOM	Fixed Operation and Maintenance Cost (million USD per GW)
FUEL	The primary and secondary fuel input at power plants (PJ)
G	Annual CO_2 reduction per generated electricity ($ktkWh^{-1}$)
g	Gravity (ms^{-2})

GW	Giga Watt
GWh	Giga Watt Hour
$\overline{H}$	Solar Radiation ($kWhm^{-2}$)
h	Height (m)
HFC	Hydro Fluoro Carbon
INVCOST	Investment Cost (million USD per GW)
K	Kelvin
kt	Kilo Tonnes
kW	Kilo Watt
m	Mass (kg)
MMBtu	Million British Thermal Units
mSv	Mili Sievert
Mt	Mega Tonnes
Mtoe	Millions of Tonnes of Oil Equivalent
MW	Mega Watt
MYR	Malaysian Ringgit
$\hat{n}$	Number of hours per annum
n	Sample size
N_2O	Nitrous Oxide
NOx	Nitrogen Oxide
$\hat{p}$	Probability
p	Number of lags of the considered variable

P	Power (W)
PJ	Peta Joule
q	Number of lags of the error term
Q	Net heat (J)
r	Radius of turbine blade or turbine blade length (m)
SF_6	Sulphur Hexafluoride
T	Period for a wave to travel from crest to crest (s)
TWh	Tera Watt hour
USD	United States Dollar
V	Wind speed (ms^{-1})
VAROM	Variable Operation and Maintenance Cost (million USD per PJ)
W	The quantity of work (J)
x	The independent variables, i.e. Gross Domestic Product, Population etc.
y	The measured time series or the dependent variable
Z	Hub height (m)

Acronyms

AC	Autocorrelation
ADF	Augmented Dickie Fuller
AGR	Agriculture

AIC	Akaike Information Criterion
ANN	Artificial Neural Network
ANNCOST	Annual Cost
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
AR	Auto Regressive
ARIMA	Auto Regressive Integrated Moving Average
AFA	Availability Factor
BY	Base Year
BAU	Business as Usual
CAP2ACT	Conversion factor from capacity to activity
CCS	Carbon Capture and Storage
CCGT	Combined Cycle Gas Turbine
CO	Electricity consumption data in level form
COM	Commercial
COMEMI	Emission Coefficient
CSP	Concentrated Solar Power
CV	Critical Value
DLCO	Electricity consumption data by the logarithmic function and first difference
DPP	Discounted Payback Period
4E	Engineering, Energy, Environment, and Economics

EFB	Empty Fruit Bunch
EFOM	Energy Flow Optimisation Model
EIA	United States Energy Information Administration
EMI	Emission
ERS	Elliot Rothenberg and Stock
ETSAP	Energy Technology System Analysis Program
FFB	Fresh Fruit Bunch
FiT	Feed in Tariff
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GT	Gas Turbine
GWP	Global Warming Potential
H	Hypothesis
HFO	Heavy Fuel Oil
HHV	High Heating Value
HOGA	Hybrid Optimisation by Genetic Algorithms
HOMER	Hybrid Optimisation Model for Electric Renewable
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
I (1)	Integrated to the first order
I (2)	Integrated to the second order

I (d)	Integrated to the d^{th} order
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IIASA	International Institute for Applied Systems Analysis
IMPSA	Industrias Metalurgicas Pescarmona SA
IND	Industry
INES	International Nuclear Event Scale
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return (%)
IT	Income Tax Rate (%)
LCOE	Levelized Cost of Energy
LEAP	Long Range Energy Alternatives Planning Systems
LED	Light Emitting Diode
LWR	The Generation III Light Water Reactor for Nuclear Power
MA	Moving Average
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MARKAL	MARket ALlocations
MEIH	Malaysia Energy Information Hub
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environment Impacts

MFO	Medium Fuel Oil
MNPC	Malaysia Nuclear Power Corporation
MSE	Mean Squared Error
MYTEM	Malaysia TIMES Electricity Model
NASA	National Aeronautics and Space Administration
NE	Nuclear Energy
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NUC	Nuclear
OCGT	Open Cycle Gas Turbine
ORC	Organic Rankine Cycle
PAC	Partial Correlation
PCS	Pulverised Coal Supercritical
PHS	Pumped Hydro Storage
POME	Palm Oil Mill Effluent
PP	Phillips-Perron
PR	Performance Ratio
PV	Photovoltaic
PVDEP	Depreciated Present Value
PVOM	Operations and Maintenance Present Value
PVT	Photovoltaic-Thermal

R	Growth Rate (%)
R^2	R -squared value or coefficient of determination
RE	Renewable Energy
REFYR	Reference Year
REG1	Single region
RES	Reference Energy System
RETScreen	Clean Energy Project Analysis Software
RMSE	Root Mean Square Error
RNW	Renewable
RSD	Residential
S	Storage
SBC	Schwarz Bayesian Criterion
SCORE	Sarawak Corridor of Renewable Energy
SDG	Sustainable Development Goals
SEB	Sarawak Energy Bhd
SEDA	Sustainable Energy Development Authority
SESB	Sabah Electricity Sdn Bhd
SFB	Supercritical Fluidized Bed
SSE	Surface Meteorology and Solar Energy
ST	Steam Turbine
STC	Standard Test Conditions
STEM	Science, Technology, Engineering, and Mathematics

STOCK	Available power capacity
TEPCO	Tokyo Electric Power Company
TIMES	The Integrated Market Allocation-Energy Flow Optimisation Model System
TLCC	Total Life Cycle Cost
TNB	Tenaga Nasional Berhad
TRA	Transport
UKERC	United Kingdom Energy Research Centre
VEDA-FE	Versatile Data Analyst Interphase - Front End
VEDA-BE	Versatile Data Analyst Interphase - Back End
WEC	World Energy Council

Subscripts

0	Null
1	Original height
2	New height
a	Alternative
d	Discounted value
i	The i^{th} period
l	Plain terrain
n	Number of independent variables
r	Actual value
s	Sea surface
t	The series at current time t

t-1	The series at preceding period of t
t+1	The series at subsequent period of t
t-i	The preceding i^{th} period of t

Greek Signs

α	Wind shear
β	The last period with negative cumulative discounted cash flow
γ	The absolute value of cumulative discounted cash flow at period β
δ	The discounted cash flow after period β
ε	Residual
ϵ	Error term
θ	Moving Average Coefficient
μ	Efficiency or Power Coefficient
π	Pi
ρ	Density (kgm^{-3})
σ	Total number of AR and MA parameter (p + q)
τ	The number of observations
φ	Auto Regressive Coefficient
ω	The initial amount or data

Chapter 1. Introduction

1.1 Research motivation

As I recalled back what sparked my initial interest in embarking on this research, it started way before I even began my PhD studies. I was on my journey back to Malaysia from Los Angeles after spending a week in Washington. It was a Friday evening on 11th March 2011, I was sitting in one of the lounges at Los Angeles International Airport waiting for my delayed flight while listening to the news broadcast. I gathered from the news report that Japan has been hit by an enormous earthquake at a magnitude of 9.0 on the Richter scale. The epicentre originated 70 km east coast of Honshu Island. What concerned me more was that this earthquake had unleashed a huge tsunami reaching over 15 m height crashing along the Tohoku coastal region. This reminded me of the deadly tsunami that crushed Acheh Indonesia back in 2004, December 26. It was also triggered by an earthquake of similar magnitude. Acheh suffered the worst devastation, but the regions in the vicinity were impacted as well, such as the Maldives, parts of Thailand facing the Andaman Sea, the northwestern coast of Malaysia which includes Kedah, Langkawi, and Penang.

The flight on route from Los Angeles was scheduled for transit in Taiwan before heading to Kuala Lumpur. Never did I imagine that I had the privilege to catch an aerial view of the affected area as the flight was flying over Japan, and what I saw totally stunted me because the coastal land was completely covered by dark orange muddy water, there were no traces of buildings nor houses, everything has been flattened, the mountainous areas were unaffected. The next few days after I reached home, I learned that the tsunami had triggered an even more serious problem, a series of explosions had been reported at the Fukushima Daiichi Nuclear power plant reactor 1, 2, 3 and 4, the explosions were due to the build-up of hydrogen gas resulting from overheated core rods. Reactors 1, 2 and 3 were experiencing a triple meltdown as the cooling systems failed to operate due to malfunctioning backup generators that caused the loss of power supply. In the following months, I subconsciously kept track with the news coverage, the power plant operator Tokyo Electric Power Company (TEPCO) through collective efforts with the authorities managed to contain the problem by pumping seawater and injecting nitrogen to cool down the reactors. Eventually, by the middle of December 2011, all the affected units were declared in a state of cold shutdown, and the four affected reactors with total capacity of 2,719 MW has been written off for decommissioning works [1]. Currently, the state of the fuel meltdown in the reactor pressure vessels remains unclear as radiation levels are still too high and unsafe for human intervention, there were several attempts to send robotic probes to assess the situation inside the reactor vessel, which led to the discovery of a 2 m hole in the inner vessel wall of reactor 2 [2].

Though what truly gathered my attention was the extent of the risk that can be caused by nuclear fission accidents. The International Nuclear Event Scale (INES) for the Fukushima plant was rated 7 which is similar to the Chernobyl disaster back in 1986. The INES scale is created by the International Atomic Energy Agency (IAEA) as a guideline of the countermeasures required in the occurrence of a nuclear accident. The total radiation released by the Fukushima plant was estimated of being a tenth of the Chernobyl incidence. In order to control radiation exposure, over 160,000 residents within the mandated 20 km radius were evacuated and in the prolonged process had sacrificed 1,600 lives. This energy accident had created thousands of traumatized homeless victims, who suffered mental and health complications due to high anxiety levels. Radiation screening was conducted to 32,024 TEPCO plant workers in 2014, the results found that 1,578 had received 50 to 100 miliSievert (mSv) dose and 173 workers exceeded the 100 mSv evident cancer prone level [1].

The main radionuclides such as Iodine- 131 (8 days half-life), Caesium isotopes - Cs 134 and Cs 137 (2 years and 30 years half-life respectively), Strontium-90 (28.8 years half-life), and Tritium (12 years half-life) contaminated the air and water, and an average of 300 tonnes of radioactive polluted water continues to flow to the Pacific Ocean each day. Despite costly efforts to inject chemicals to solidify the soil to create a frozen wall around the reactors, it was still impossible to prevent groundwater from seeping into the contaminated reactor area. Radioactive waste management is also another challenge for TEPCO, so far radioactive debris surrounding the plant have been collected and contaminated water have been pumped into large storage tanks for further treatment. The clean-up period is expected to take 40 years with the estimated cost of USD 187 billion dollars. The compensation scheme to individuals and industries is estimated at USD 69 billion [1, 2]. Many industries including the food, forestry, fisheries, and agriculture sectors suffered direct economic impacts which resulted in billion-dollar losses. This accident was enough to cripple Japan at a macroeconomic level.

Despite swift action taken by TEPCO and the Japanese government in taking precautionary measures such as supplying potassium iodide to inhibit thyroid swelling due to radiation, halting food production and distribution to curb circulation of contaminated food, and, releasing timely evacuation orders to the public, however, significant damages were still incurred. What alarmed me was the fact that even an advanced nation such as Japan with a disciplined society and one of the highest percentage of science, technology, engineering, and math (STEM) graduates are still struggling to this very day to keep the whole nuclear chaos under control. This incident left a powerful country like Japan helpless. I pondered how a developing country like Malaysia would cope if we were placed in the shoes of Japan. This thought came in relation to Malaysia's decision to commission the 2.0 GW nuclear reactors by the year 2025. This intention to source power from nuclear was first mooted in December 2010, by the Minister of Energy, Datuk Peter Chin. This was followed by the Malaysian Premier announcement on the establishment of Malaysia Nuclear Power Corporation (MNPC) to deliver this initiative. The government justified that nuclear energy was crucial to reduce current high fossil fuel dependence. Although this effort was put on hold in 2011 due to the Fukushima disaster, nevertheless MNPC has picked up momentum again and is focusing on setting up the regulatory frameworks and conducting the related feasibility studies, preparing Malaysia to embark on her nuclear power journey. Somehow the Fukushima accident has differed plans for Malaysia to implement nuclear power up to 2030, although this decision is not 100% carved in stone and is still being considered by the Malaysian government. It's interesting to note that Malaysia's experience with nuclear is still at its infancy stage, whereby involvement with nuclear dates back to 1982 with a 1 MW reactor used for research purposes [3].

Subsequently, on 15 March 2011 Germany announced to shut down 8 of its oldest nuclear plants out of 17 plants. Later in June 2011, a law was passed by the German Parliament that all 17 nuclear power plants in Germany will be shut down by 2022. Siemens, the corporation responsible for commissioning all 17 plants in Germany, announced in September 2011 that they will no longer build new nuclear plants. To accompany Germany's nuclear exit, Italy, Spain and Switzerland are following suit with similar stance [4]. As an obligation towards public safety, Germany decided to reform its energy sector from nuclear to renewable energy. Germany has made its mark in renewable energy as a leader in this field by growing this sector immensely since the 1990s [5]. Renewable energy has indeed contributed to the economic growth and job creation in Germany.

The Fukushima nuclear disaster and Germany's firm decision to abandon nuclear in the near future had raised my curiosity to explore Malaysia's power sector at a different dimension.

1.2 Research context

Malaysia's power sector does have some prominent challenges as clarified below:

1.2.1 High reliance on fossil fuels

Malaysia has been heavily dependent on conventional fossil resources for power generation, according to 2015 available capacity data, indicated that 82.5% came from fossil fuels and 17.3% is from hydropower. To be specific, the 82.5% accounts for 47.2% natural gas, 33.9% coal, 1.4% fuel oil and diesel. The contribution of renewables aside from hydropower in the electricity mix in 2015 was only 0.2% [6].

1.2.2 Rising CO_2 emissions

Malaysia is also one of the largest carbon dioxide (CO_2) emitters in South East Asia, ranked third after Indonesia and Thailand. In 2014, the CO_2 emission marked a tremendous over four-fold increase to 242.8 Mega tonnes (Mt) compared to 56.6 Mt in 1990. Furthermore, the power sector in 2014 contributed to 54.0% out of the total CO_2 emissions [7]. Malaysia has ratified the Paris agreement on 22 April 2016 and has pledged to reduce 45% of greenhouse gas (GHG) emissions relative to 2005 levels by 2030, in which 35% reduction is on voluntary basis and 10% is upon receipt of climate finance, technology transfer and capacity building from advanced countries [8]. This commitment has been reiterated a number of times by Malaysia over the past years. This agreement seeks to minimise the global temperature rise within this century by a limit of 1.5 to 2.0 degrees Celsius (^oC). Prior to this, Malaysia signed the Kyoto Protocol in September 2002, it is a legally binding document initiated in 1997 with the purpose to reduce GHG to address climate change involving 192 parties under the United Nations Framework Convention on Climate Change. Developed nations have pledged their commitments to reduce the CO_2 levels while developing nations are encouraged to adapt on a voluntary basis [9, 10].

1.2.3 Depleting oil and gas reserves

At current reserve to production ratio, oil and gas reserves are showing signs of depletion[6] . Malaysia is currently a net exporter of oil and gas, however owing to high national demand Malaysia may turn into a net importer of oil and gas in the near future. Several scholars [10-12] shared the same opinion that Malaysia will eventually turn into a net importer of oil based on the current reserve to production rate. Nevertheless, the slight observed difference lies in the expected year for it to materialize, for instance, Oh et al. [10] projected 2030, whereas Ali et al. [11] expected for it to occur in 2020, whilst Khor and Lalchand believes it will take place earlier than 2020 [12].

1.2.4 Underachieved renewable smart targets

The Malaysian Government has set renewable smart targets of 975 MW capacity or a 5.0% electricity generation share by 2015, and by 2020 it should increase to 9% electricity share or 2,065 MW capacity. However, these targets are still far off tangent despite the implementation of the feed-in tariff (FiT) mechanism which took effect in 2011 [13]. Cumulated available capacity for renewables as of 31 December 2015 stood at 63.8 MW, which equals to just 0.2% of the total capacity [6] and in a shortage of 911.2 MW to the specified target. By 2050, the renewable electricity share target set by the government was fixed at 13%, which is just an increase by 4% over a 30 year period [14] which is a lethargic growth projection in renewable electricity.

1.2.5 Malaysia susceptible to seismic activities

Malaysia is located within 0^{o} 9’ to 7^{o} 3’ North latitudes and 100^{o} 7’ to 119^{o} 2’ East longitudes and happens to fall in the Ring of Fire zone as shown in Figure 1 [15], therefore Malaysia is also vulnerable to the effects of earthquakes and tremors caused by the movement of tectonic plates.

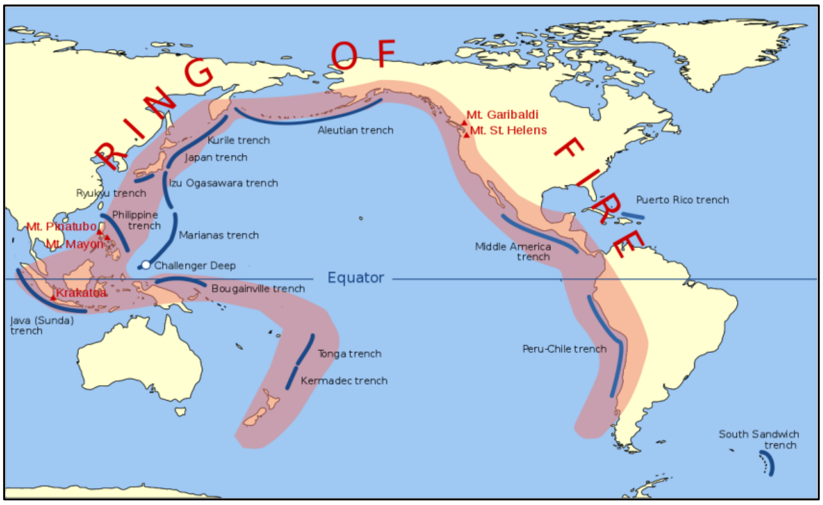


Figure 1. Pacific Ring of Fire [15]

In fact, on 5 June 2015, a strong earthquake of 6.0 magnitude hit the highest peak in South East Asia Mount Kinabalu, Sabah, East Malaysia [16] which deformed one of the famous peaks known as Donkey’s Ears [17] (refer Figure 2) and also caused 18 casualties. There are seismic movements detected in the Peninsular as well [18], if an earthquake were to hit Sumatra, the tremors and aftershocks can be felt in West Malaysia as well. Hence, it may not be a suitable location for commissioning nuclear power plants.

Figure 2. The Donkey's Ears before and after the earthquake [17]

1.2.6 Volatile primary coal price

The power sector faces market volatility in coal price since this sector is highly dependent on imported coal. In 2013, about 21,457, 511 tonnes (89.8%) of coal was utilized for electricity generation and the balance of 2,441,617 tonnes (10.2%) was spread across the steal, iron and cement industries. Coal imports for Malaysia mostly originate from Australia and Indonesia and imports figures are expected to increase to meet the nation's rising demand. Nonetheless, the price of coal has been volatile since this commodity is liable to market forces, lately the price has been escalating upwards exceeding USD 100 per tonne from a market low USD 48.80 per tonne [19] as shown in Figure 3.

Figure 3. Coal prices from 2012 -2017 (USD per tonne)[19]

1.3 Problem statement

There are several problems experienced by Malaysia's electrical power sector which includes heavy reliance on fossil fuels for power generation, high release of CO_2 emissions from power plants, diminishing indigenous natural gas reserves which will eventually cause Malaysia to rely on imported gas, and on top of that having to deal with volatile primary coal prices. Despite the efforts of the Malaysian government in rolling out renewable smart targets and implementation of the FiT scheme, penetration of renewables in the electricity mix is still deemed insignificant. The government intends to increase coal in the future generation mix, while imported coal is volatile to the market price. In addition to this, the government is planning to source power from nuclear by 2030 to divert the electricity mix from conventional fuels. But the hard truth is that nuclear power is associated with inherent risks, especially when nations such as Germany, Italy, Spain, and Switzerland are taking bold steps to expel nuclear for renewables. Is it still wise for Malaysia to source energy from nuclear when advanced nations are opting out? Not forgetting the fact that Malaysia is nested in the Ring of Fire region and not immune from seismic activities. An ideal state for power generation would be if Malaysia could enhance her energy security in the medium to long term by relying more on indigenous energy resources and narrowing down the emission levels to mitigate climate change to meet international commitments. Malaysia definitely needs to restructure her electricity generation mix to ensure a more sustainable power sector. Thus, there is a need to explore other long term options for power generation in Malaysia. This type of long term foresight studies are still lacking in Malaysia and optimization models are known to be able to provide an objective evaluation of future generation technologies and fuel mix selection. Taking a leap forward into the future is vital to understand the possible scenarios in the power sector that could ultimately lead to effective strategic planning towards strengthening Malaysia's energy security by enabling the smooth integration of renewables in the power mix. In this research, the International Energy Agency's (IEA) - The Integrated Market Allocation-Energy Flow Optimisation Model System (TIMES) optimization tool will be deployed to analyze possible energy scenarios projection in contrast to the business as usual scenario for a period from 2015 until 2050. The future electricity load will be examined by projecting the electricity demand. Subsequently, the renewable energy potential in Malaysia will also be assessed. This study attempts to find a sustainable solution for the electrical power sector in Malaysia to further enhance the energy security level as well as mitigate climate change and above all provide an alternative option to nuclear energy.

1.4 Research questions

Taking into account the challenges faced by Malaysia's power sector and Fukushima's energy accident led to the following questions:

- Is it still a wise option for Malaysia to source power from nuclear when advanced nations are prepared to shut down their nuclear power plants after the Fukushima accident in 2011?
- Are there better options for Malaysia in the long term rather than nuclear energy?
- What will the electricity demand be for Malaysia by 2050?
- What type of renewable resources are potentially viable in Malaysia?
- How much power capacity needs to be installed by 2050?
- How much electricity needs to be generated by 2050 and what is the generation mix percentage by fuel type?
- Can the CO_2 emission levels from the power sector be reduced to mitigate the impacts of climate change?
- Can Malaysia meet the pledge agreed in the Paris Agreement?
- What is the total system cost for power generation from 2015 until 2050?
- Is the 13% renewable electricity generation smart target set by the Malaysian government in 2050 sufficient or can it be further optimized?
- Is it cheaper to source power from nuclear or from renewables?
- Is there a way to compare the cost of electricity produced from different technologies?

1.5 Aims and objectives

The main aim of this research is to find a solution for Malaysia's future power generation portfolio by leveraging on sustainable and indigenous renewable energy resources available in the country. In order to find the solution, the TIMES linear programming model developed by the IEA is deployed in this study. A Malaysia TIMES Electricity Model (MYTEM) is developed that is able to present a comprehensive foresight analysis for power generation options in Malaysia by contrasting the business as usual against other optimized scenarios through a selection of different fuels and technologies to meet the electricity demand up to 2050.

This particular aim can be accomplished by achieving the following objectives:

i. To estimate Malaysia's future electricity demand requirement until 2050;
ii. To assess the renewable energy potential available in Malaysia;
iii. To build the Reference Electricity System (RES) for Malaysia; and,
iv. To analyze all the MYTEM scenarios according to the engineering, energy, environment, and economics (4E) perspective, whereby capacity levels, fuel input and electricity output will be evaluated, CO_2 emission profile and total system cost between scenarios will be contrasted.

1.6 Research contribution

The results of this study can be directly used by policymakers in shaping Malaysia's future energy policy and strategic strategies especially in relation to the electrical power sector, due to following reasons:

- towards achieving a high-income nation by 2020 and beyond, Malaysia will need to develop a strategy on how to progressively substitute reliance on fossil fuel with other sources to sustain its economic growth as an emerging economy;
- it will provide an alternative solution for Malaysia to boost the growth of renewable energy as one of its main fuels rather than continue with nuclear energy that has high risks associated with it;
- it will provide a systematic approach in producing Malaysia's optimum renewable energy percentage in the electricity generation mix via the MYTEM model;
- It can be a reference document in fulfilling Malaysia's future electricity demands without jeopardizing the people's safety and negatively impacting the environment; and,
- MYTEM could aid policy efforts in terms of mitigating climate change and enhancing the nation's energy security for the intermediate to long term horizon.

1.7 Research overview

This thesis is organised into 7 further chapters as follows:

- To better understand and guide the research query, the current research will be positioned by reviewing the state of the art literature relevant to this field in Chapter 2;
- The design of the reference energy system (RES) and the research approach for this study will be elaborated in Chapter 3 and 4;

- The electricity demand projections will be presented and discussed in Chapter 5;
- The potential power generation using renewable energy in Malaysia will be reflected in Chapter 6;
- All the optimised scenarios developed under MYTEM will be examined in Chapter 7 and a sensitivity analysis will be included too; and,
- In Chapter 8, a summary of the findings will be presented to conclude this study and recommendations for future works will be made.

Chapter 2. Literature Review

2.1 Introduction

Energy is the driving force behind a nation's prosperity and its societal wellbeing, the economic growth and the quality of life experienced by the people in a country could be adversely affected without sufficient supply of energy to meet the nation's rising demand. This notion is supported by studies that concluded that there is a correlation between energy consumption and the economy [20-24]. In addition, Mazur [25] demonstrated the application of per capita electricity consumption as one of the indicators to reflect the improvement in the quality of life. The importance of efficient energy resource planning and energy modelling studies started to gain impetus by policymakers and researchers from all over the globe after the first world oil crisis occurred in 1973 to 1974 and followed by the second crisis in 1978 to 1979 [26] which caused shortage of oil and an upsurge in oil prices.

This chapter will cover pertinent thermodynamics concepts fundamental to stationary power generation. The review shall cover the state-of-the-art literature related to energy systems modelling with emphasis on electrical power systems. Apart from that, the models typically used in energy demand projections will also be reviewed. Subsequently, the relevant background of the case study country will be presented, followed by a review of the renewable energy resource prospects in Malaysia. Through this review, the gaps in the literature will be revealed and the appropriate approach to achieve the study objectives will be identified.

2.2 Thermodynamics fundamental concepts pertinent to stationary power generation

Since the subject of this study is related to energy, thus a good understanding of the four laws of thermodynamics is essential. Thermodynamics, in general, is the science of the flow of heat springing from the root word 'thermo' which means heat and 'dynamics' which means flow, this field evolved in the 1800s which studies the relationship between energy, heat, work and temperature. On a mechanical perspective, it concerns the transformation of heat into mechanical work and vice versa [27]. It is recognised as a branch of physics. There are four thermodynamic laws, the zeroth law of thermodynamics was formulated after the other laws of thermodynamics were established. Basically, these four universal laws were deduced through generalisation or in other words through the observation of natural occurrence in our environment. Thus there is no proof to substantiate these laws, however, these laws are so consistent that over the years no violations or contradictions have been confirmed.

2.2.1 The zeroth law of thermodynamics

The zeroth law is crucially important as it defines temperature and the measurement of temperature. The zeroth law was discovered in the early twentieth century after the first and second laws of thermodynamics were established. This law essentially states when there are two systems A and B that are in thermal equilibrium, and B is in thermal equilibrium with system C, then C will be in thermal equilibrium with A [28]. To explain this law in simple terms, it is a natural observation when two objects with different temperatures for instance hot and cold, when in contact with a diathermic boundary, which is a surface that allows both the transfer of work and heat, the heat will flow in the direction from hot towards cold until both objects achieve an isothermal state (a constant or equilibrium temperature).

2.2.2 The first law of thermodynamics

The first law of thermodynamics defines energy (E) which is also known as the 'Principle of Conservation of Energy' which states that energy cannot be created nor can it be destroyed, energy can only be changed from one form to another form, put it differently the quantity of energy in the universe will remain the same. The formulation of the first law of thermodynamics [29] can be expressed as per equation (2-1) as follows:

$$\Delta E = Q - W \tag{2-1}$$

Where ΔE refers to the internal energy of a system, whereas Q is the net heat and W is the quantity of work through the change of state. This law in simple understanding explains that energy can be transferred from a system to another system through the interactions of heat and work.

2.2.3 The second law of thermodynamics

However, the first law of thermodynamics could not explain the direction of a spontaneous process. Furthermore, no limitation was implied in the first law, thus there exist a possibility that heat could be fully transformed into work and vice versa. Therefore the second law of thermodynamics surfaced and entropy as a new property was defined, entropy refers to the energy variable that is unavailable to do work or the degree of disorder. The second law of thermodynamics states that the entropy of an isolated system will keep on increasing over time compared to its initial state [30]. In simpler connotation, it is a natural occurrence when energy is transformed from one form into another, more energy tends to get wasted or dissipated in the form of heat to its surroundings and this wasted energy is entropy. Another way of understanding this law is that energy can never be fully extracted into work with efficiency at 100% or 1 unless the system achieves a temperature of absolute zero Kelvin (K) or -273.15 Celsius (^{o}C).

2.2.4 The third law of thermodynamics

The third law of thermodynamics also known as the Nernst theorem, states that if one could reach 0K, then all bodies would have an entropy change that equals zero which also ultimately results in entropy of zero. Another way to express this third law is that it is impossible to cool a body to 0K in a finite sequence of operations no matter how ideal the condition [28]. Basically, this law explains that an energy system would never be able to reach a temperature of 0K in the natural state as too much work is required to cool down the system. Therefore, entropy can never reach 0 and the energy system can never achieve a perfect efficiency of 100 % or 1 to fully convert heat into work.

In summary, the importance of the four laws in thermodynamics basically explains the vital properties of energy such as temperature, energy, and entropy. The zeroth law defines temperature and explains that energy moves from hot towards cold until it reaches an equilibrium state. While the first law defines energy, in which it highlights that energy cannot be gained nor can it be lost, but it can take up different forms. Whereas the second law defines entropy, which is the degree of disorder or wasted energy that dissipates in the form of heat. The second law also states that perfect efficiency to convert heat to work can only be achieved at 0K. However, the third law clarifies that 0K can never be achieved in a natural state, thus it is impossible for an energy system to reach perfect efficiency. All these four laws are significant and applicable to the stationary conversion technologies in the electrical power sector to transform primary or secondary fuel into exergy that is able to do work, in this context energy is converted into electricity.

2.3 The energy security and sustainability challenges

Security and sustainability are two essential prerequisites in devising intermediate to long term energy policies and strategies for any nation. A country with sufficient resources that could meet its energy demands without high reliance on foreign fuel imports is generally categorised as having a high level of energy security in which the country is in control and have sufficient energy resources. Another concept for energy security set forth by the International Energy Agency (IEA) refers to "the uninterrupted availability of energy sources at an affordable price" [31].

Whereas sustainability in the context of energy often implies the responsible use of energy resources that could substitute depleting fossil fuels, lengthen the oil and gas reserves and at the same time reduce the harmful impacts of greenhouse gas (GHG) emission in mitigating climate change. All these global collaborative efforts in achieving a sustainable world are demarcated in the Sustainable Development Goals (SDG) set by the United Nations Development Programme, especially the 7th, 11th, 12th and 13th are directly related to sustainability in the perspective of energy. The 7th SDG calls for access to affordable and clean energy, whereas the 11th SDG supports the development of sustainable cities, while the 12th SDG promotes resource and energy efficiency, and the 13th SDG combats climate change [32].

Another ongoing energy challenge is the rapid depletion of national fossil fuel reserves faced by many oil and gas producing nations. Countries that no longer have the indulgence to rely on fossil fuels as the main supply for electricity generation due to diminishing oil and gas reserve would need to consider the progressive alteration of the conventional electricity system into a transformed electricity system. The conventional electricity system set up is based on one directional flow from a centralised electricity generation supplied by utility companies and independent power producers and then being transmitted to the consumers via the High Voltage Alternating Current (HVAC) grid. The supply of electricity in the conventional system is based on the demand for electricity by the end-user sectors. However, in the transformed electricity system, the development of a bi-directional flow in electricity generation is considered, meaning not only from utility supplied to consumers (centralised generation) but consumers are also supplying to the grid (dispersed generation). In the transformed electricity system, electricity demand would be adjusted to the supply due to increased penetration of renewable energy that has an intermittent nature. In order to overcome the intermittency issue in renewables, large-scale electricity storage systems need to be integrated into the electrical system network. The grid in the transformed electricity system would assimilate two types of transmission system, namely, not only the HVAC grid but also the High Voltage Direct Current (HVDC) grid as more and more solar photovoltaics and wind farms are installed [33].

With the rollout of the Paris Agreement in 2015, collaborative efforts across the world to reduce the emission levels of greenhouse gases has been agreed. This multilateral agreement seeks to combat climate change by preventing a global temperature rise above $2^{o}C$ by the end of this century. In fact, signatory countries have pledged respective national emission reduction targets by 2030 in order to further limit the temperature rise to $1.5^{o}C$ [8]. Thus, finding the appropriate implementable strategies to achieve these emission reduction targets remains a great challenge to the countries involved.

Hence long term energy planning via the energy modelling approach for the electrical power sector remains crucial for any country to realise an energy system which is secured, sustainable and environmentally friendly. Energy modelling is an effective means to provide insights into possible energy futures which would allow for an informed decision-making process on which generation technologies are viable for investment technically and economically [34, 35]. This is particularly important for the long term perspective of the power sector fraternity since electrical power generation technologies are frequently planned and procured in advance to ensure that the power sector generation capacity is sufficient to sustain the nation’s electricity load.

2.4 Energy modelling approach and characteristics

With the breakthrough of computer technologies, many different modelling tools have been developed to model the complexities of the energy system. Hussain et al. [36] concurred with Dementjentjeva’s [37] views that using readily available energy modelling tools for energy planning purposes is more sensible rather than reinventing the wheel from scratch. While Weijermars et al. [38] suggested the use of integrated optimisation models for studying future energy solutions as this can be a powerful tool to convince stakeholders in their decision making process. Connolly et al. [39] conducted a review of 37 out of 68 possible computer tools that can be used in analysing the integration of renewables into the energy system from a scale at project level to country level, while Suganthi and Samuel [40] extensively reviewed the various energy demand forecasting models. Further reviews on energy modelling tools have been performed by Jebaraj and Iniyan [41], Hall and Buckley [42] and Lopion et al.[43]. Based on the reviews, it can be deduced that energy models can be classified into several factors [44] as summarised in Figure 4. These factors need to be considered before selecting the ideal model.

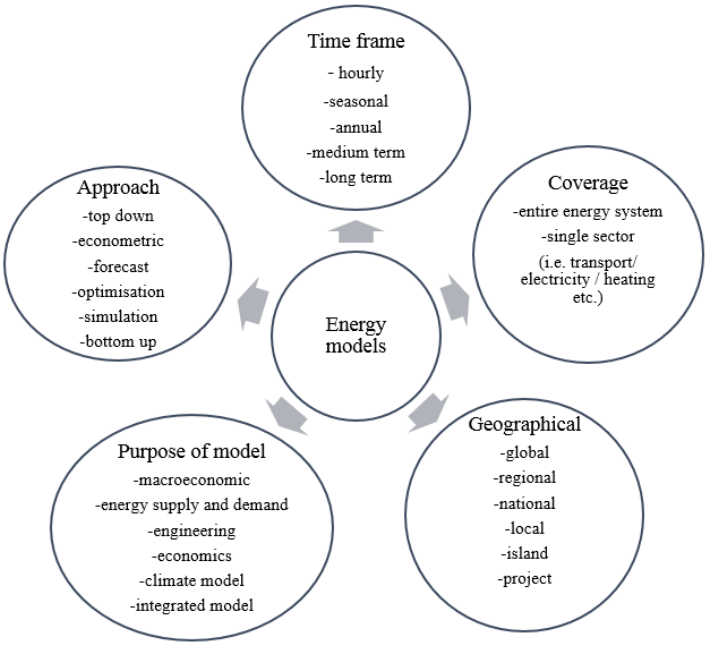


Figure 4. Factors in selecting the appropriate energy model [44]

Overall, energy models can be distinguished from one another based on the purpose of the model development, apart from that, other important factors such as the approach, time frame, sectoral coverage, and geographical scope need to be considered in determining the right model.

There are several approaches adopted in energy tools which include the top down, bottom up, equilibrium, econometric, forecast, optimisation and simulation models. A top-down tool is usually used to carry out macroeconomic studies to study the behaviour of energy prices or a change in demand. While the bottom up is an engineering approach that seeks to determine the appropriate energy conversion technologies along with the energy system cost for investment considerations. Bottom-up tools can be equipped with equilibrium tools which are valuable in explaining the supply, demand and price relationship [45]. Econometric models such as regression models are useful to correlate the energy demand with other economic variables and can be used to perform forecasts to determine the energy supply or energy demand. From the viewpoint of electricity, this would refer to electricity generation and electricity consumption. One of the more popular models extensively used in studies related to energy demand forecasting is the autoregressive integrated moving average (ARIMA) model [46-48]. Optimisation tools are used to optimise the operations or the cost of an energy system and often also considered as scenario tools which cover an intermediate to long term horizon. Contrariwise, the modelling exercise involving the operations of an energy system in a shorter term entailing minutes, hourly to one full year is typically considered as a simulation tool.

In addition, the time horizon of the study is also one of the determining factors in opting for a suitable model, this is usually linked with the inputted data time frame whether it is in hourly, seasonal, annual, medium or long term. Furthermore, the sectoral coverage of the study needs to be identified as well, whether the study includes the entire energy system or just for a single energy subsector such as electricity, heating or transport etc. Last but not least, the setting of the geographical scope plays a vital role in the selection of a proper model, this scope could be either at a global, regional, national, local, island, or project level.

As this study is intended to cover an intermediate to long term foresight analysis and power expansion planning specifically for the electrical power sector by identifying pathways which could enhance the nation's energy security, sustainability and concurrently alleviate the threats of climate change. Thus it can be deduced that the selected energy model for this study needs to be versatile in simultaneously solving multiple aspects of the electrical sector which includes assessing the fuel input levels, ascertaining the generation capacity of the conversion technologies, identifying the electricity generation to accommodate the demands, measuring the carbon emissions, and determining the economic cost of the total reference energy system (RES). Therefore based on the aforementioned criteria, the application of an integrated optimisation model which combines several interactions concurrently such as energy, engineering, environment and economics would be a good option [39].

As described earlier, the energy models suitable for medium to long term studies are categorised as scenario tools. In fact, the oil and gas Multi-National Company Shell have relied on scenario analysis for four decades to support decisions in business strategic planning, also in billion dollar investment decision-making process and in facing future uncertainties in the oil and gas industry [49]. This approach has helped leaders in Shell make informed strategic decisions for the long term benefit rather than giving a knee-jerk reaction which frequently may only address a short-term problem. Energy outlooks at global, regional energy and national levels are also developed using scenario tools. Undeniably there have been concerns raised that long term energy system modelling has uncertainty issue associated with it since the depicted scenarios cannot be fully measured or observed due to the stretched time factor, thus making it impossible to properly validate something that has not transpired [50]. However, Pfenninger et al. reasoned that results from energy modelling scenario tools should be treated as possible storylines or pathways founded on key assumptions, and as a source of knowledge apart from empirical or experimental data [50]. Furthermore, scenario analysis is useful to study the consequence of currently implemented policy pathways and also possible alternative policy pathways that could solve issues such as energy security, energy resource planning, energy supply and demand, technology planning and at the same time mitigate climate impacts.

A few widely used scenario tools includes the Long Range Energy Alternatives Planning Systems (LEAP), Clean Energy Project Analysis Software (RETScreen), Model for Energy Supply Strategy Alternatives and their General Environment Impacts (MESSAGE) , MARket ALlocations (MARKAL), and The Integrated Market Allocation-Energy Flow Optimisation Model Systems (TIMES) which is the successor of MARKAL [39]. Details of these tools will be briefly elaborated in the following section.

2.5 Scenario generators commonly used in long term energy system studies

2.5.1 LEAP

LEAP is a bottom-up and top-down integrated scenario tool, it has been developed since 1980 by the Stockholm Environment Institute in Boston, United States of America. It has been traced in studies related to energy savings [51], energy supply and demand projections [52, 53], electricity generation expansion planning and demand assessment [54-56], long term assessment of GHG emissions [57, 58], for analysing the energy efficiency in the transport sector [59, 60] and the heating sector [61]. This tool has also been deployed for assessing renewable energy penetration in the electrical power sector [62, 63]. However, Connolly et al. noted that this tool lacked the optimisation function, it was only later on that the cost optimisation was incorporated just for the electricity sector but not inclusive to other energy end-user sectors [39].

2.5.2 RETScreen

The RETScreen “Renewable energy and Energy-efficient Technologies (RETs)” platform was developed in 1996 by the Canadian government and currently managed by Natural Resources

Canada. This tool is frequently used in techno-economic feasibility studies to analyse potential renewable technologies [64-66], apart from that this tool is also visible in studies related to retrofitting buildings with renewable systems [67-69] and in emission reduction studies [70, 71]. However, this tool cannot be used for simulating transport technologies and storage technologies aside from batteries [39, 42].

2.5.3 MESSAGE

The International Institute for Applied Systems Analysis (IIASA), Austria developed the MESSAGE model in the 1980s, and under a special agreement, members of the International Atomic Energy Agency (IAEA) have access to this tool. MESSAGE is suitable for detailed climate mitigation studies [72] because GHGs such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon (HFC) and sulphur hexafluoride (SF_6) have been included in this tool and the results are oriented on multi-sectoral mitigation strategies rather than solving a climate target. Unfortunately, this model could not be used to simulate the transport and residential sector [42]. This model generator has been applied in numerous climate studies by the World Energy Council (WEC) [73] and Intergovernmental Panel for Climate Change (IPCC) [74-76], supply and demand studies for the electricity sector [77-79], policy options by including nuclear [80, 81] or renewable energy [82-84] to reduce the emissions.

2.5.4 MARKAL or TIMES

The Energy Technology System Analysis Program (ETSAP) which is an implementing agreement under the auspices of the International Energy Agency (IEA) developed the MARKAL model in 1976. It is a bottom-up, linear programming, least cost optimisation model suitable for long term assessment of the total energy system or also for a single sector such as the electrical power sector. The energy system analysis via MARKAL can be implemented at local, national, regional and global level. Then in 2005, ETSAP introduced the TIMES model generator which is the combination of the MARKAL, Energy Flow Optimisation Model (EFOM) and climate model [85]. TIMES is an ideal foresight model for scenario development and analysis based on the Engineering, Energy, Environmental and Economics (4E) approach. The TIMES model requires an extensive rich input on technical data related to primary energy resource supply, fuel cost, power plant technologies, investment and maintenance costs, and electricity end-user demand sectors. Usage of TIMES is advocated by IEA due to the more flexible features compared to MARKAL.

2.5.5 Comparison of commonly used scenario tools

All the main characteristics of the four prevalent scenario generators found in energy studies are summarised in Table 1.

Table 1. Comparison of commonly used scenario tools

Tool	Developer	Purpose	Approach	Period	Time slice	Coverage	Limitation
LEAP	Stockholm Environment Institute	To study energy production, consumption, resources and emission levels	simulation, scenario, bottom-up, top-down and partial optimisation	20 to 50 years	Annual	Regional, National, Local	The earlier version had no optimisation function, but later the least cost optimisation was only applied to electrical energy systems
RET-Screen	Natural Resources Canada	To assess energy production, financial viability for renewable energy and energy efficient technologies	scenario, bottom-up, investment optimisation	Max 50 years	Monthly	User-defined	Storage is limited to battery technology and transport technology cannot be simulated
MESSAGE	International Institute for Applied System Analysis (IIASA), Austria	To produce energy systems with cost-effective strategies for GHG reduction	scenario, partial equilibrium, bottom up, operation optimisation, investment optimisation	Max 120 years	5 or 10 years	Global, Regional or National	Residential and transport sector cannot be modelled. Emission reductions cannot be set to climate targets
MARKAL or TIMES	International Energy Agency-Energy Technology Systems Analysis Programme	To study the 4E perspective of an energy system	scenario, equilibrium, partial top-down, bottom-up, investment optimisation	user-defined 20 to 100 years	Hourly, Daily, Monthly, Annual, 5 years, user-defined	Project level, Local, National, Regional, or Global	The NPV is the only economic indicator generated. A least-cost optimisation tool.

After reviewing the energy scenario tools, the MARKAL or TIMES model would be a better option to model the long term possible pathways for the electrical power sector, as this tool can simultaneously analyse the techno-economic and environmental assessment. This corresponds with the review findings conducted by Hall and Buckley that the most prevalent scenario tool adopted in UK studies are either the MARKAL and family models [42]. MARKAL has been used by more than 40 countries [86] for energy research and planning purposes. The similarities and major differences between TIMES and MARKAL [85] are summarized in Table 2.

Table 2. Similarities and differences between TIMES and MARKAL

Similarities of MARKAL & TIMES	Differences present in TIMES only
1. Technology explicit - each technology is described by a number of technical and economic parameters, thus each technology can be uniquely identified.	1. Variable length time periods - the periods in TIMES can be defined in a more flexible way as compared to MARKAL which has fixed periods.
2. Partial equilibrium models - the energy suppliers will produce energy according to the amounts that the consumers are willing to purchase.	2. Data decoupling - In TIMES change related to time periods can be done easily since time-dependent data are specified based on the year it applies. In MARKAL, immense database alteration needs to be done.
3. Linear programming - a mathematical optimisation method to minimise or maximise a linear function when subject by linear constraints.	3. Flexible time slices and storage process - in TIMES any commodity and process may have its own flexible time slices such as annual, seasonal, weekly and daily. However, in MARKAL only electricity and heat have rigid time slices.
4. Multi-regional feature - refers to the model being geographically integrated, where actions taken in one region may affect other regions.	4. Process generality - in TIMES every process share the same features. While in MARKAL, each process has different data and mathematical properties.
	5. Flexible processes - each process in TIMES are flexible which allows better modelling of a technology. In MARKAL processes are more complex.
	6. Investment and dismantling lead times and cost - TIMES has new parameters that could account for the construction phase and dismantling of facilities.
	7. Vintage processes – in TIMES when new investments and vintage processes are declared, two variables namely time and the vintage period are deployed. Vintage process in MARKAL is limited to demand devices.

8. Commodity variables - TIMES has a large number of commodity-related variables. Whereas MARKAL has limited commodity variables.

9. More accurate and realistic depiction of investment cost payments in TIMES due to detailed payment timing. In MARKAL each investment is assumed to be paid entirely at the initial year.

10. TIMES has climate equations that are able to quantify the CO_2 emission levels.

2.6 Prior studies related to energy modelling with MARKAL or TIMES

2.6.1 Modelling works with MARKAL

The next section gives a review of prior documented energy system studies modelled with MARKAL as follows:

Bhaskar and Shukla presented the long term implications of bioenergy penetration into India's major energy end-use sectors such as the transport, electricity, and residential using a top-down macroeconomic model and a bottom-up MARKAL model [87]. The study horizon is for 40 years from 2010 until 2050. The first scenario was paved on a resource-intensive path, while the other scenario took on the green development path. The CO_2 emission levels were tracked in both paths [87]. In this study, MARKAL was used to study energy end-user sectors at a national level in the context of energy security, energy access, air pollution and climate change.

Mondal et al. carried out a long term optimization on United Arab Emirates's power sector from 2010 until 2050 using the MARKAL model, their study investigated the future energy supply strategies and possible technology options for electricity generation that could reduce the CO_2 emissions. Three alternative scenarios with policy interventions namely the renewable target production, CO_2 emission reduction and international gas price scenarios were contrasted against the base case scenario [34]. Some interesting approaches noted in this model is that no upper boundary was imposed on the renewable resources such as solar and wind energy, apart from that the electricity demand projection was derived by fixing a constant annual growth rate of 4.8% throughout the horizon. This study basically assumed that the resource potential for solar and wind resources were unlimited. Nevertheless, in reality, solar panel installations are constrained by the availability of land space. The same goes for wind energy, in order to harness wind energy, suitable locations with sufficient wind speeds need to be identified prior to commissioning of wind farms, thus these resources would also be confined to viable locations. As for electricity demand projection increasing steadily for the entire 40 years duration, may not be realistic as more and more energy efficient devices are introduced which could lead to energy savings, furthermore, some economies are facing low GDP and low population growth rates which may affect the demand trend for energy.

Mallah and Bansal adopted the energy conservation approach on India's power sector, whereby different energy savings potential valued at 5%, 10%, 15% and 23% were tested using the MARKAL model throughout 2005 up to 2045 [88]. The installed capacity, electricity generation portfolio and CO_2 emissions associated with each assessed energy savings were presented [88]. Energy saving approach is a good strategy for a highly populated developing nation such as India as this strategy could reduce electricity demand and at the same time reduce the carbon footprint.

Another study by Jaskólski investigated the long term perspective of Poland's power sector from 2009 until 2060 using the MARKAL model [89]. He projected the future electricity and heat demands, the power capacity mix and electricity generation levels for Poland [89]. In this study, the electricity demand projections were endogenously derived based on historical data (1985-2010) of electricity consumption per unit of GDP and electricity consumption per unit of population or capita.

MARKAL has played an integral role in shaping the energy and climate policy in the UK post-millennium, it first appeared in the 22nd report of the Royal Commission on Environmental Pollution, related to the energy issue 'The Changing Climate' which proposed for the government to adopt a 60% emission reduction target based on the 2000 levels by 2050. MARKAL was able to project the technology portfolio and the expected cost to meet the emission target. Later on, in the 2003 Energy White Paper, MARKAL explored the plausible configurations to meet the 60% reduction target. Then through the 2007 Energy White Paper, the MARKAL-MACRO which is the newer version of MARKAL merged with a macroeconomic model to evaluate the impacts of emission reduction on the GDP and the primary fuel supply. Pursuant to the white papers, the Climate Change Act was tabulated and approved by Parliament in 2008. A significant change here is that the CO_2 emission reduction target was increased from 60% to 80% and through this legislation, the Committee on Climate

Change was established. This was followed with the 2011 UK Carbon Plan which sets the policy to achieve the carbon budgets until 2027. In fact, the Committee on Climate Change refers to the UK MARKAL model in proposing potential decarbonisation pathways [90]. The UK Energy Research Centre (UKERC) also acknowledged the MARKAL model as a systematic tool for long term optimisation of energy systems [90].

A recent study by Victor et al. adopted the MARKAL model to identify possible decarbonisation pathways for the power sector in the US to achieve an 80% CO_2 reduction by 2050 according to the 2005 levels [86]. The tested scenarios include default technology, natural gas at low and high prices, CO_2 emission based scenario and the carbon tax scenarios [86]. This paper suggested an interesting mitigation strategy that by integrating technologies such as carbon capture and storage (CCS), renewable and nuclear in the long run would play a vital role in CO_2 abatement. This is more effective rather than just deploying more natural gas plants to substitute the coal plants. The transport sector could also contribute if more low emission or emission-free vehicles are promoted on the roads.

Gül et al. analyzed the long term options until 2100 for use of alternative fuels in personal transport under different levels of CO_2 emission constraints using the global multi-regional MARKAL model [91]. This study revealed that biofuels are more feasible under mild climate policy targets, nevertheless as climate policy targets become more stringent the model depicts hydrogen fuel as a cost-effective solution [91]. Hydrogen fuel is a zero-emission fuel and therefore would be one of the promising future fuels in the transport sector. Water and energy will be released when hydrogen reacts with oxygen. Nevertheless, in order for hydrogen fuel to substitute fossil fuel, large-scale centralize production and infrastructure for distribution of hydrogen fuel needs to be developed concurrently. In addition, some unresolved issues for hydrogen fuel such as storing liquid hydrogen in high pressurized tanks need to be perfected and the tendency for leakage in the distribution pipelines may be higher since hydrogen molecules are very small. Thus the right material needs to be used to prevent leakages. It is also worth mentioning that hydrogen fuel produced by electrolysis would be one of the ideal solutions for future large-scale electricity storage especially when a significant proportion of the electricity is generated by intermittent renewables such as photovoltaics and wind energy.

The global multi-regional MARKAL model was deployed in a recent study by Kober et al. whereby the long term dynamics of global energy systems was explored not to exceed the temperature limit of 1.5 ^{o}C [92]. The findings of this study revealed that the 1.5 ^{o}C climate goal can be met if the CO_2 emission levels reach a negative value by 2060 [92]. To achieve this ambition, the integration of renewable, nuclear and CCS are critical technologies. In addition, fossil fuel consumption must be reduced by means of improving the energy efficiency levels and the demand sectors should embrace technologies based on electricity. It is noted that an exogenous demand and an upper boundary was applied for biomass and CO_2 storage for this assessment.

MARKAL was also used by Rajbhandari and Limmeechokchai (2017) to examine the energy system development of two Asian developing countries, they analyzed the impacts of emission mitigation policies such as implementing different carbon tax rates on the energy systems of Nepal and Thailand from 2010 until 2050 [93]. An obvious consequence of the carbon tax is that it significantly reduced the overall CO_2 and emission levels in both countries and the model opted for cleaner fuel usage like renewables and nuclear. Furthermore, the carbon tax strategy also reduced the primary energy supply consumption.

Another appealing approach in analyzing energy policy interventions like the implementation of energy import reduction targets was demonstrated by Anwar on the energy system of Pakistan. He assessed the effects of different levels of energy import reduction targets at 5%, 10% and 15% over the period from 2005 up to 2050 [94]. The study found that the energy import reduction policy managed to enhance Pakistan's overall energy security level whereby the penetration of renewable energy indicated a significant positive growth which alleviates substantial emissions. All the related literature pertaining to modelling works with MARKAL are summarized in Table 3.

Table 3. Summary of studies based on the MARKAL model

Model	Sectors	Objective	Location	Horizon	Reference
MARKAL	Transport, electrical power and residential	To study bioenergy penetration and track the CO_2 emissions.	India	2010 - 2050	[87]
MARKAL	Electrical power	To study future supply and technology portfolios that could reduce CO_2 emissions.	United Arab Emirates	2010 - 2050	[34]
MARKAL	Electrical power	To study the energy savings approach on the capacity and electricity generation mix and the impacts on CO_2 levels.	India	2005 - 2045	[88]
MARKAL	Electrical power	To project the electricity and heat demands, the capacity and electricity output.	Poland	2009 - 2060	[89]
MARKAL	Electrical power	To identify decarbonisation pathways for the power sector to achieve 80% emission reduction target relative to 2005 levels by 2050.	USA	2005 - 2050	[86]
Global Multi-regional MARKAL Model (GMM)	Transport	To analyze alternative fuel options for personal transport under climate emission constraints.	Global (six regions): Western Europe, The former Soviet Union and Eastern Europe, ASIA, Other OECD, North America, Latin America-Middle East-Africa.	2000 - 2100	[91]
Global Multi-regional MARKAL Model (GMM)	Energy	To explore long term energy transformation to meet the climate goal to limit temperature increase at no more than 1.5ºC.	Global	2016 - 2060	[92]

MARKAL	Energy	To analyze the effects of imposing carbon tax on the primary supply and reduction of CO_2 in developing countries.	Nepal and Thailand	2010 - 2050	[93]
MARKAL	Energy	To ascertain the impacts of energy import reduction targets on the energy system dynamics.	Pakistan	2005 - 2050	[94]

2.6.2 Modelling works with TIMES

The next section will review energy modelling studies that utilized the TIMES model, which is the successor of MARKAL and also currently advocated by the IEA as the ideal tool for long term energy scenario studies. Previous studies with TIMES include the following:

Rout et al. deployed the TIMES-G5 model to project the long term sectoral energy demand and emission levels from 1990 until 2100 based on key energy indicators approach for China [95], while Rout used the same model to perform the same study on India for the same period [96]. It is interesting to note that sectoral energy demand which includes transport, industry, commerce and residential sector were projected based on the growth model approach on selected key indicators which were exogenously fed into the model. These growth rates were determined by analyzing past trends or adopted the growth rates estimated by other scholars or energy outlooks by the International Energy Agency. The quantified key indicators for the transport sector are person-kilometres and ton-kilometres. While the indicators for the industry sector were heat demand per GDP and electricity demand per GDP. Whereas energy demand for cooling, heating and other electricity usage were the three indicators considered for the commercial sector. Four indicators were adopted by the residential sector, namely cooking, heating, cooling and other electricity demands. These two studies projected the sectoral energy demand and emission levels for China and India using the key indicator approach in the TIMES-G5 model.

Ma et al. projected the future water demand requirement for China's electricity generation from 2010 to 2050 with the TIMES model [97]. They investigated the effects of selected water fees on the electricity generation technology mix and water demand at the sectoral level [97]. The demand for water will increase in the dominant electricity generation technologies such as coal-fired plants, nuclear and hydropower. It is observed that when water fees were imposed, there were signs of water savings in the power sector. It is noted that this study introduced a new perspective in their analysis which is by linking water demand to electricity generation.

A localised study using the TIMES model of the entire energy system of the Basilicata Region in the southern part of Italy was demonstrated by Leo et al., whereby the base case scenario was modelled from 2007 until 2030 to support the local authorities in energy planning and estimating the greenhouse gases emissions [98]. Their paper gave a detailed description of the model development methods for each sub-sectors. What was thought-provoking about this study is that the energy demand projection was based on a declining population growth rate, whereby in 2030 the projected population size would experience a 10% reduction compared to the population statistics in 2007.

Pambudi et al. presented a preliminary analysis of the potential CO_2 savings for Japan from 1990 until 2050 through integrating CCS technology in the steel production and cement manufacture industries [99]. In the cement industry, CO_2 is produced during the calcination process of limestones. While in the production of steel, CO_2 is released owing to the combustion of coal. The CCS is a technology that is able to capture, compress and store 90% of the emitted CO_2 in a reservoir hidden beneath the land or sea. Japan is quite optimistic that CCS technologies would be a viable solution for abatement of CO_2 emissions from manufacturing industries like steel and cement.

CO_2 emission coming from the industrial sector in China is a growing concern since this sector is an energy and pollution-intensive sector. Thus studies to mitigate carbon emissions from the industrial sector in China is vital to ensure that the situation is kept under control. For instance, Li et al. analysed the energy consumption trends and the CO_2 emissions of China's cement sector throughout 2010 until 2050 using TIMES [100]. The notable features of this particular study are that the scenarios were developed with three different carbon tax rates as well as alternative abatement measures such as fuel switching, efficient technologies and CCS integration. Another similar study by Ma et al. investigated carbon mitigation pathways for China's steel sector using the TIMES model covering a 40 years horizon until 2050 [101]. Their study demonstrated that by imposing a carbon tax, increasing the production share by the recovery of steel scrap, switching to energy savings and emission reduction technologies are effective measures for decarbonising China's steel sector over the long run.

The long term energy consumption for the building sector in China from 2010 until 2050 was analysed by Shi et al. using the TIMES model with the aim to decarbonised this sector by improving the building insulation and renewable energy integration [102]. Their study findings highlighted that insulation would not leave a major impact on future energy savings since only a small portion of the buildings comply with advanced building standards. However, a low level of carbon emissions is possible if the usage of renewable energy is increased in the building sector.

A TIMES bi-regional model of the electrical power sector for Portugal and Spain covering a perspective from 2010 until 2050 was evaluated by Amorim et al [103]. Their main objective is to assess the cost-effective options for Portugal to achieve a decarbonised power sector by comparing the electricity system of Portugal as an isolated system and as an open system where the electricity system between Portugal and Spain are interconnected [103]. An attractive approach in this study is that the CO_2 emission reduction targets are the model constraints, in which 60% and 95% reduction are correspondingly imposed by 2030 and 2050. The results indicated that an open electricity system would be more beneficial for Portugal rather than a closed system because this opens the opportunity for Portugal to shift from a net importer of electricity into a net exporter of electricity when more renewables are developed. Furthermore, this would result in a lower investment cost risk to Portugal on renewable penetration.

The latest study by Mondal et al. applied the TIMES model to analyse the consequence of four separate policies on the power sector of the Philippines from 2014 up to 2040 [35]. The four policies involved are the deployment of the carbon tax, target-based renewable energy penetration, subsidized renewable power generation, and limited share of coal in the fuel supply mix [35]. The model suggested possible alternative development pathways for the power sector that could fulfil the rising electricity demand, and at the same time enhance the nation’s energy security as well as effectively mitigate environmental impacts. The prior studies using the TIMES model are summarised in Table 4.

Table 4. Summary of literature based on the TIMES model

Model	Sectors	Objective	Location	Horizon	Reference
TIMES G5	Electrical power, Transport, Industry, Services and Residential	To ascertain the sectoral energy demand and CO_2 emissions based on key indicators.	China	1990 - 2100	[95]
TIMES G5	Electrical power, Transport, Industry, Commerce and Residence	To project energy demands and emissions by adopting the key indicator approach	India	1990 - 2100	[96]
TIMES	Electrical power	To investigate the effects of selected water fees on water demand and electricity generation technology portfolio.	China	2010 - 2050	[97]
TIMES	Residential, Commercial, Agriculture, Industry, Transport, and Electricity plus heat.	To model the base case scenario for the entire energy system to support the local authorities in energy planning and emission reduction strategies.	Basilicata Region (Southern Italy)	2007 - 2030	[98]
TIMES	Cement and Steel industries	To assess the CO_2 emission saving by integrating CCS technology in the cement and steel industries.	Japan	1990 - 2050	[99]
TIMES	Building	To analyzed possible decarbonisation pathways by the use of insulation and renewable energy in buildings.	China	2010 - 2050	[102]
TIMES	Electrical power	To evaluate cost-effective opportunities for Portugal to achieve decarbonisation under a close and open system.	Portugal and Spain	2010 - 2050	[103]
TIMES	Cement industry	To assess future sectoral demand for cement, energy consumption and	China	2010 - 2050	[100]

		carbon emission. Three different carbon tax rates were tested and abatement strategies were simulated.			
TIMES	Steel industry	To study the energy consumption, and air emissions by adopting alternative carbon mitigation strategies. The strategies include the carbon tax, energy efficient technologies and increase in production share by the recovery of scrap steel.	China	2010 - 2050	[101]
TIMES	Electrical power	To assess the effects of alternative policies on achieving a low carbon power sector.	Philippines	2014 - 2040	[35]

After reviewing state of the art literature pertaining to studies that adopted the MARKAL or TIMES framework, it is clear that these two models are specialized tools used by energy experts for medium to long term analysis and planning for the entire energy system or just for a single energy subsector such as the electrical power sector, heat, residential, transport, industry etc. It is observed that the scope of the MARKAL or TIMES framework may cover the whole value chain from resource supply, conversion technologies, emission and the energy outputs as well as the demand side. Constraints of the model can be set by imposing CO_2 emission reduction targets, limiting fuel imports or exports, applying renewable energy targets, implementing a carbon tax or production share limits.

It is noted that the methods applied in these studies vary to a certain extent from one another since scenario development deals with policy interventions described by the modeller involving assumptions and adopted constraints. The methodology can either be complex or kept simplified, for instance, data on power plant cost can either be sourced from actual primary data in the studied country or by applying secondary data from credible reports such as the Energy Technology Reference Indicator from the European Commission [104]. Another obvious difference lies on the exogenous demand being inputted into the model generator, the demand projections based on the review were obtained by different approaches which include the simple growth model, linear regressions, key indicators like GDP or population growth rates, the LEAP model output etc.

Hence, it can be deduced that modelling with MARKAL or TIMES generators requires a data-rich and intensive process, whereby the necessary data from the studied location needs to be inputted in order for the model to be able to run the optimization based on an integrated approach. For instance, the main input and output data for modelling the electrical power sector with TIMES are illustrated in Figure 5.

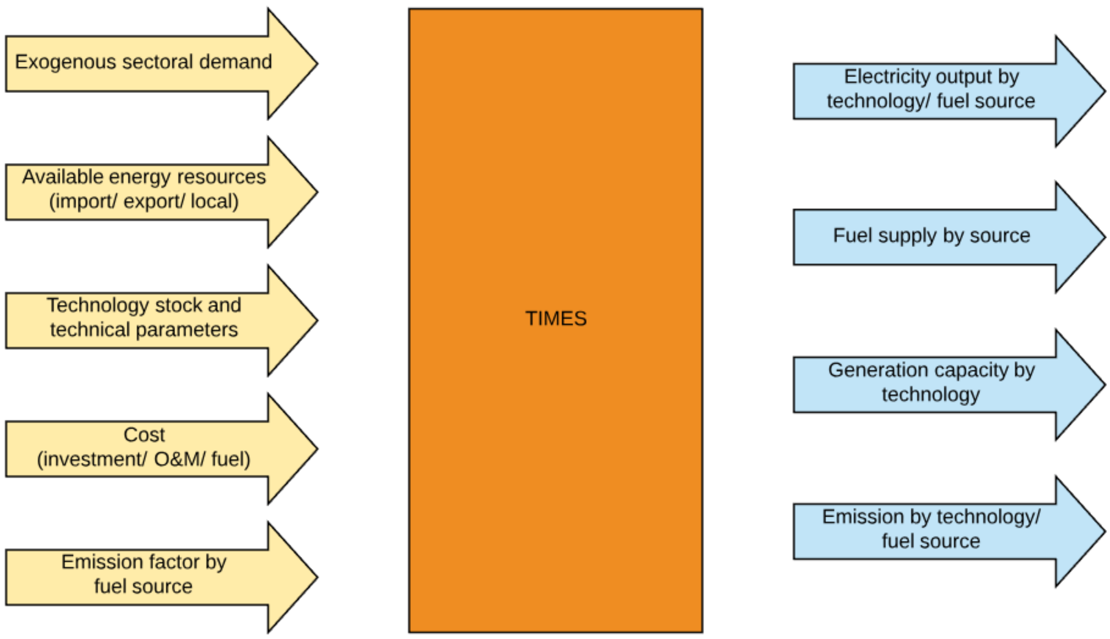


Figure 5. Major input and output parameters of TIMES in power sector modelling

Therefore, it is hard to fully adopt the methods used in prior studies since most of them are customized to match the objectives of their respective research interest. Furthermore, the policy interventions vary upon regions and countries, in fact, the input data such as energy balance and technology stock also differs from country to country depending on their available energy resources. Nonetheless, modelling energy systems with MARKAL or TIMES should not be treated as explicit predictions into the future but rather as possible pathways derived by a systematic modelling approach underpinned by a set of assumptions by the modeller.

2.7 Prior studies related to energy demand projections

As modelling with TIMES necessitates to input prospective endogenous or exogenous energy (electricity) demand. Thus the next section will briefly cover the review related to energy demand forecast. The literature on forecasting became more prominent in the 1880s when weather services were introduced in America and Europe [105]. There are various forecast approaches which can be considered either from a qualitative or quantitative perspective [106]. For instance gathering opinions or judgements about certain expectations from a group of specialists in a specific area is a qualitative means. Whereas, the quantitative-based forecast relies on statistical or econometric estimations. Depending on the research framework, a combined approach may also be adopted. Nonetheless, it is common to apply a certain level of qualitative judgement, even on a quantitative forecast. Selection of forecast method can be determined based on several considerations such as availability of data, the timeframe to perform the analysis, ease of method, and forecast period which includes short, medium or long term projections.

Energy demand forecast has gained momentum as it becomes imperative to comprehend the future energy fraternity as an accurate forecast could help formulate an effective energy resource plan. The perspective view of electricity demand can be drawn through analysing time series data such as peak load demand, or electricity consumption data. Another determinant could be looking at the supply angle which is to consider the total power capacity or the electricity generation figures. There are various forecast models, generally, these models can be further categorised as a traditional statistical approach which includes the time series univariate autoregressive integrated moving average (ARIMA) analysis and the econometric backed linear regression models. Another category is the non-linear artificial system solution such as the artificial neural network (ANN), fuzzy-logic, and genetic algorithm. The univariate Grey model has also appeared in energy demand prediction studies. Suganthi and Samuel conducted a comprehensive review of models typically adopted for energy demand forecasting [40].

In general, time series data refers to data observed over time and time series analysis can be performed via the univariate ARIMA model which explores a single variable to perform the forecast and this model is particularly useful when there is a data constraint on other determinants. A number of studies have previously associated ARIMA with energy forecasting. To highlight a few, Barak and Sadegh performed an energy consumption forecast for Iran until

2030 using the hybrid model based on ARIMA and the Adaptive Neuro-Fuzzy Inference System (ANFIS) [47]. Yuan et al. forecasted China's primary energy consumption using two different univariate models, namely the ARIMA and the Grey model [46]. While Ediger et al. forecasted the primary energy demand for Turkey from 2005 until 2020 by comparing results derived from ARIMA and Seasonal ARIMA (SARIMA) [107]. A few scholars contrasted the ARIMA and the ANN model energy consumption forecast for Hong Kong [48] and Taiwan [108] in which both studies concluded that ARIMA is the more effective and parsimonious approach in producing an accurate forecast. Chavez et al. produced a two-year ARIMA forecast on Asturias's energy production and consumption by analysing 16 years of past monthly data [109].

ARIMA was also applied in renewable energy-related studies. Whereby Sham et al. conducted a forecast on Bahrain's daily averages of wind speed, solar irradiance, ambient air temperature, and PV module temperature using the ARIMA approach to ensure an effective renewable energy system [110]. Another study by Erdem and Shi forecasted the short term wind speed and direction via ARIMA technique [111]. Whilst, Pedro and Coimbra completed the solar power production prediction for a photovoltaic power plant in Merced, California by adapting the ARIMA model [112]. Liu et al. compared the performance of two hybrid models for wind speed forecast namely the ARIMA-ANN and ARIMA-Kalman Filter to a single ARIMA model and found that the ARIMA-Kalman Filter model had the best performance [113]. Cadenas and Rivera's claims that hybrid models gave better wind speed projections rather than a single model approach [114]. While Torres et al. suggested that ARIMA is suitable for longer-term wind speed forecasting [115].

The ARIMA approach has also been used in for electricity demand projections studies. A short-term forward projection was performed on monthly electricity consumption data for Eastern Saudi Arabia [116] and Lebanon [117]. Besides that, Pakistan's electricity consumption was projected until 2020 using data from 1980 to 2011 by comparing the ARIMA and Holt-Winter forecasts, whereby the findings revealed that the latter model prevailed [118]. ARIMA was also engaged to predict 5-year forward projection of Turkey's net electricity consumption [119]. Short-term electricity demand loads were projected with ARIMA for Greece [120] and California [121] in order to identify the proper demand to allow for sufficient load dispatch.

Another flexible tool used in energy demand related studies is the linear or multiple regression model. Kialashaki and Reisel investigated the energy consumption in the residential sector of the United States using the multiple regression model [122]. Fumo and Biswas examined the energy consumption of a residential building using the simple linear and multiple linear regression approach [123]. The gas consumption for Ankara was predicted from 2002 until 2005 with the multiple regression model by analysing data for the past 10 years [124]. Turkey's energy consumption and CO_2 emissions were forecasted until 2015 via the multi-regression method based on gross national product and population growth data gathered from 1970 to 2002 [125].

As for electricity consumption forecast via the multiple regression approach have been documented in studies for New Zealand [126], Italy [127] and Eastern Southern Arabia [128]. However, the considered variables varied in these studies. The GDP, averaged price of electricity and population data from 1965 until 1999 were parameters considered for New Zealand's electricity consumption forecast from 2000 until 2015. While Italy's projection up to 2030 was based on the analysis of GDP, population and GDP per capita data from 1970 to 2007. Whereas, the electrical consumption for Eastern Saudi Arabia was projected as a function of weather, global solar radiation and population data. Renewable energy forecasting with the regression model has been demonstrated by Jónsson et al. who analysed the effects of day-ahead wind power forecast on the electricity price [129] and Reikard performed a short-term solar radiation forecast with the regression model by iterating the data to logarithmic form [130].

Apart from the traditional models, artificial systems like the artificial neural network (ANN) have been implemented for energy demand projections. The ANN model is a non-linear function and is classified as a multivariate analysis. Kankal et al. projected Turkey's net energy consumption using the neural network by analysing social, economic and demographic variables such as GDP, population, employment, import and exports [131]. South Korea's energy demand projections up to 2025 were determined with the ANN technique based on GDP, population, import and export data from 1980 until 2007 [132]. The ANN was adopted to forecast electricity consumption for Spain [133] , Turkey [134] and Iran [135]. In terms of renewable energy, prediction studies of wind speed [136-138] and solar radiation [139, 140] engaged the ANN procedure.

Alternatively, the use of multivariate non-linear based intelligent systems such as the Genetic Algorithm and Fuzzy Logic has been identified in several studies related to forecasting energy consumption [141, 142], photovoltaic [143] and electricity demand [144, 145]. Similarly, the univariate Grey Prediction model is also applicable for carrying out energy consumption [146] renewable energy [147] and electricity demand [148] projections.

As for energy-related projections studies carried out for Malaysia are still quite limited in the literature. Ibrahim et al. performed a short-term ARIMA projection up to 2016 on Malaysia's petroleum, natural gas, coal and electricity production and consumption by sector by analysing data from 1996 until 2007 [149]. Another study by Chandran et al. implemented a bivariate and trivariate (multivariate) analysis on electricity consumption, GDP and electricity price data from 1971 until 2003 to identify the causality relationship, their study revealed that a long run relationship existed between these variables [150]. Malaysia still lacks an overall country level electricity demand projection, currently, only two regions namely Peninsular and Sabah have peak demand and electricity generation forecasted until 2035 [151, 152], Sarawak still lacks these sort of projection (refer to map of Malaysia in Figure 6). Thus, it is essential to comprehend the medium to long term electricity demand requirement of the entire nation to enable sustainable energy planning and effective policymaking to take precedence.

In essence, there are numerous energy related forecasting studies as summarised in Table 5 that compared the results produced by different models and most of these studies suggested the model with better forecast performance in terms of accuracy which can be determined by comparing error statistics such as the mean squared error (MSE), root mean squared error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE) [153, 154]. To this point, there are contradictions related to scholars view on which model is the better forecasting tool, thus at this juncture, it can be drawn that there is no best forecasting technique because every forecast has some level of uncertainty. However, in order to avoid a spurious or invalid forecast, it is recommended to perform the forecast with a widely accepted and reliable approach that is backed by statistical or econometric theories. Therefore for the purpose of this study, the predictions will be estimated with the traditional models such as the simple growth and regression model as the baseline method along with the more sophisticated ARIMA model.

Table 5. Common energy forecasting models

Model	Energy	Renewable energy	Electricity
ARIMA	[46-48, 107-109]	[110-115]	[116-121]
Regression	[122-125]	[129, 130]	[126-128]
ANN	[131, 132]	[136-140]	[133-135]
Others	[141, 142, 146]	[143, 147]	[144, 145, 148]

2.8 Background of Malaysia and its power sector progress

As this study is centred on the long term prospects of Malaysia's electrical power generation portfolio, important insights need to be understood in order to better contextualise the current state of the power sector in Malaysia. The aforementioned insights include the climate profile, electrical supply and demand records, economic and demographic data, reserve to production ratio, fuel consumed in power plants as well as the energy regulatory framework.

2.8.1 Climate

Malaysia is located in South East Asia and has a total land area of 328,550 km^2 [155]. This country comprises of two land masses, namely Peninsular Malaysia and the northern upper part of Borneo Island which are separated by the South China Sea as shown in Figure 6 [156]. This country has a tropical climate since it is positioned near the equator, being hot and humid throughout the year with an average temperature from 21 to 32^oC during the night and daytime. It has two monsoon periods namely the Northeast monsoon which occurs from November to March and the Southwest monsoon which ensues in May until September [156].

Figure 6. Map of Malaysia [156]

2.8.2 Electricity supply and demand, economic and demographic data 1973-2015

The historical data as shown in Figure 7 and represented in Table 6 was compiled from several credible sources [6, 157-160], it denotes the time series data from 1973 until 2015 related to electricity generation and consumption alongside with the Gross Domestic Product (GDP) and population progress for the past 43 years.

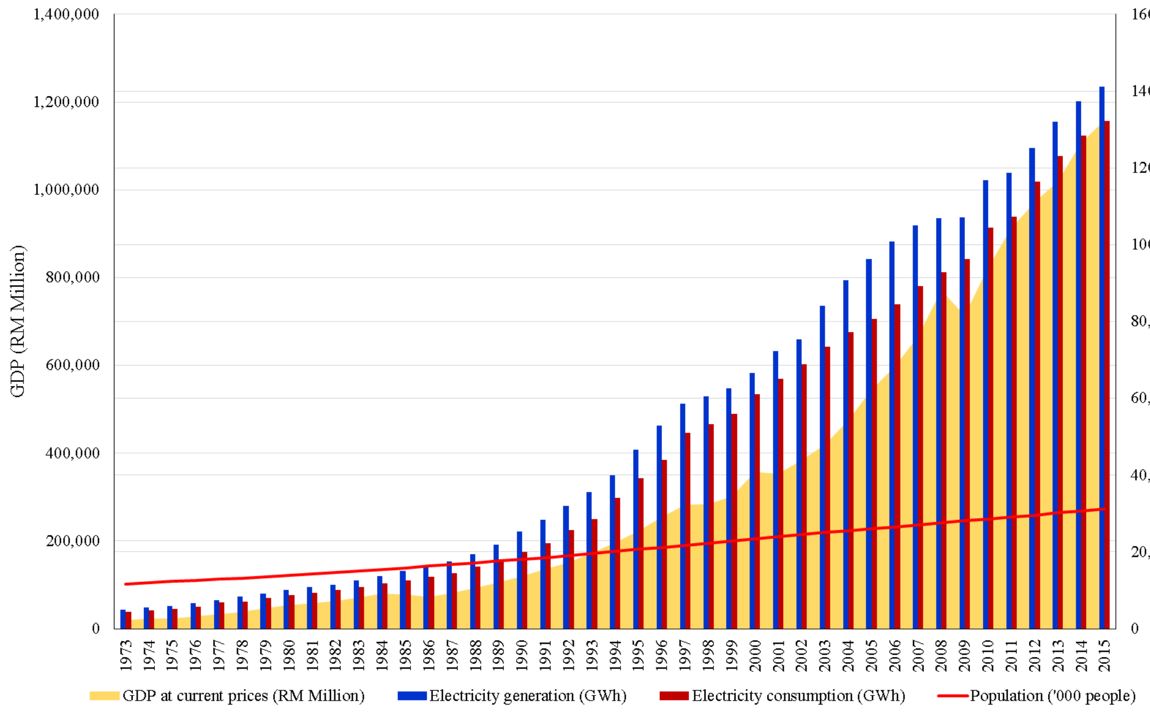


Figure 7. Electricity generation and consumption corresponding to the GDP and population [6, 157-160]

Table 6. Time series data for Malaysia 1973 -2015 [6, 157-160]

Year	Electricity generation (GWh)	Electricity consumption (GWh)	GDP at current price (RM Million)	population (people)
1973	4,970	4,339	18,723	11,719,800
1974	5,507	4,742	22,858	12,001,300
1975	6,010	5,224	22,332	12,300,300
1976	6,749	5,814	28,085	12,588,100
1977	7,522	6,795	32,340	12,901,100
1978	8,377	7,025	37,886	13,200,200
1979	9,234	7,955	46,424	13,518,300
1980	10,186	8,688	53,308	13,879,200
1981	10,895	9,304	57,613	14,256,900
1982	11,498	10,072	62,599	14,651,100
1983	12,655	10,874	70,444	15,048,200
1984	13,651	11,851	79,550	15,450,400
1985	14,996	12,549	77,470	15,882,700
1986	16,289	13,537	71,594	16,329,400
1987	17,616	14,572	81,085	16,773,500
1988	19,362	16,201	92,370	17,219,100
1989	21,889	18,003	105,233	17,662,100
1990	25,263	19,932	119,081	18,102,400
1991	28,335	22,373	135,124	18,547,200
1992	31,886	25,778	150,682	19,067,500
1993	35,579	28,474	172,194	19,601,500
1994	40,057	34,076	195,461	20,141,700
1995	46,632	39,225	222,473	20,681,800
1996	52,819	43,897	253,732	21,222,600
1997	58,675	50,952	281,795	21,769,300
1998	60,471	53,195	283,243	22,333,500
1999	62,553	55,961	300,764	22,909,500
2000	66,686	61,168	356,401	23,494,900
2001	72,280	65,015	352,579	24,030,500
2002	75,328	68,827	383,213	24,542,500
2003	84,022	73,371	418,769	25,038,100
2004	90,661	77,195	474,048	25,541,500
2005	96,214	80,705	543,578	26,045,500
2006	100,841	84,517	596,784	26,549,900
2007	104,950	89,294	665,340	27,058,400
2008	106,927	92,815	769,949	27,567,600
2009	107,116	96,302	712,857	28,081,500
2010	116,808	104,519	821,434	28,588,600
2011	118,788	107,331	911,733	29,062,000
2012	125,245	116,350	971,252	29,510,000
2013	132,047	123,079	1,018,614	30,213,700
2014	137,400	128,333	1,106,443	30,708,500
2015	141,147	132,199	1,157,723	31,186,100

Malaysia's economy has transformed from an agriculture-based economy in the 1970s and 80s into a manufacturing based economy in the 1990s and has moved up the value chain post millennium by being a service-oriented economy. As a developing country, Malaysia experienced a positive GDP growth throughout 1973 until 2015, the average growth rate over the past 43 years was 10.3%. However, in the last ten years since 2006 up to 2015, the economy has slowed down and the average GDP growth per annum over this period was 7.6%. In 2015, the Malaysian economy experienced a downfall to 5.0% growth compared to 6.0% in 2014 [6]. The anticipated GDP growth is expected to be resilient at 5.9% from 2016 until 2020 and 6.2% during the course of 2021 until 2030 [161]. Thus the power sector needs to sustain this positive economic outlook.

Malaysia's population record stood at 11.7 million in 1973 and the figures expanded to 31.1 million people in 2015. Over this 43 years, the average population growth rate per annum was 2.36%. Interestingly in the last ten years from 2006 up to 2015, the population annual growth rate had depreciated to 1.80%. Nevertheless, based on the United Nation's World Projection Report, Malaysia's population will still continue to expand and reach 42.1 million by 2050 [162].

The electricity consumption data increased from 4,339 GWh to 132,199 GWh between 1973 until 2015 with an average annual growth rate of 8.47%. However, the electricity consumption growth rate per annum over the last 10 years (2006-2015) declined to 5.10%. As for electricity consumption, Peninsular Malaysia consumed the highest using 83.79% or 110,770 GWh, followed by Sarawak with 11.81% or 15,624 GWh and Sabah has the least share with only 4.39% or 5,805 GWh [6]. This shows that social and economic development is far more concentrated in the Peninsular rather than East Malaysia. Malaysia's reserve margin for electricity in 2015 stood at 25.17% which is a healthy margin, this stipulates that the available power capacity is adequate to cater for the peak demand. Based on Figure 8, the electricity consumption by sectors in 2015 was accorded highest for the industry at 45.87% or 60,641 GWh followed by the commercial with 32.17% or 42,524 GWh and residential by 21.41% or 28,301 GWh. Whereas the transport and agriculture sectors hold a minimal consumption share at 0.20% or 266 GWh and 0.35% or 467 GWh respectively [6].

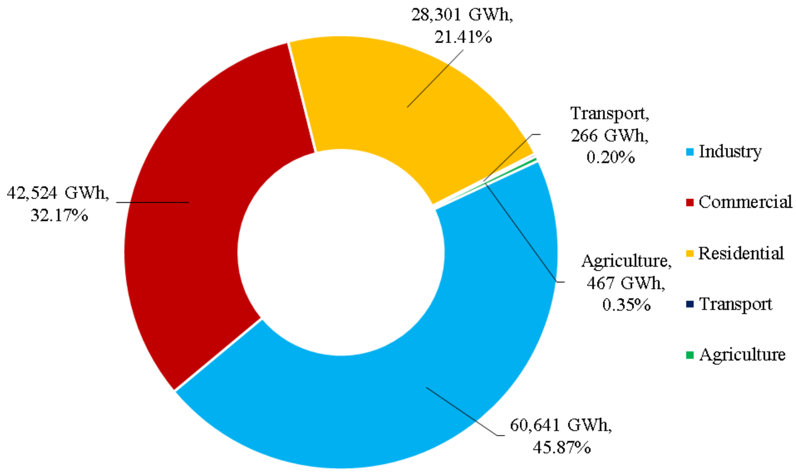


Figure 8. Electricity consumption by sectors in 2015 [6]

It is apparent that Malaysia's economic and population growth has steered the growth of power generation capacity and also the increase in electricity consumption. To maintain the momentum of a vibrant emerging economy in South East Asia, Malaysia must warrant sufficient power capacity to meet the required electricity demand. In order to sustain the economic growth of Malaysia as an emerging nation and cope with the increase in population size, urbanization, enhanced quality of life, advancement in information and communication technology, it is anticipated that the electricity consumption will continue to increase over the future course.

2.8.3 Fossil fuel reserve to production

Fossil fuel reserve to production balance as of 1st January 2015 in Malaysia [6] is presented in Figure 9. Malaysia's oil reserves stand at 5.907 billion barrels (36,151 PJ), if production rate continues at 661.62 thousand barrels per day which is equivalent to 241,491.3 thousand barrels per annum (1,478 PJ), then the oil reserves will be exhausted in approximately 24 years. Recently the consumption of heavy or medium fuel oil (HFO/MFO) as fuel for power generation has greatly reduced as it is only used as an emergency supply [152].

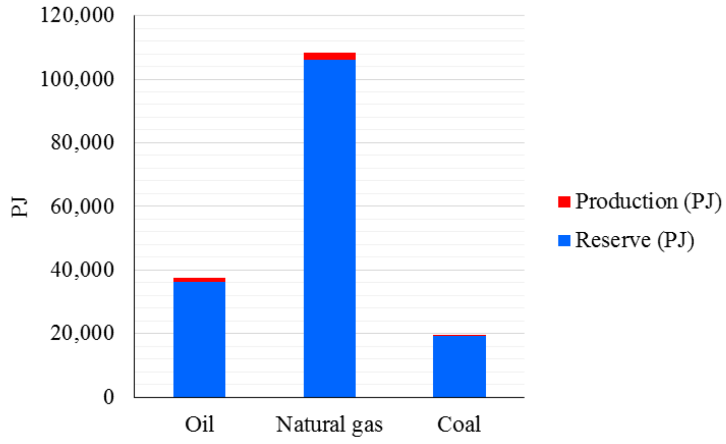


Figure 9. Fossil fuel reserve to production ratio [6]

While Malaysia's natural gas reserves are expected to last for another 43 years based on reserves of 100.413 trillion standard cubic feet (105,941 PJ) to the annual production of 2,362,539.15 million standard cubic feet (2,493 PJ). Hence, it is inevitable that Malaysia will turn into a net importer of oil and gas in the near future. Malaysia's measured and indicated coal reserve is estimated at 659.07 million tonnes (19,316 PJ), however, domestic production of coal is kept at the low end amounting to 2,559,444 tonnes (75 PJ) which allows for the reserve to last about 258 years. At a glance, it appears that Malaysia has great potential to develop its coal industry, however, 90.9 % of the coal reserves are located in remote areas of Sarawak which is hard to access due to lack of proper infrastructure. Therefore the country's demand for coal, especially for power generation, is largely met through imports from Indonesia, Australia and China. The power sector consumes 100% imported coke and coal [6].

2.8.4 Energy inputs in power stations

The total energy input for power stations in Malaysia as of 1st January 2015 stands at 33,134 ktoe [6]. This total energy supply can be allocated by fuel source as reflected in Figure 10, it is dominated by coal reaching 47.2%, followed by 40.4% of natural gas and 10.8% hydro. Fuel oil and diesel occupied 0.3% and 0.8% correspondingly, while renewables confined to biomass accounted for 0.5%.

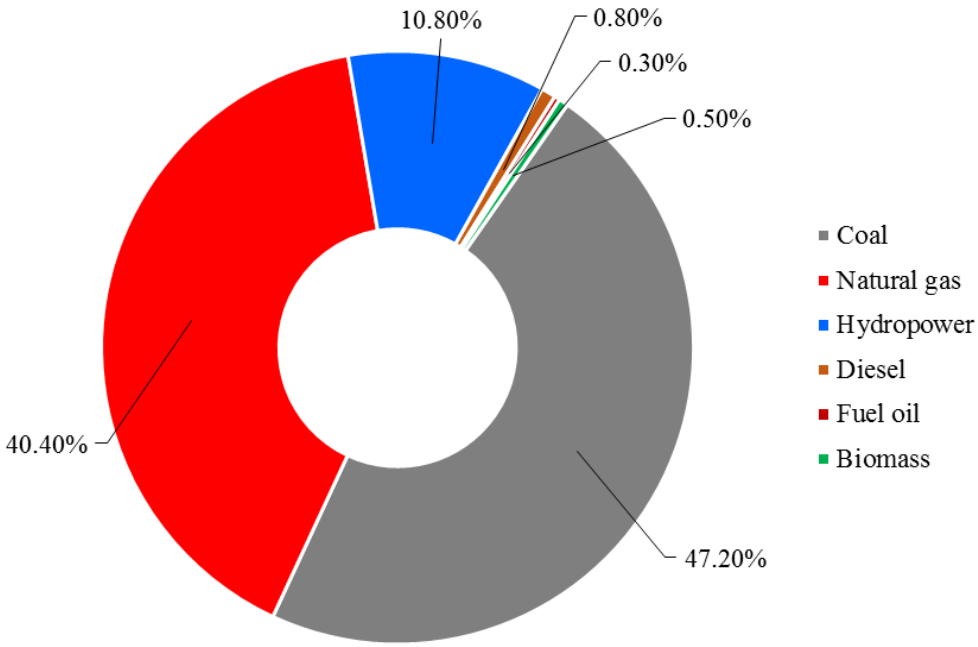


Figure 10. Energy input in power plants by source [6]

2.8.5 Energy regulatory regime

In Malaysia the power sector is regulated by the Government through the Ministry of Energy, Green Technology and Water as the policy custodian, whereas the Energy Commission and the Sustainable Energy Development Authority (SEDA) acts as the regulatory bodies [10]. The main power utility providers are Tenaga Nasional Berhad (TNB), Sarawak Energy Bhd (SEB) and Sabah Electricity Sdn Bhd (SESB). Independent power producers (IPP) also supply power to the three utility companies through long term power purchasing contracts. The government has laid a few energy policies and regulatory frameworks as listed in Table 7 with the intention to prolong Malaysia's hydrocarbon reserves and to diversify fuels in the energy mix to include hydro, renewables and nuclear to fulfil the rising demand. It is noted that wind energy is still not listed in the Renewable Energy Act 2011 [13] as one of the renewable resources eligible for feed-in tariff application, renewable technologies which are currently being reflected in the act are only limited to biogas, biomass, small hydropower and solar PV.

Table 7. Main energy policies and regulatory frameworks in Malaysia

Policy/ Act	Purpose
National Energy Policy, 1979	To ensure a secure energy supply by alternative energy sources, efficient energy usage and minimise the environmental impacts.
National Depletion Policy, 1980	To prolong and preserve Malaysia's oil and gas resources through annual production limit setting.
Four Fuel Diversification Policy, 1981	To diversify the energy mix in electricity generation through optimisation of oil, gas, hydro and coal.
Five Fuel Diversification Policy, 2001	To include renewable energy as the fifth fuel in the energy mix after oil, gas, hydro, and coal.
National Green Technology Policy, 2009	To attain energy independence, promote efficient utilization, minimize environmental impacts, enhance economic development and improve quality of life.
National Renewable Energy Policy and Action Plan, 2010	To enhance utilization of RE resources to contribute towards national electricity supply security and sustainable socio-economic development.
New Energy Policy, 2010	To incorporate efforts to ensure economic efficiency, security of supply by including renewable energy and nuclear.
Renewable Energy Act, 2011	To provide for the implementation of the feed-in tariff system to spur the growth of renewable energy.
Sustainable Energy Development Authority Act, 2011	To provide for the establishment of the Sustainable Energy Development Authority Malaysia.

Malaysia has been heavily relying on 88.7% of fossil resources to generate power, given that proven reserves are gradually diminishing, and having to deal with the energy security and the climate change issues, it is high time for Malaysia to restructure her electricity generation portfolio into a sustainable one. Therefore it is crucial to ascertain the possible future electricity generation options that are both sustainable and clean to the environment. It would be interesting to see how fuel diversification policies such as nuclear or renewable energy could address energy security and climate change challenges.

Since modelling the electrical power system sector requires inputs of fuel resources, therefore it would be good to comprehend Malaysia's renewable resource potential. Thus in the next section, the prospects of available renewable resources will be reviewed and presented.

2.9 Renewable energy current state and prospects in Malaysia

Renewable energy refers to inexhaustible energy resources such as wind, solar, hydro, biomass, biogas, tidal, wave and geothermal. Understanding the potential of renewable resources is a crucial step in energy planning specifically for electrical power planning and simulations at the country level. Renewable resource assessment has always been customised to the case study country because its availability is dependent on factors such as geographical, climate, terrain structure, hydrological, precipitation, crops that are country specific. It can be drawn that all forms of energy present on earth today apart from geothermal and tidal energy are derivatives of solar energy, this viewpoint includes fossil fuels as well.

2.9.1 Wind

The occurrence of wind happens when there is a regular shift of high pressure to low-pressure air. Practically cold air will become heavier which causes the air to descend and this phenomenon enhances the pressure of the air. While low pressured warm air will ascend to allow new cool air to fill the gap. Put it in simple words, the variation in heat or temperature caused by the solar insolation creates wind which in essence clarifies why wind is considered as a derivative of solar energy. Wind energy has long been exploited for at least 3000 years, it was principally harnessed for sail vessels to cross the oceans or as water pumps to drain rivers and also as windmills to grind crops. Wind energy is fundamentally influenced by the wind speed which is cubically proportional to wind power, thus a slight change in wind velocity can significantly affect the power generation. Therefore prior studies related to wind energy in Malaysia were concentrated on on-site wind speed assessment. Application of the Weibull statistical approach in analyzing onshore wind speed distribution for a few locations in Malaysia was discovered in studies performed by [163-168], as this technique is considered one of the more versatile statistical approaches in describing wind speed frequency distribution [169]. The earliest studies in Malaysia in evaluating wind power density using the Weibull function dates back to 1986 [163]. Tiang and Ishak adopted the Rayleigh distribution function on Penang's wind speed data which was extrapolated to 50 m by the power law, their findings found that Penang is not viable for wind power [170]. The Weibull distribution is handy when there are more data measured in the shorter duration, whilst the Rayleigh function is convenient if the data are based on annual or monthly mean values [169].

Sopian et al. discovered via the Weibull distribution analysis that the wind speed at Terumbu Layang-Layang (Swallow Reef) exceeded 6.0 ms^{-1}[165]. Following this, the first pilot project to install a 150 kW wind turbine stationed in Terumbu Layang-Layang, was initiated in 2005 by National University of Malaysia [171]. However, the wind turbines have stopped functioning [171]. Successively, a hybrid system consisting of 100 kW photovoltaic panel and 2 units of 100 kW wind turbines were commissioned at Pulau Perhentian in 2007 and the reported mean wind speed is 7.26 ms^{-1} and each wind turbine generated 18 kW [172]. However, the reported wind speed was queried by Albani and Ibrahim [173] and Ho [171] claimed that the installed wind turbines have ceased to function a year after the commission.

A collaborative wind resource study by TNB and Industrias Metalurgicas Pescarmona SA (IMPSA) suggested several locations such as the Thai-Malaysia borders, Kota Kinabalu, Mersing and Kuala Terengganu were suitable for onshore wind. IMPSA estimated that Malaysia's wind power potential could achieve 2,000 MW and wind speeds along the Thai-Malaysia border were claimed to stream at 15.0 ms^{-1} [11]. It would be ideal to examine the wind speeds at the locations proposed by IMPSA to validate their findings. On the mechanical front, a group of Malaysian engineers designed the Eqwin small-scale wind turbine prototype which is operational at low wind speeds between 3.0 to 5.0 ms^{-1}, the rotor diameter is only 3.0 m and has a hub height of 10 m [174]. Albani and Ibrahim investigated wind speed for coastal zones in Kudat, Mersing, Kijal, and Langkawi through anemometer measurement at variable heights and the power law, the study revealed that only Kudat reached 5.00 ms^{-1} at 50 m height [173]. On a different note in 2003, Chiang et al. attempted first offshore wind speeds assessment in Malaysia, 15 years of wind speed data from 1985 to 2000 compiled through marine surface observations from 16 chosen locations were analysed. They established that offshore wind speed is highest at the east coast of Kelantan and Terengganu reaching 4.1 ms^{-1} [175]. The relevant past studies related to wind resource assessment carried out in Malaysia are listed in Table 8.

In brief the literature related to wind resource assessment in Malaysia are more inclined to on-site anemometer measurements and statistical analysis. However, this method can be costly and time-consuming, another alternative approach to obtain wind speed readings is through accessing wind resource satellite databases such as the National Aeronautics and Space Administration (NASA) surface meteorology and solar energy (SSE) [176] or the QuikSCAT ocean wind speed [177] or other long term compiled Geographic Information System (GIS) meteorology databases. Whereas the Gipe's power law [178] can be applied to obtain wind speeds at higher elevations. Combining satellite wind speed data with the power law approach for preliminary wind speed assessment has been demonstrated in following studies [179-181] that managed to established wind resource maps for China, Bangladesh and the Newfoundland Island respectively. For estimating wind power density a referenced wind turbine model is usually applied. The prospective step forward is to value add the literature in evaluating Malaysia's onshore and offshore wind speed and wind power potential by obtaining wind speeds attained from global satellite databases combined with the power law approach to identify suitable locations for harnessing wind power in Malaysia.

Table 8. Wind resource assessment-related research in Malaysia

Location	Data source	Method	Results	Reference
Penang Island	2008 wind speed data at 15.3m from the Bayan Lepas meteorological station	Rayleigh function and power law at 50m altitude	Mean wind power density of 24.54 Wm^{-2} (not viable for grid network utility-scale wind turbines)	[170]
Multiple sites in Malaysia	20 different meteorological stations	Weibull function	wind power densities exceeded 20 Wm^{-2} at stations located on the east coast and in the southern region of the Peninsular	[163]
Kuala Terengganu	anemometer readings at 18 m from 2005-2006	Weibull function	average wind speed is 3.7 ms^{-1}	[166]
i) Mersing; ii) Kuala Terengganu; iii) Alor Setar; iv) Petaling Jaya; v) Cameron Highland; vi) Melaka; vii) Kota Kinabalu; viii) Tawau; ix) Labuan; x) Kuching.	meteorological station wind speed data at 10 m	Weibull function	Mersing has the most potential with wind power density of 85.6 Wm^{-2}	[164]
Tioman, Redang and Perhentian Island	meteorological station wind speed data at 10 m	Weibull function	wind power density in Redang Island has the greatest potential at 85.1 Wm^{-2}	[168]

Kudat and Labuan	meteorological station wind speed data at 10 m	Weibull function	Monthly and yearly highest mean wind speed in Kudat is 4.76 ms^{-1} and power density is 67.40 Wm^{-2} Monthly and yearly highest mean wind speed in Labuan is 3.39 ms^{-1} and power density is 50.81 Wm^{-2} these two sites are found unsuitable for utility-scale wind energy	[167]
Terumbu Layang-Layang	meteorological wind speed data	Weibull function	a high power density of more than 500 Wm^{-2} and wind speed exceeds 6 ms^{-1}	[165]
Terumbu Layang-Layang	a 150 kW wind turbine installed in 2005	-	The first pilot project, wind turbine no longer functioning	[171]
Perhentian Island	A hybrid system of 100 kW photovoltaic panel and 2 units of 100 kW wind turbines were commissioned in 2007	Actual output	the mean wind speed is 7.26 ms^{-1} and each wind turbine generated 18 kW	[172]
-	Ambiguous (Report inaccessible to public domain)	measurement towers above 80 m height for one-year duration	IMPSA's suggested: i) the Thai-Malaysia borders, Kota Kinabalu, Mersing and Kuala Terengganu were suitable for onshore wind; ii) Malaysia's wind power potential is estimated at 2,000 MW; iii) Wind speeds along the Thai-Malaysia border are streaming at 15 ms^{-1}.	[11]
Johor Bahru	a hybrid photovoltaic-wind-diesel system	HOMER model	Wind speed is in the low range of 1.9 to 4.0 ms^{-1}	[182]
-	the Eqwin prototype with rated power between 0.5-1.5 kW	Mechanical engineering	The Eqwin prototype was designed, a small-scale wind turbine which is operational at low wind speeds within 3.0 to 5.0 ms^{-1}, the rotor diameter is	[174]

			only 3.0 m and has a hub height of 10 m	
Kudat, Mersing, Kijal, and Langkawi	Anemometer wind speed readings at variable height or extrapolated through the power law	Anemometer wind speed readings and power law	wind speeds were low except for Kudat which has a wind speed of 5.00 ms^{-1} above 50 m height	[173]
Offshore wind assessment	Wind speed data from1985 to 2000, compiled through marine surface observations.	Data provided by Malaysia Meteorological Service	offshore wind speed is highest at the east coast of Kelantan and Terengganu states reaching 4.1 ms^{-1}	[175]

2.9.2 Solar

Solar is indeed an enticing resource as it is an infinite source of energy. Currently, there are two types of technologies that can convert solar energy into electricity, namely the concentrated solar power (CSP) and the solar photovoltaic (PV) array. CSP uses mirrors to focus sunlight onto a receiver, which collects and transfers the heat to a transfer fluid that can be used to supply heat for end-use applications or to generate electricity through conventional steam turbines. CSP plants are generally feasible in areas with high radiation that exceeds 1,800 $kWhm^{-2}$ per annum [183] which exist in certain parts of the Middle Eastern countries, Africa, southern and middle America, Australia, China, and India. The ideal place to establish a CSP plant would be in areas with minimal cloud covers such as dessert or semi-arid zones. Since Malaysia is located near the equator, the climate is humid and constantly cloudy with high rain precipitation, which makes the environment unsuitable for CSP technology.

Technologies appropriate for tropical climates are the photovoltaic (PV) array which transforms photon into direct current (DC) and the solar thermal collectors which are used for heating up fluids. These two distinct technologies are very promising applications in Malaysia, as the daily average solar radiation falls between 4.0 to 5.0 $kWhm^{-2}$ [11, 184]. The daily sunshine hours in Malaysia span on average for 12 hours, however daylight hours for a PV array to optimally generate electricity can be reduced to between 4 to 8 hours due to shading effects from clouds and frequent rainfall in the afternoon. PV panels were initially used in remote parts of Malaysia to provide decentralised small-scale electricity supply. Through the successful implementation of a few PV grid-connected pilot projects, currently, the National Energy Utility Company TNB has the experience to manage grid-connected PV installations [11]. There are a few kinds of PV array like monocrystalline silicon, polycrystalline silicon, and thin films such as amorphous silicon, cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). Despite the high potential, the uptake of PV is still very low because of capital cost barriers [185]. Instead, solar thermal panels are more preferred for water heating in the hotel industry and in some middle to upper-class residential areas.

There are a number of solar energy-related studies as summarised in Table 9 which were carried out to investigate the solar irradiance of selected cities based on different approaches [184, 186-189]. Amin et al. through a field study exercise analysed and compared the performance of different commercial PV panels under Malaysian climate [190]. There were simulation studies on PV hybrid models for off-grid rural electrification that analysed the technical and economic feasibility of the system [182, 191].

It is noted that most of the prior solar resource literature were invested in determining the solar radiation and off-grid applications of solar PV. Prospective studies related to grid-connected solar PV system which considers land use constraints in Malaysia are rather limited. Such studies have been demonstrated by Mondal and Zenich who analysed PV potential for Bangladesh founded on land area for installation at 1.7% out of the country's total land area [192]. Another viewpoint, since PV systems are noise and pollution free technology, thus PV installations on existing rooftops of the residential, commercial and industrial area or the use of building integrated PV can be a pragmatic solution as this would not compromise further land usage and are already in the vicinity of the transmission and distribution networks.

Table 9. Solar resource assessment-related research in Malaysia

Location	Objective	Data source	Method	Reference
Perlis	To analyze solar irradiance and electrical output of a PV module	Meteorological data	Theoretical estimations	[186]
Kuala Terengganu, Kuantan, Kota Bharu	To estimate the monthly mean hourly global solar radiation from the daily global radiation in the east coast of Malaysia	Meteorological data	Empirical models	[187]

Kuching, Kota Kinabalu, Kota Bharu, Senai, Bayan Lepas, Kuala Lumpur, Petaling Jaya, Bandar Baru Bangi	To estimate monthly global solar radiation	Meteorological data	linear regression analysis on hourly data	[184]
Alor Setar, Ipoh, Johor Bahru, Kuala Lumpur, Kuching	To develop accurate models for global and diffuse solar radiation on a horizontal surface in Malaysia	Meteorological data	linear, nonlinear, fuzzy logic, and artificial neural network (ANN) models	[188]
Field study	To compare the performance of different types of solar panels in Malaysia - mono-crystalline silicon, polycrystalline silicon, amorphous silicon and copper–indium–diselenide (CIS)	Actual data logger output	Real performance evaluation of commercial PV panels	[190]
Johor Bahru	To simulate and perform technical and economic analysis of a hybrid system PV/wind turbine/diesel with and without storage	Solar radiation and wind speed data was obtained from NASA-SSE Satellite data	hybrid optimisation model for electric renewable (HOMER)	[182]
Kampung Opar, Sarawak	To simulate a PV-wind-battery hybrid system and analyzed the economic feasibility	Load demand for a rural house based on simple appliances	hybrid optimisation by genetic algorithms (HOGA)	[191]
Kota Kinabalu, Kuching, Ipoh, Alor Setar, Kuantan	Meteorology and satellite data are evaluated to estimate global and direct solar irradiance and contrasted using error statistics.	NASA-SSE Satellite data and Meteorological data	Regression analysis and error indicators	[189]

2.9.3 Biomass and biogas

Biomass refers to plant-based organic material used directly through combustion or indirectly by thermochemical conversion (gasification or pyrolysis) into biogas or other solid or liquid biofuels. As a matter of fact, biomass is not an emission-free source, nonetheless, it is considered a carbon neutral and renewable resource since it can be replenished by the regrowth of plants. The photosynthesis process that occurs in plant cells converts solar energy and CO_2 into chemical energy which is stored as carbohydrates in plants, hence this is the reason for considering biomass as a form of solar derivative.

Agricultural waste counts as a good biomass source, the agricultural plantations which include palm oil, rubber, timber, and rice generates significant waste in Malaysia. However out of all the mentioned crops, the most promising in terms of continuous mass supply of agricultural waste would be from the palm oil industry as Malaysia is one of the major palm oil producing nations in the world, whereby on a daily basis a significant amount of shells, fibre, empty fruit bunch (EFB), palm tree trunks and fronds will be accumulated and this provides a consistent biomass supply [193]. These waste residues especially shells and fibre are currently contributing to 211 MW of power through self-generating palm mills which are grid-connected [11]. Ng et al. and Sulaiman et al. highlighted that EFB can serve as a good biomass source [194, 195].

Another potential biomass source would be organic material from municipal solid waste (MSW), each day, 17,000 tonnes of solid waste is produced [196]. Landfill biogas is also another untapped resource that could be exploited since Malaysia has over 261 landfill sites [10, 197], methane (CH_4) the main content of biogas is produced from anaerobic degradation of organic materials. There have been several studies that showed that palm oil mill effluent (POME) a waste by-product from crude palm oil production could be a great medium for biogas synthesis owing to its high organic content that can be anaerobically digested [198-200]. The combined potential of biomass and biogas for power generation has been estimated to reach 2,000 MW by the Malaysia Energy Centre [10]. It is noted energy potential assessment for biomass and biogas resources in Malaysia that contemplates the increase in agricultural yield over a long term is still absent in the literature. Therefore, the power potential of EFB and CH_4 from POME will be explored in this perspective.

2.9.4 *Tidal*

Tidal energy is formed by the periodic variations of gravitational forces at different positions inter earth and moon, inter earth and sun, and mutually with the rotation of the earth at its axis influences the ocean currents which is known as the Coriolis Effect. The effect of the gravitational pull combined with the Coriolis Effect produces the alternating high and low tides [201, 202]. The Coriolis force, in brief, refers to the deflection pattern exerted by fluid mediums such as the air and the ocean, in the northern hemisphere it is deflected to the right or anticlockwise circulation and in the southern hemisphere, the deflection is inclined to the left or clockwise motion. The two available commercial technologies developed to harness tidal energy are the tidal barrage system and the tidal stream generator. The tidal barrage system is a mature technology similar to hydro dams which use the potential energy from the alteration in vertical tidal range to generate energy [202]. Whereas the tidal stream generator is a technology governed by similar principles as the wind turbine [201]. The prominent difference between wind turbine and tidal turbines is the density difference on the fluid medium, tidal turbines thrive in seawater which is 836 times much denser than air.

According to Sakmani et al. the tidal range in Straits of Malacca falls within the range of 1.6 to 3.7 m [203]. It is not practical to implement tidal barrage technology in Straits of Malacca since it requires a minimum tidal range of 5.0 m [204]. The current designs of tidal stream converter require the minimum tidal current speed of at least 1.5 ms^{-1} [202, 205]. It is also important to note that tidal current speed varies from site to site due to the influence of the seabed structure, in the shallow seabed and narrow passages like the water passage wedged within an island and mainland will have higher tidal current velocity due to the increase in friction. Research related to tidal stream resource assessment in Malaysia is quite limited, it was reported that the average tidal speed in Straits of Malacca is 2.0 ms^{-1} and Pangkor Island’s tidal speed was estimated at 0.48 ms^{-1} using the acoustic Doppler current profiler, an instrument that uses sonar waves for profiling tidal characteristics [203].

2.9.5 *Wave*

Waves are produced as a consequence of wind activities that transpires due to the change of air pressure emanating from heat differences in the air caused by sun radiation. In other words, wave similar to wind resource is also a solar derivative. Wave energy converters are still at the prototype development stage, the various prototype design is still vigorously being researched and developed. Wave energy resource assessment using satellite altimetry (height measurement is taken from the satellite to the sea surface by a radar pulse) data combined with discrete buoy measurement to retrieve wave heights and crest to crest wave period has been demonstrated by Barstow et al. [206] and also Krogstad and Barstow [207]. Wave assessment literature for Malaysia seawaters is also quite limited. Muzathik et al. applied the Rayleigh and Weibull statistical functions on data collected on site to estimate the wave heights and wave interval in the South China Sea territorial waters near to Peninsular Malaysia [208]. Another study by Mirzaei et al. evaluated the wave power potential along the east coast of Peninsular Malaysia by using the output from the National Oceanic and Atmospheric Administration (NOAA) wave simulation model WAVEWATCH III [209].

2.9.6 Hydro

Water is considered as a transformed solar energy, as the sun controls the earth's hydrological cycle. This hydrological cycle comprised of the continuous movement of water on, in and above the earth's surface by main processes such as evaporation, condensation, transpiration and precipitation. As a tropical country, Malaysia's average rainfall per annum is above 2,600 mm and its mean elevation is 300 m above sea level. Hence, Malaysia has a promising potential for hydropower. The Sarawak Corridor of Renewable Energy (SCORE) estimated that the hydropower potential for Sarawak alone is valued between 20,000 MW [210] up to 28,000 MW [10, 211], there are a few large hydro projects in the pipeline such as the dams in Murum, Baleh, and Pelagus each with capacities of 940 MW, 950 MW and 770 MW [10]. While the potential for mini-hydro development in Malaysia is projected to reach 490 MW [212]. Most of the potential sites to build hydro projects are in East Malaysia with a proportion of 85 % and the remaining 15 % is situated in West Malaysia [11]. The largest hydropower dam currently in operation is the Bakun project with an installed capacity of 2,400 MW [211].

2.9.7 Geothermal

Geothermal energy emanates heat from the internal heat stored within the molten rocks called magma underneath the earth's crust. There is potential to produce electricity from steam derived from 40 hot water springs across the Peninsular, currently, TNB is planning to generate 2 MW of electricity from 4 potential geothermal sites. While in East Malaysia, a geothermal source with 67 MW capacity per day was discovered in Apas, a town nearby Tawau [11]. Therefore the total potential for geothermal power in Malaysia would reach 69 MW.

2.10 Chapter summary

In a nutshell, through this review, the gaps in literature were revealed. Furthermore, the modelling tool and relevant methods to deliver this study were identified. Ultimately, the importance of this study was able to be established. The key findings, in essence, are as follows:

- It is noted that long term foresight studies for Malaysia in relation to sustainable electricity generation portfolios by exploring different energy resources and technologies to meet the electricity demand by 2050 are still scarce in literature;
- Long term electricity demand projections up to 2050 for Malaysia at the national level are absent;
- Renewable energy resource assessment-related research is still fairly limited in Malaysia as renewable energy is still in its nascent stage of development;
- The TIMES optimisation modelling generator will be the ideal tool for developing the Malaysia TIMES Electricity Model (MYTEM), the detailed approach will be elaborated in Chapter 3;
- The exogenous electricity demand projection up to 2050 will be forecasted with the traditional techniques such as the growth, regression and ARIMA model as described in Chapter 3;
- The renewable resource potential in Malaysia will be assessed by deploying the methods detailed in Chapter 4;
- Thus with the arising challenges of diminishing fossil fuel reserves and meeting climate obligations, it would be high time for Malaysia to find an optimal solution for the power generation system;
- It is expected that this study will provide a technically feasible and economically viable solution in an intermediate to long term for Malaysia by transforming the electrical power generation into a sustainable and low carbon state through the unconventional fuel diversification policy interventions.

Chapter 3. Development of Malaysia TIMES Electricity Model

3.1 Introduction

This chapter proposes a holistic approach to the development of Malaysia TIMES Electricity Model (MYTEM). This is a foresight study that involves the prediction of future possible scenarios for Malaysia's power sector up to 2050. For this reason, the future electricity demand requirement by 2050 needs to be ascertained as the initial step. This is then followed by an assessment of renewable energy potential in Malaysia to determine which renewable resources are of potential and to identify the reasonable upper boundary. The third step is to set the reference energy (electricity) system (RES) to establish the simulation boundary. Subsequently, several scenarios with specific policy interventions will be simulated in the TIMES model. The developed optimised scenarios will be analyzed and contrasted against the business as usual (BAU) scenario. In this chapter, the primary emphasis is placed on describing the methods used in the electricity demand projections, defining the RES, as well as the design inputs for developing the various scenarios under MYTEM. Whilst the approach in assessing the renewable energy potential for Malaysia will be described in Chapter 4.

3.2 Electricity demand forecast

This section of the study is to address the following research question:

- What is the expected electricity demand for Malaysia by 2050?

This question eventually evolved into the first research objective of this study, which is:

Objective 1: To estimate Malaysia's future electricity demand requirement until 2050.

Electricity demand forecasts can be established by analysing demand data such as electricity consumption (GWh), peak load (MW), or by looking at the supply angle which includes the generation capacity (MW) or the electricity production (GWh). There are different options to project electricity demand, however, in scenario modelling, the projection must mirror the real world situation as close as possible. In order to obtain a realistic projection of the electricity demand by 2050, a few methods will be applied in this study as summarised in Figure 11.

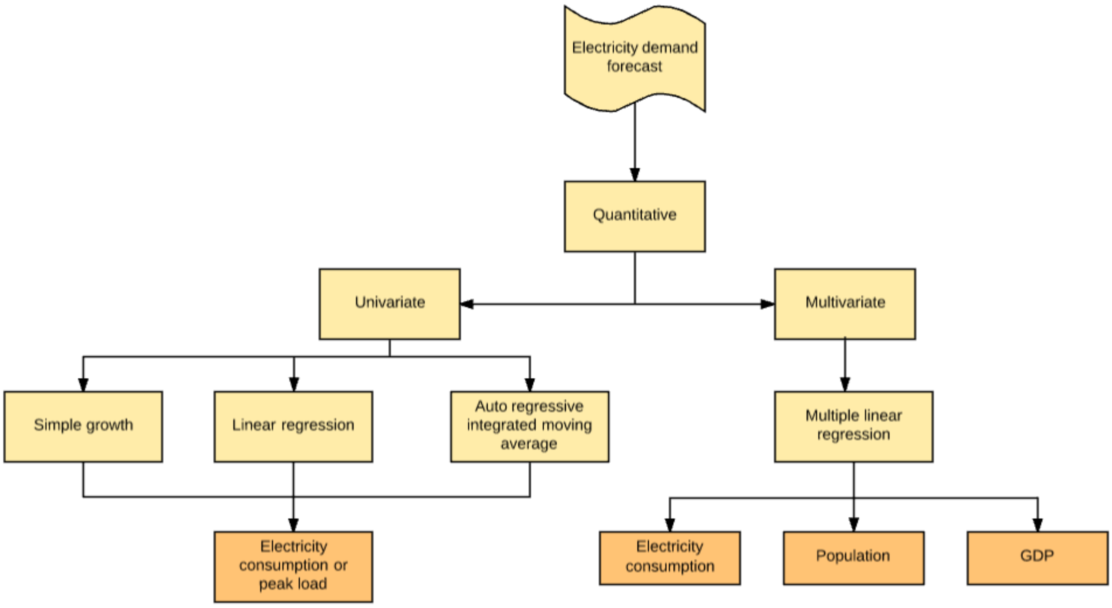


Figure 11. Electricity demand forecast research framework

All the methods involved in electricity demand forecast are based on the quantitative approach and can be further divided into the univariate time series or multivariate (includes two or more independent variable) analysis. Baseline techniques such as the simple growth model and linear regression model will be demonstrated, as well as the more refined approaches such as the multiple linear regression and the Autoregressive Integrated Moving Average (ARIMA) time series analysis. The baseline approach in forecasting such as the simple growth and the linear regression was performed in Excel, while the ARIMA analysis was performed in eViews software, a time series econometric forecasting tool.

3.3 Data gathering for electricity demand projection

As some of the tested methods will require historical data to produce the electricity demand forecast, therefore relevant data such as electricity generation and consumption, Gross Domestic Product (GDP) and population size since 1973 to 2015 will be compiled from credible secondary sources. The sample size is 43 annual observations.

3.4 Simple growth

The growth rate technique is a simple methodology which can be deployed even if the historical record is unavailable, in fact, the only necessary data would be the base year information. The forward projections can be derived by linking the growth rates to a certain set of assumptions. Nevertheless, if historical data is available, then past growth rates can be calculated and future growth rates can be set by analysing past trends. Some forecasts are based upon a constant growth rate throughout the full forecast period, which often may not be the case in the real world. Variable growth rates can also be introduced at different forecast stages.

The general formula for the simple growth approach can be expressed as per equation (3-1):

$$y_t = \omega(1 + R)^t \quad (3\text{-}1)$$

Where y_t is the measured variable or in simple terms can be explained as the new estimated amount at period t, while ω is the initial or prior amount being considered, and R is the growth rate in decimal form. In this assessment, the electricity demand forecast up to 2050 is projected based on electricity demand growth rates as projected by the Energy Commission of Malaysia [152, 161] as per Table 10. These growth rates were derived from a multiple linear regression analysis performed by the Energy Commission by analysing past data related to variables which include electricity demand, electricity sales, electricity tariff, GDP, population and efficient energy utilisation policy. The decreasing growth rate apparent during the projection period is due to the energy efficiency initiatives and the consumer response to the increase in electricity tariff which to a certain extent did dampen the electricity sales.

Table 10. Electricity demand growth rates [152, 161]

Year	Growth (%)
2011	2.7
2012-2015	3.7
2016-2020	3.1
2021-2025	2.6
2026-2035	1.4
2036-2050	1.4[1]

[1] Assuming that the growth rate has plateaued

3.5 Linear regression

The linear regression is a statistical approach that studies the linear association between two quantifiable variables, namely the dependent variable, y_t and one explanatory (independent or predictor) variable, x_t. Under the circumstances in which the explanatory variable x_t is known, y_t can be predicted by fitting a linear equation to the set of observations. The goodness of fit of the regression line can be statistically measured by the R-squared (R^2) value.

The mathematical formula for a linear regression model with an intercept c and an explanatory variable coefficient b_1 is expressed in equation (3-2):

$$y_t = b_1 x_t + c \tag{3-2}$$

3.6 Multiple linear regression

The multiple linear regression as represented in equation (3-3) is an extension of the linear regression method, however, a substantial difference is that this linear equation attempts to examine the correlation between the dependent variable, y_t and two or more independent variables x_n. The intercept c is a constant value, while b_n are coefficients to the independent variables.

$$y_t = b_1 x_1 + b_2 x_2 + \cdots + b_n x_n + c \tag{3-3}$$

3.7 Autoregressive integrated moving average

ARIMA or also known as ARMA model is a distinctive linear stochastic difference equation also known as the Box-Jenkins method named after the two statisticians who popularised this technique in 1976. It is an acknowledged forecasting approach and widely applied across multiple disciplines in which its uniqueness depends entirely on a single-variable to identify a model with the goodness of fit [213]. ARIMA is the combination of the autoregressive and moving average models [214].

The general mathematical formula for an ARIMA (p, q) model can be expressed as per equation (3-4):

$$y_t = \sum_{i=1}^{p} \varphi_i y_{t-i} + \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \quad (3\text{-}4)$$

Where y_t is the measured time series, φ_i is the ith auto-regressive coefficient, y_{t-i} is the series in the preceding ith period, p is the number of lags of the considered variable, ε_t is white noise error term, q is the number of lags of the error term, θ_i is the ith moving average coefficient, and, ε_{t-i} is the preceding error term at ith period. In an Autoregressive (AR) model, the effect on the variable y_t is largely determined by its own value in the preceding period. Whereas in a Moving Average (MA) model, the implication on y_t is that it relies on the value of its past error. An integrated series of dth order or I (d) shows the number of differences experienced by a data series to prompt stationarity for the purpose of detrending the series.

First differencing, I (1) is represented by equation (3-5):

$$\Delta y_t = y_t - y_{t-1} \quad (3\text{-}5)$$

Where y_t is the series at current time t , and y_{t-1} is the series at preceding time $t-1$. If the series still has not achieved the state of stationary after undergoing the first difference, then a second difference is undertaken and can be expressed as per equation (3-6):

Second differencing, I (2):

$$\Delta\Delta y_t = \Delta^2 y_t = \Delta y_t - \Delta y_{t-1_t} \quad (3\text{-}6)$$

When the integrated series is combined into ARIMA, the general ARIMA model is denoted as ARIMA (p, d, q). In order to obtain a meaningful ARIMA forecast, literature suggested that the least number of an annual data series should be in between 30 [215] to 50 observations [214]. In this research, the sample data consist of 43 annual observations which fulfil the prior condition. Whereas, for seasonal data and monthly data the minimum number of observations proposed should be between 80 to 120 respectively.

The ARIMA forecast estimations for electricity consumption time series from 2016 up to 2050, was modelled by deploying the eViews software package. Box and Jenkins popularised the three-step process namely identification, estimation and diagnostic check in the selection of a parsimonious ARIMA model to perform the forecast. This is then followed by the forecast and validation steps.

3.7.1 Identification

During the identification stage, the sample data is assessed for being non-stationary or stationary via visual assessment of the series line plots to see if a trend does exist or not. This is then followed by the evaluation of the correlogram spikes which includes the autocorrelation (AC) and the partial autocorrelation (PAC) function of both level and transformed series. By referring to the AC, stationarity can be determined by identifying if a constant mean exists over time and also to ascertain the lagged order q for error terms in a moving average (MA) model. While PAC is important to analyse the lag order p in an autoregressive (AR) model. At this stage, level data is usually transformed by undergoing the natural logarithmic function and the differencing process. Usually, the Augmented Dickie Fuller (ADF) [216] test is performed to confirm stationarity by screening out unit roots. However, in this research, higher powered unit root test procedures such as the Phillips-Perron (PP) [217] and the Elliot Rothenberg and Stock (ERS) [218] test will be implemented. The null (H_0) and alternative (H_a) hypothesis for these test are defined as follows:

H_0: Tested series has a unit root (data is non-stationary)

H_a: Tested series does not have a unit root (data is stationary)

If the test detects a unit root, this implies that the series is non-stationary, and vice versa, data is deemed stationary if there is no presence of unit root.

3.7.2 Estimation

The maximum likelihood approach is applied in the estimation stage. Referencing the minimum value of the Akaike Information Criterion (AIC) or the Schwarz Bayesian Criterion (SBC) are the most common model selection criteria in selecting a parsimonious model for the forecast because both criteria attempt to fit the data into the model. AIC tends to overfit the model, while the SBC tends to underfit the model. The equation for AIC and SBC [213] are defined in equation (3-7) and (3-8) respectively:

$$AIC = \tau\, ln(sum\ of\ squared\ residuals) + 2\sigma \tag{3-7}$$

$$SBC = \tau\, ln(sum\ of\ squared\ residuals) + \sigma \ln\ (\tau) \tag{3-8}$$

Where σ represents the total number of AR and MA parameter (p + q) and τ is the number of observations. Since ARIMA advocates for a parsimonious model where $p + q \leq 6$, therefore fifteen (15) ARIMA model combinations can be estimated under the condition that it exhibits stationarity as follows AR (1), AR (2), AR (3), MA (1), MA (2), MA (3), ARIMA (1,1), ARIMA (1,2), ARIMA (1,3), ARIMA (2,1), ARIMA (2,2), ARIMA (2,3), ARIMA (3,1), ARIMA (3,2) and ARIMA (3,3).

3.7.3 Diagnostic check

Residual diagnostic checks are conducted to remove any bias in the forecast by ensuring the residuals (ε_t) are uncorrelated. This can be evaluated by constructing the residual correlogram graphs and Ljung-Box Q statistic [219] to ensure that the AC and PAC of the estimated model are uncorrelated and has the characteristics of white noise process. This can be visually screened by observing the spikes of the residual correlogram, all of the AC and PAC spikes should be within the standard error bands. While statistically this can be verified by referring to the probability ($\hat{p}$) value of the Q statistics present in the final lag. If the corresponding $\hat{p}$ value at 95% confidence level exceeds the 5 percent significance level (0.05), then this confirms that the residuals are not correlated.

The Chow test can be implemented at this point to check on the structural stability of the series [220]. The hypothesis associated with the Chow test is:

H_0: There is no break at specified breakpoint

H_a: There is a break at specified breakpoint

In theory, a midpoint stint is preferred to undertake the test, but in testing real data, a certain period is chosen with justified reasoning. If the Chow test shows that a structural break is present, then the chosen model needs to be estimated from the breakpoint forward. In order to obtain a meaningful ARIMA forecast, the least number of an annual data series should be in between 30 [215] to 50 observations [214].

3.7.4 Forecast and evaluation

In order to obtain a meaningful forecast, the forecasted data must be transformed back to the level form. Since the forecasted data is constructed based on natural logarithmic first differenced series, it needs to be transformed back to the logarithmic state by adding the first-differenced logarithmic forecasts series to the last collective observation in the logarithmic series based on equation (3-9):

$$ln\, y_{t+1} = ln\, y_t + \Delta ln\, y_{t+1} \tag{3-9}$$

Where $ln\, y_t$ is the preceding logarithmic series, while $ln\, y_{t+1}$ refers to the subsequent logarithmic series and $\Delta ln\, y_{t+1}$ is the resulting forecast in the first differenced logarithmic form. Consequently, when the data has been changed to its logarithmic form, the exponential function is arrayed to transform the logarithmic series into the level state. After obtaining the forecast results from the selected models, forecast evaluation is conducted to identify the model with the better forecast based on a comparison of one of the preferred forecast performance measures such as the Root Mean Squared Error (RMSE) or Mean Absolute Error (MAE) estimated by eViews. The model with the minimum error term will be the best fit model for the forecast.

3.8 Validation

Validation of forecast results will be performed through withholding a five year period of known observed data to produce an in sample forecast. The holdback period is fixed from 2011 to 2015. The results of the in-sample forecast during the holdback period is then compared to the actual data to obtain the error measures for determining which model performs with a higher forecast accuracy [153]. If the compared series are identical in scale, then it is suggested to either use RMSE or MAE, but if the comparison is made between different scale or different methods, hence it is more sensible to compare the error statistics in the percentage form via Mean Absolute Percentage Error (MAPE) [153]. Since the forecast accuracy derived from different methods are being compared, therefore MAPE will be the preferred error statistics.

The error term, ϵ_t and MAPE calculations [153, 154] during the holdback period can be expressed as per equation (3-10) and (3-11) as follows:

$$\epsilon_t = y_t - \widehat{y_t} \tag{3-10}$$

$$MAPE = \frac{1}{n}\sum 100\,\frac{\epsilon_t}{y_t} \qquad (3\text{-}11)$$

In which y_t is the actual series, $\hat{y_t}$ is the predicted value and n refers to the sample size. Usually, the model with the lowest error value will be the plausible model. However, this may not always be the case, sometimes the judgement of an appropriate forecast may require some qualitative consideration rather than solely founded upon a quantitative approach.

3.9 Reference energy system

The Reference Energy System (RES) is a visual diagram to set the boundary of the MYTEM model. The RES designed for this study as in Figure 12 incorporates the whole value chain perspective.

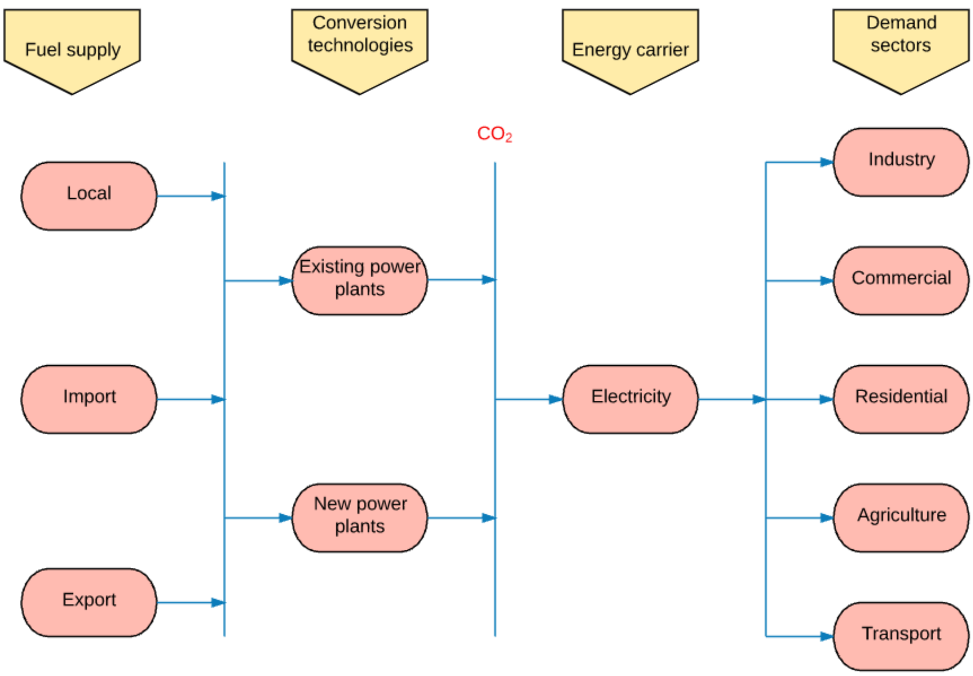


Figure 12. Reference energy system of the power sector in Malaysia

It basically covers the inter-relationships from the supply of primary or secondary fuel resources across conversion technologies right up to the end user electricity demand sectors. The fuel supply route is clearly defined according to origin either via imports, exports or local production. While the conversion technologies reflect on all the technologies used to convert energy into exergy (electricity), this includes the conventional fossil-fired plants, renewable technologies and alternative energy such as nuclear fission technology. The energy carrier in the form of electricity will fulfil the load requirement of the end user which can be further substantiated into five end-user demand sectors namely industry, commercial, residential, agriculture and transport. Last but not least, the emitted carbon emissions from electrical power generation will be traced as well. A list of the MYTEM commodities and technologies are provided in **Appendix A** and **B**.

3.10 Malaysia TIMES electricity model development

The main objective is to develop the Malaysia TIMES Electricity Model (MYTEM) for exploring future possible pathways for Malaysia's optimised electricity generation mix. A few scenarios will be evaluated as shown in Figure 13.

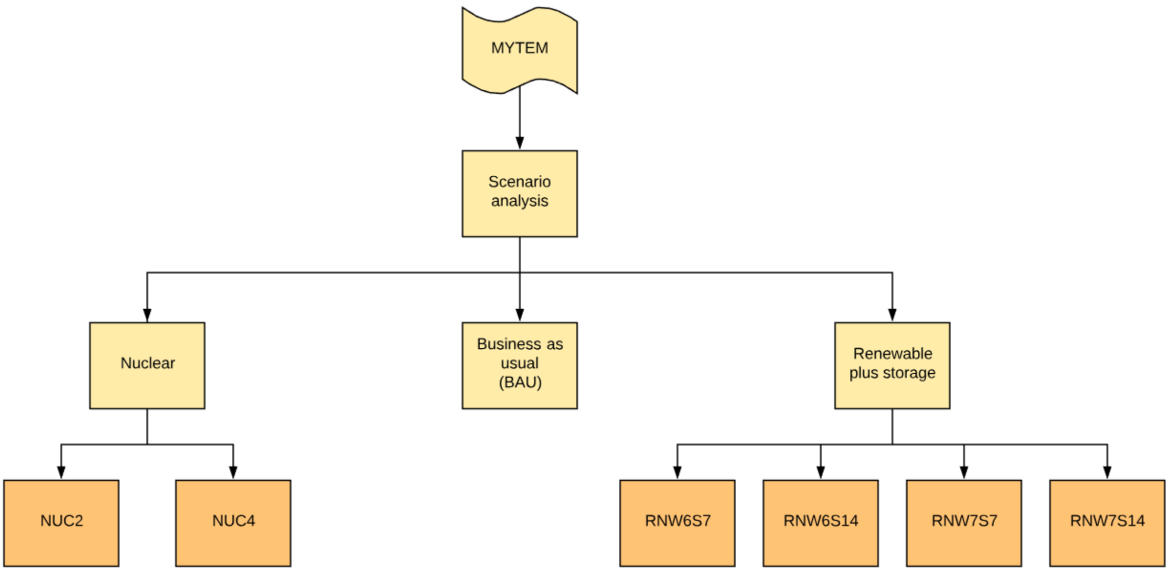


Figure 13. MYTEM scenario analysis research framework

The **I**ntegrated **M**arket Allocation-**E**nergy Flow Optimisation Model **S**ystem (TIMES) software will be deployed to create all the MYTEM scenarios through the **VE**rsatile **D**ata **A**nalyst Interphase - **F**ront **E**nd and **B**ack **E**nd **(**VEDA FE & BE). MYTEM will be optimised based on the minimised cost objective. All the scenarios will be analysed and contrasted against the business as usual (BAU) scenario according to the 4E (Engineering, Energy, Environment, and Economics) perspective, whereby power capacity levels, electricity output, fuel supplied at the power plants, besides that the carbon dioxide (CO_2) emission and the total system objective cost or net present value (NPV) will be evaluated. Power sector modelling with TIMES requires essential key parameters to be input in setting up and developing the MYTEM model which includes defining the system setting, identifying the fuel reserve to annual production, fuel cost, electricity demand throughout the study period, technology cost namely the investment cost (INVCOST), fixed operation and maintenance cost (FIXOM), variable operation and maintenance cost (VAROM) and other technical details of the technology involved such as plant lifetime, availability factor, and efficiency to convert energy or fuel source into electricity.

3.11 Scenario definition

The Reference Energy System (RES) as illustrated in Figure 12 will be manipulated based on the following MYTEM scenarios defined in Table 11 as follows:

Table 11. Scenario definitions

Scenario	Description
1. Base year 2015 (BY2015)	The power capacity and electricity output segregated by technology will be accounted for the base year 2015. This is to keep stock with existing technology and the energy fuel mix relied upon for power generation.
2. Business as usual (BAU)	This scenario will incorporate the base year 2015 stock, new capacity addition and retirement as planned by the government up to 2030. This trend is then extrapolated until 2050. The capacity for certain power plants with shorter lifetime such as biomass, biogas, and CHP has been fixed throughout the study period assuming that these power plants have been restored or upgraded. Under this scenario, it is assumed that no strong policy impetus is advocated on the use of alternative or renewable resources. This scenario will be used to contrast other scenarios that have applied certain policy interventions.
3. 2.00 GW Nuclear scenario (NUC2)	Under this scenario, the 2.00 GW Generation III Light Water Reactor nuclear power plant will be entered to the RES in 2030. This is to envisage the implementation of the nuclear

		fuel diversification policy for power generation as mooted by the government.
4.	4.00 GW Nuclear scenario (NUC4)	This scenario demonstrates the expansion of the NUC2 scenario with an additional 2.00 GW Generation III Light Water Reactor nuclear power plant introduced in 2040. Hence, the nuclear expansion turned the total cumulated nuclear power in the RES to be 4.00 GW.
5.	Renewables plus storage scenario (RNW6S7)	This scenario will explore the integration of six renewable technologies into the RES, along with the pumped hydro storage technology that could store seven days of generation capacity. Pumped hydro storage acts as a backup reserve which can be dispatched instantly to cater for peak load when renewable power is not producing sufficient electricity. The respective upper boundary for the six designated renewables include: geothermal (69.00 MW), biogas (1,103.00 MW), biomass (1,181.00 MW), mini hydro (490.00 MW), large hydro (23.84 GW), and solar PV (37.40 GW). The solar PV upper bound is derived by including the 800.00 MW solar farm and 36.60 GW of PV installations on rooftops. The 36.60 GW can be achieved if 0.15% out of Malaysia's total land area were installed with PV systems on existing rooftop, nevertheless 20% of the 0.15% allocated area were factored out to be unfit for PV fittings mainly due to reasons such as shading and structure being too weak to support the PV panels.
6.	Renewables plus storage scenario (RNW6S14)	This scenario maintains the same renewable technologies as per RNW6S7 scenario, except that the pump hydro storage capacity has been increased to cater for 14 days of electricity generation requisite.
7.	Renewables plus storage scenario (RNW7S7)	Under this scenario, offshore wind is added to the model from 2030 onwards on top of the six aforementioned renewable technologies. The targeted generation from offshore wind is 108.33 PJ (9.71%), while the pumped hydro storage capacity is set for 7 days stored electricity.
8.	Renewables plus storage scenario (RNW7S14)	Seven renewable technologies are demonstrated in this scenario, the only difference is that the pumped hydro storage is calibrated to 14 days of storage capacity.

3.12 Fuel supply and cost

The primary or secondary fuel supplied to the conversion technologies is estimated based on equation (3-12):

$$FUEL * \mu = ACT \tag{3-12}$$

Where $FUEL$ refers to the primary or secondary fuel inputted at the power plant in Peta Joule (PJ), the ability of the power plant to convert energy into electrical energy is reflected by the efficiency (μ) of the conversion technology, and ACT is the activity of generated electricity in PJ. As for fuel prices, such as coal, natural gas, distillates like diesel, oil residuals such as Heavy or Medium Fuel Oil (H/MFO) and uranium fuel needs to be declared in Million USD per PJ. Usually, biomass prices are ascertained as a function to motor gasoline price, this is to account for the cost of transporting the biomass source to the location of the power plant. Nevertheless, palm oil waste in the form of empty fruit bunch (EFB) are readily available at the palm oil mill site, thus the price for EFB will be assumed as cost free in this model. At present the palm oil mills are self-generators mostly fuelled by palm oil waste such as palm kernel shells or mesocarp fruit fibers. Therefore the generated electricity through combustion of dry EFB has great potential to be developed and this excess electricity can be transmitted to the grid. The market fuel price projections up to 2050 were gathered from the United States Energy Information Administration (EIA) [221, 222] and the local selling price in 2015 for distillates (USD 64.47 per barrel) and residual fuels (USD 44.52 per barrel) were obtained from the Malaysia Energy Information Hub (MEIH) [223]. While the cost through 2020-2050 for both distillates and residual fuel were normalised according to the percentage difference between the local and international price in 2015. The cost for biogas is assumed to be the same as natural gas since the molecular content in biogas predominantly comprise of methane gas (CH_4) which is natural gas in its pure form.

The power sector in Malaysia had benefitted from subsidised cheap natural gas as a direct form of government endowment to the people since Malaysia is an oil and gas producing nation. However, the drop in oil prices in recent years had caused Petronas, the National Oil and Gas Company to reduce their dividend, tax and royalty payments to the government. As a consequence, the government had to carry out the subsidy reform initiative by justifying that this move is essential in order not to further distort the economy. The subsidy rationalization program implemented since 2011 has narrowed down the natural gas prices for the power sector to the actual market price. The projected cost for indigenously produced fuels and cross-border traded fuel cost for the power sector are listed in Table 12. The conversion factor of 1 Million British Thermal Units (MMBtu) is equivalent to 1.055 x 10^{-6} PJ was applied to derive the final fuel cost in Million USD per PJ. The price of diesel was based on a conversion factor of 5.825 MMBtu per barrel diesel, while residual fuel oil (H/MFO) was based on 6.287 MMBtu per barrel.

Table 12. Primary and secondary fuel cost in Million USD per PJ [221-223]

Fuel	Origin	2015	2020	2025	2030	2035	2040	2045	2050
H/MFO (residual)	local	6.71	9.18	9.96	10.60	11.19	11.61	11.33	11.60
	import/ export	9.60	13.14	14.26	15.17	16.01	16.62	16.21	16.60
Diesel (distillates)	local	10.49	12.75	14.39	14.94	15.73	16.52	16.79	17.04
	import/ export	14.46	17.57	19.84	20.60	21.69	22.78	23.15	23.50
Natural gas	local/import/ export	3.12	3.94	4.25	4.38	4.37	4.61	4.81	5.14
Coal	local/import/ export	2.16	2.12	2.16	2.19	2.23	2.28	2.31	2.33
Uranium	import	0.51	0.62	0.63	0.64	0.64	0.64	0.65	0.66
Biogas	local	3.12	3.94	4.25	4.38	4.37	4.61	4.81	5.14

3.13 System setting

System setting is important to set key parameters for the model which involve specifying the region, period definition, fixing the currency and discount rate.

3.13.1 Region

MYTEM is a model designed specifically to simulate the electrical power sector in Malaysia, thus this is categorised as a single region and termed as REG1.

3.13.2 Period definition

TIMES has the flexibility in adjusting the period length according to the model milestone reporting years. For this simulation, the start year (base year) is fixed to 2015, as the latest Energy Balance data for Malaysia is up to 2015. MYTEM has a total study horizon of 35 years (2015 -2050) which is further divided into 8 uneven periods (pdef-8) to highlight the milestone years in which results are reported. The period definition settings are presented in Table 13. The time slice was fixed to annual since Malaysia is a tropical country and does not have the seasonal variations experienced in temperate countries.

Table 13. Setting up the period definition for the milestone years

Period number	Actual periods	Length of period (year)	Milestone (reporting year)
1	2015 - 2015	1	2015
2	2016- 2024	9	2020
3	2025 -2026	2	2025
4	2027 -2033	7	2030
5	2034 - 2036	3	2035
6	2037 - 2043	7	2040
7	2044 - 2046	3	2045
8	2047 - 2053	7	2050

3.13.3 Currency

Malaysia is a trading nation, hence most import and exports transactions are executed in United States Dollar (USD/$), and therefore in MYTEM all costs related to technology and fuel is declared in USD. The adopted foreign exchange rate is 1 Euro (€) equals 1.2091 USD.

3.13.4 Discount rate

The discount rate is a percentage that depreciates in value each year throughout the investment period of a power plant project. Throughout the model horizon, the 3% discount rate by the Central Bank of Malaysia is adopted since this is also the recommended rate for energy investment decision making by the National Renewable Energy Laboratory (NREL) [224].

3.13.5 Transmission and distribution efficiency

The nominal grid frequency in Malaysia is maintained at 50 Hz. The electricity transmission and distribution efficiency for the Malaysian transmission network is 94.21%, thus leaving the overall transmission and distribution losses at 5.79% [225].

3.14 Base year template

There are several necessary pieces of information that need to be furnished in the base year template such as the energy balance for the designated base year, Reference Energy System (RES) and system objective function or the net present value (NPV), primary fuel information, conversion technologies and the electricity demand value. In the primary fuel sheet, there are tables to define the related technologies, commodities and processes. The sector fuels sheet is for linking the fuels with the processes. In the conversion technologies sheet, electricity is declared as an energy commodity derived from primary fuel that has undergone a conversion process in power plants. The base year and future demand value are exogenously defined in the demand sheet.

3.14.1 *Energy balance*

The energy balance sheet needs to be entered in the default energy units, Peta Joule (PJ) since Malaysia's energy balance sheet is in kilotonnes of oil equivalent (ktoe) [6], thus the conversion factor of 1ktoe = 0.0419 PJ has been applied to create the data in Figure 14. The entire primary fuel supply, conversion and demand are reflected in the energy balance.

		COA	GAS	DSL	OIL	SOL	BIO	BIG	HYD	ELC	
		Solid Fuels	Natural Gas	Diesel	Fuel Oil	Solar	Biomass	Biogas	Hydro	Electricity	Total
	PRIMARY										
MIN	Domestic Supply	68	2601	0	0	3	8	1	150	0	2830
IMP	Imports	672	327	191	40	0	0	0	0	0	1230
EXP	Exports	-7	-1177	-225	-59	0	0	0	0	0	-1468
TPS	Total Primary Supply	733	1751	-35	-19	3	8	1	150	0	2592
	CONVERSION										
ESC	Energy Sector Consumptior	0	-162	-2	-1	-4	-5	0	0	-32	-206
ELC	Electricity Plants	-654	-639	-12	-4	-3	-3	-1	-150	519	-947
REF	Petroleum Refineries	0	0	414	71	0	0	0	0	0	485
	Total Conversion	-654	-800	400	66	-8	-8	-1	-150	487	-667
	FINAL										
RSD	Residential	0	0	0	0	0	0	0	0	102	102
COM	Commercial	0	1	6	0	0	0	0	0	153	160
IND	Industry	74	201	58	21	0	0	0	0	218	573
AGR	Agriculture	0	0	33	0	0	0	0	0	2	35
TRA	Transport	0	11	296	0	0	0	0	0	1	308
NEN	Non Energy	0	187	0	0	0	0	0	0	0	187
BNK	Bunkers	0	0	0	-14	0	0	0	0	0	-14
TFC	Total Final Consumption	74	401	393	6	0	0	0	0	476	1350

Figure 14. Energy balance sheet 2015

3.14.2 *RES*

In the MYTEM model, the RES flowchart can be derived from VEDA_FE, by selecting the basic function menu followed by the RES option. It can be built by browsing three types of options, either based on technology, commodities or processes. It is important that the RES derived from the model matches the initial intended RES as per Figure 12 to ensure that the output is relevant to the research objectives. The RES developed in TIMES for the BAU scenario appears in Figure 15.

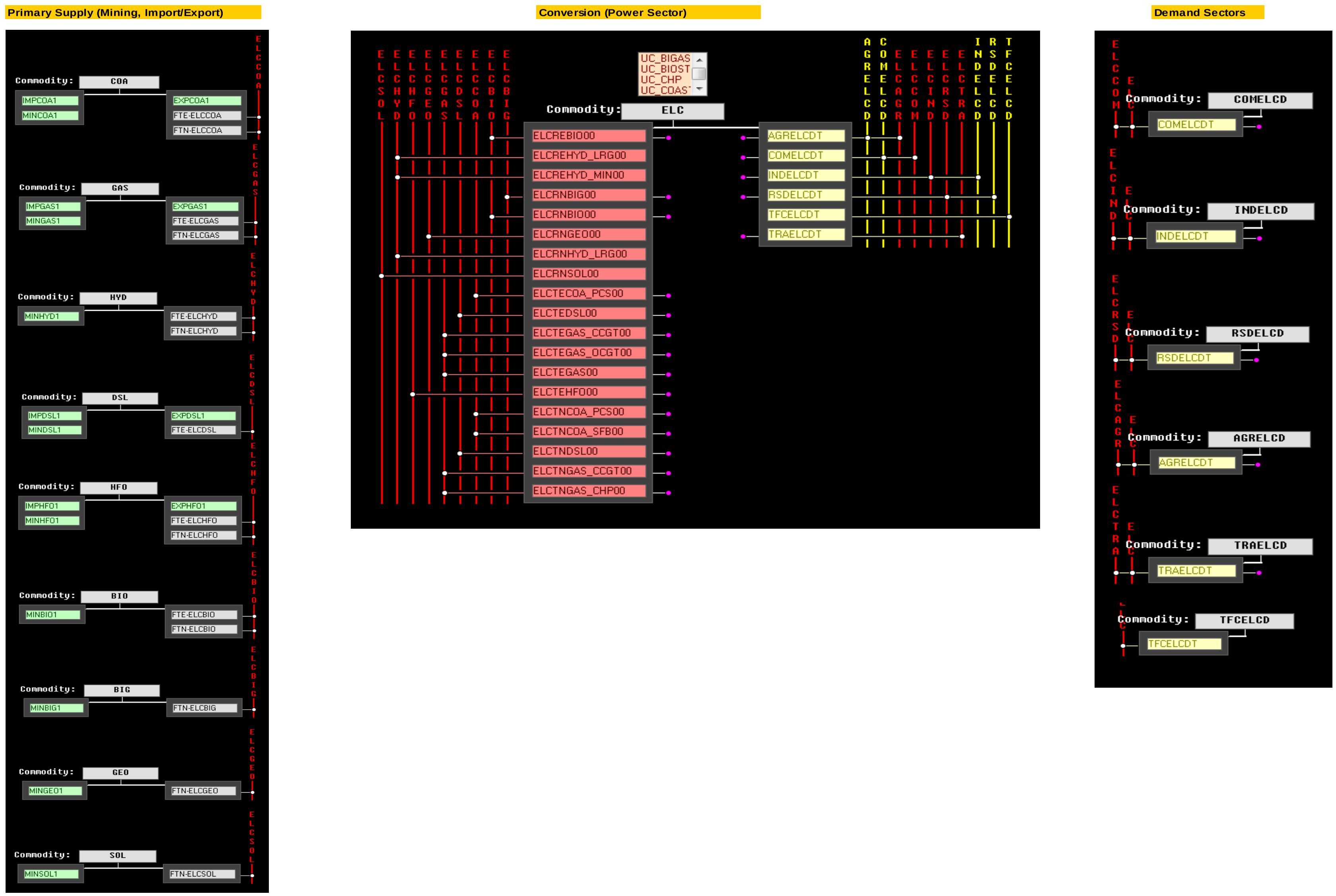


Figure 15. The RES illustration in MYTEM BAU scenario

3.14.3 System objective function

The mathematical structure of all the TIMES model is basically similar. TIMES is a linear program in which the optimisation system objective function is to minimize the total system cost based on equation (3-13):

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} \left(1 + d_{r,y}\right)^{REFYR-y} \cdot ANNCOST(r, y) \tag{3-13}$$

Where:

NPV	-	net present value of the total cost for the region;
$ANNCOST(r, y)$	-	total annual cost in region r and year y;
$d_{r,y}$	-	general discount rate;
$REFYR$	-	reference year for discounting;
$YEARS$	-	the set of years for which there are costs; and,
R	-	the selected region (in this case Malaysia).

3.14.4 Electricity output

The electricity output in MYTEM is processed based on equation (3-14):

$$ACT = STOCK * AFA * CAP2ACT \tag{3-14}$$

Where ACT refers to the activity of electricity generation in PJ, $STOCK$ is the capacity variable in Giga Watt (GW), while AFA denotes the availability factor of a power plant to operate at less than its full capacity, and $CAP2ACT$ is the conversion factor between the units of capacity and activity in which the default value for power plants to convert power into electricity output is fixed at 31.536 PJ/GW per annum.

3.14.5 Technology stock in 2015

All the existing conversion technologies stock in the base year along with the technical specifications needs to be input into the model. The technical details are specified according to plant type which includes available capacity [6], plant efficiency (μ) [226] in converting energy resources into electrical energy, plant availability factor (AFA) and lifetime [104, 227], contribution to peak load, as well as the electricity generation (PJ) [228]. The power sector technology stock count for Malaysia in 2015 and technical details are summarised in Table 14.

Table 14.Technology stock count in 2015

Technology type	Available capacity (GW)	Efficiency [μ]	Availability factor [AFA]	Life (year)	Peak load contribution [Peak]	Electric output (PJ)
Mini Hydro	0.03	0.90	0.90	60	0.90	0.40
Large Hydro	4.30	0.95	0.95	60	1.00	57.46
Gas-Combined Cycle (CCGT)	9.19	0.44	0.90	30	1.00	194.48
Gas-Open Cycle (OCGT)	2.08	0.38	0.90	30	1.00	43.96
Gas-Conventional Thermal	0.56	0.32	0.90	30	1.00	11.89
Coal-Pulverized Supercritical	8.49	0.39	0.85	40	1.00	221.68
Biomass (ST)	0.06	0.34	0.70	25	0.70	4.87
Diesel Engine	0.28	0.34	0.90	20	1.00	5.79
Fuel Oil Engine	0.07	0.33	0.90	20	1.00	0.16

3.14.6 Fixed and variable maintenance cost for base year technologies

The Fixed Operation and Maintenance (FIXOM) cost, as well as the Variable Operation and Maintenance (VAROM) cost for base year technologies are accounted in the model. Nevertheless, the investment cost (INVCOST) is not considered in the base year since all the existing power plants have been commissioned in the past years. Investment cost will be included when new power plants are added to the RES. The FIXOM (million USD per GW) and VAROM (million USD per PJ) cost for all technologies in the base year are listed in Table 15 [104].

Table 15. Fix and variable operation and maintenance cost for technologies in 2015 [104]

Technology type	FIXOM (Mil. USD/GW)	VAROM (Mil. USD/PJ)
Mini Hydro	79.80	1.68
Large Hydro	26.60	1.01
Gas-Combined Cycle (CCGT)	25.69	0.67
Gas-Open Cycle (OCGT)	9.31	4.37
Gas-Conventional Thermal (GT)	15.00	1.69
Coal-Pulverized Supercritical (ST)	48.36	1.21
Biomass (ST)	76.87	1.18
Diesel Engine	15.00	4.17
Fuel Oil Engine	17.50	3.47

3.14.7 Electricity demand

The electricity demand is input exogenously by adopting the growth model projections as described in para 3.4. In the MYTEM model, the electricity demand is further segregated into end-user demand sectors which comprises of the residential (RSD), industry (IND), commercial (COM), agriculture (AGR), and transport (TRA) sectors. For the BAU scenario, to reflect a status quo scenario the demand across the sectors throughout the study horizon is kept constant according to the base year fractions as per Figure 16, whereby industry holds 45.87%, followed by the commercial with 32.17% and residential with 21.41%, whereas the transport and agriculture sectors kept a minimal share at 0.20% and 0.35% respectively [6]. These proportions may alter depending on the implemented policies by the government. For instance, if Malaysia were to encourage and enable more use of hybrid and electric vehicles, then the demand for electricity in the transport and agriculture sector would definitely increase. The uncertainty of the electricity demand projection derived from the growth model falls within the MAPE range of ± 4.68%, therefore the upper and lower electricity demand boundary by end user sector will be estimated as well. The electricity generation levels are set with a 25% reserve margin to the electricity demand to cater for peak demand.

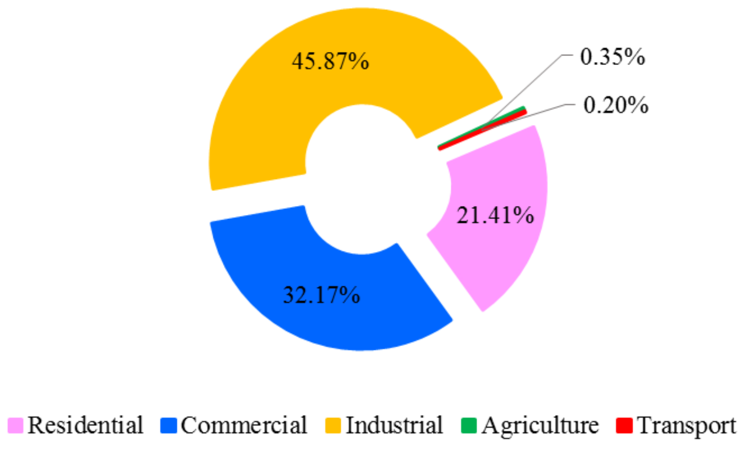


Figure 16. Electricity demand percentage by end-user sectors in 2015

3.15 CO_2 emission

Most economies around the globe including Malaysia have acknowledged the need to address the threats of climate change through a collective multilateral effort known as the Paris Agreement, Malaysia ratified this agreement on 22 April 2016 [8]. The Paris Agreement aims to prevent a global temperature rise exceeding the limit range between 1.5 to 2.0°C by the end of this century [8]. Based on the emission data in 2014, 54.04% of carbon dioxide (CO_2)

emissions in Malaysia comes from the combustion of fuel for electricity generation [229]. The MYTEM model measures the CO_2 levels emitted throughout the study horizon via equation (3-15):

$$EMI = ACT * COMEMI \tag{3-15}$$

Whereby EMI is the emission level measured in kilo tonne (kt), as mentioned earlier ACT refers to the generated electricity in PJ, while $COMEMI$ is the emission coefficient gained after dividing the emission factor with the efficiency of the conversion technologies in units of kt per PJ. The default emission factors by fuel type in kt per PJ as listed in Table 16 adopted the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for stationary combustion [230].

Table 16. Emission factors by fuel type for stationary combustion in the power sector [230]

Emission factor	CO_2 (kt/PJ)
Coal (Bituminous)	94.6
Coal (Sub-bituminous/ Lignite)	101.0
Natural gas	56.1
Distillate (Diesel)	74.1
Residual (Fuel Oil)	77.4
Biogas	54.6
Biomass	100.0

Most renewable energies do not emit any direct carbon emissions such as solar, wind, hydro and geothermal. Nevertheless, biomass and biogas are still considered as an organic compound and therefore would still emit carbon content. Alternative fission energy from nuclear power plants is presumed to be carbon free as well and the same is applied for transmitted electricity through interconnectors.

3.16 Planned addition and retirement of capacity

The government planned cumulative capacity addition up to 2030 [151, 152, 231] as listed in Table 17 will be accounted in all simulated scenarios. The description of the projects with new added capacity are detailed in **Appendix C, D** and **E**. The power plant capacities are maintained throughout the study period either by plant upgrades or refurbishment except for certain technologies that have been identified to retire early from the system. It is anticipated that power plants fuelled by residual oil HFO or MFO and diesel will retire from the RES by 2020. While the open cycle gas plants are scheduled to retire from the system in 2025 and conventional thermal gas plants will shut down by 2030.

Table 17. Cumulative capacity addition by technology (GW) until 2030 [151, 152, 231]

Capacity (GW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	Start
CCGT	1.45	0.06	0.03	2.80	0.10	2.50	0.00	0.00	0.00	0.00	0.00	2016
Coal (PCS)	1.00	1.00	0.00	2.30	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2016
Coal (SFB)	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	2017
Diesel	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2016
Large Hydro	0.41	0.00	0.00	0.00	0.00	0.17	0.00	0.18	0.63	1.53	2.74	2016
Solar PV	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	2017
Biomass	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2016
Biogas	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2016
Geothermal	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2017
CHP	0.00	0.40	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2017

All the retired power capacities from the system will be replaced with advanced technologies, for instance, the Combined Cycle Gas Turbines (CCGT) and the pulverised supercritical coal steam turbine with higher efficiency to convert energy into electrical energy. The planned retirement of power plants as per Table 18 [151, 152] will be reflected in all the scenarios.

Table 18. Cumulative capacity retirement by technology (GW) [151, 152]

Technology	Fuel type	Year	Capacity (GW)
Diesel Engine	diesel	2020	0.302
Fuel Oil Engine	HFO/MFO	2020	0.066
Gas-Open Cycle (OCGT)	gas	2025	2.077
Gas-Conventional Thermal (GT)	gas	2030	0.562
Gas-Combined Cycle (CCGT)	gas	2020	1.651
Gas-Combined Cycle (CCGT)	gas	2025	2.945
Gas-Combined Cycle (CCGT)	gas	2030	3.434

3.17 New and future technology cost and technical characteristics

New power plants and future technologies cost and technical details are introduced into the RES based on the designated scenarios and vintage years as depicted in Table 19, 20 and 21. Vintage years refers to the year that the specified technology becomes available and operative in the RES, the main vintage years are 2016, 2020, 2030, 2040 and 2050. The technical details of the power plants such as the efficiency is retrieved from the Union of the Electricity Industry [226], whereas the availability factor, lifetime and technology cost which includes investment cost, fixed operation and maintenance cost, and the variable cost was obtained from the European Union Energy Technology projections [104].

Table 19. New technology cost and technical characteristics for BAU [104, 226]

Technology	Vintage Year	μ	AFA	Life	Peak	INVCOST (Mil USD/GW)	FIXOM (Mil USD/GW)	VAROM (Mil USD/PJ)
CCGT	2016	0.58	0.90	30	1.00	1027.74	25.69	0.67
	2020	0.60	0.90	30	1.00	1027.74	25.69	0.67
Coal (PCS)	2016	0.45	0.90	40	1.00	1934.56	48.36	1.21
	2020	0.46	0.90	40	1.00	1934.56	48.36	1.21
Coal (SFB)	2016	0.42	0.85	40	1.00	2297.29	45.95	2.02
	2030	0.45	0.85	40	1.00	2297.29	45.95	2.02
Large Hydro	2016	0.95	0.95	60	1.00	2660.02	26.60	1.01
	2020	0.95	0.95	60	1.00	2660.02	26.60	1.01
	2030	0.95	0.95	60	1.00	2660.02	26.60	1.01
Solar PV (no track)	2016	0.15	0.25	25	1.00	1184.92	20.14	0.00
	2020	0.17	0.25	25	1.00	967.28	16.44	0.00
Biomass	2016	0.34	0.70	25	0.70	3494.30	76.87	1.18
Biogas	2016	0.36	0.70	20	0.70	4691.31	192.34	1.04
Geothermal (ORC)	2016	0.15	0.95	30	1.00	8427.43	176.98	0.00
CHP	2016	0.61	0.96	30	1.00	1221.19	47.63	1.34
Diesel Engine	2016	0.34	0.90	5	1.00	650.00	15.00	4.17

Table 20. New technology cost and technical characteristics for nuclear scenarios [104, 226]

Technology	Vintage Year	μ	AFA	Life	Peak	INVCOST (Mil USD/GW)	FIXOM (Mil USD/GW)	VAROM (Mil USD/PJ)
Nuclear (Gen III LWR)	2030	0.38	0.90	60	1.00	4957.31	94.19	0.84
	2040	0.38	0.90	60	1.00	4594.58	78.11	0.84

Table 21. New technology cost and technical characteristics for renewable scenarios [104, 226]

Technology	Vintage Year	μ	AFA	Life	Peak	INVCOST (Mil USD/GW)	FIXOM (Mil USD/GW)	VAROM (Mil USD/PJ)
Biomass	2020	0.35	0.70	25	0.70	3167.84	69.69	1.18
	2030	0.36	0.70	25	0.70	2865.57	63.04	1.18
	2040	0.38	0.70	25	0.70	2599.57	57.19	1.18
	2050	0.38	0.70	25	0.70	2357.75	51.87	1.18
Biogas	2020	0.38	0.70	20	0.70	3844.94	157.64	1.04
	2030	0.40	0.70	20	0.70	3337.12	136.82	1.04
	2040	0.42	0.70	20	0.70	3046.93	124.92	1.04
	2050	0.45	0.70	20	0.70	2780.93	114.02	1.04
Solar PV (rooftop)	2030	0.20	0.25	25	1.00	1197.01	23.94	0.00
Geothermal (ORC)	2030	0.15	0.95	30	1.00	7544.78	173.53	0.00
Mini Hydro	2030	0.90	0.90	60	0.90	5320.04	79.80	1.68
Offshore wind	2030	0.45	0.75	30	0.00	3119.48	93.58	0.00
	2040	0.48	0.75	30	0.00	2877.66	80.57	0.00
	2050	0.48	0.75	30	0.00	2756.75	63.41	0.00
Pumped Hydro Storage	2030	0.85	1.00	60	1.00	1813.65	27.20	0.00

Power plants can be categorised into base load or peak load technologies, electrical load refers to the fluctuating demand of electricity required at a certain period of time. Base load technologies are like nuclear power plants and coal power plants. Peak load plants are oil and conventional gas plants. They can be activated and shut down in a shorter time frame compared to the base loads plants. The cost to produce power from peak load plants is often more expensive than the baseload plants. Baseload plants usually are operated on a 24-hour basis due to a more complex process to start and shutdown operations. Baseload plants are also more efficient and cost-effective. Hydropower plants can be considered as a flexible technology that could fulfil both base and peak load requirements depending on the water level in the reservoir. Renewables technology such as solar and wind that are intermittently available produce power at certain times only, therefore they are not reliable to contribute to the peak demand unless large-scale energy storage technology becomes more viable. In this simulation, the pumped hydro storage system will be considered as it is a mature technology that is widely integrated with the use of renewable electricity. The measured distance for installing the subsea HVDC cable to connect the grids of the Peninsular and East Malaysia needs to be determined. In order to transmit 2.0 GW power through the HVDC interconnectors, at least two cables are required for a bipolar circuit, hence the total length is doubled. The related cost and technical characteristics of a subsea HVDC cable [104] are listed in Table 22.

Table 22. HVDC subsea interconnector cost [104]

Year	μ	AFA	Life	Peak	INVCOST (USD/km)
2025	0.93	0.99	40	1.00	2,901,840.00

3.18 Sensitivity analysis

A sensitivity analysis of the system objective cost will be performed by testing a higher and a lower discount rate. Since Malaysia is considered a developing country and also an emerging market in South East Asia, the economy is expected to grow. Therefore the identified discount rates for the sensitivity analysis will be a higher rate of 7% which is the acceptable rate by commercial banks for loan offers. However, a lower rate of 2% is chosen to simulate the occurrence of an economic recession.

In fact, there are also other factors or parameters besides the discount rates that could have significant effect on the results, these include applying a higher or lower electricity demand range. As technologies advances through time, changing some technical parameters such as enhancing the efficiency or adjusting the availability factor or increasing the lifetime of selected conversion technologies may also influence the power capacity levels and electricity yield. Nevertheless, in this study the improvement in efficiency rate of the conversion technologies have already been factored in the model.

3.19 Chapter summary

In essence, there are several methodologies applied in this research as summarised in the methodological research framework as shown in Figure 17:

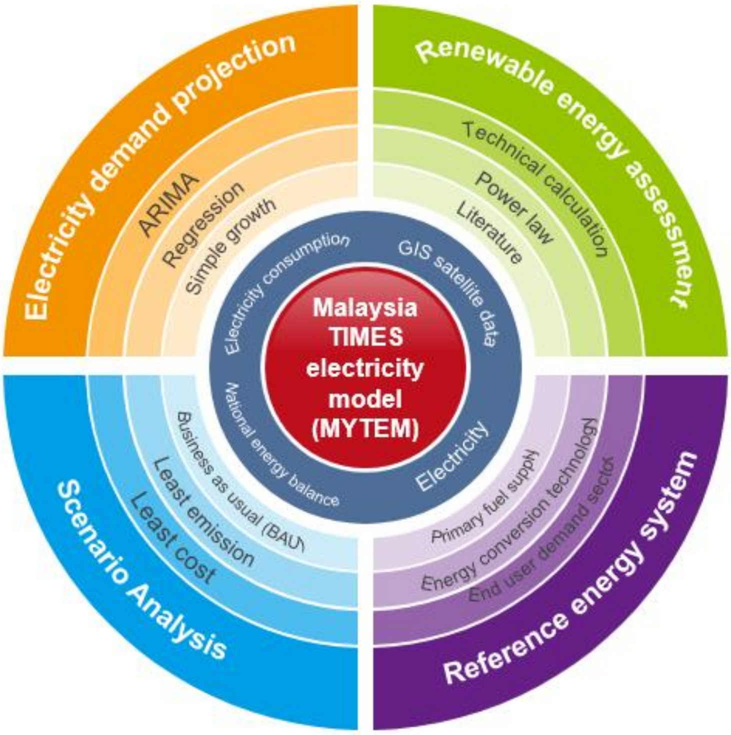


Figure 17. Methodological research framework

- The chosen methods for projecting electricity demand in this study will be delivered by some baseline techniques like the simple growth model, the linear regression and multiple linear regression models. Whereas the more sophisticated approach will be demonstrated by the ARIMA model. The model which mirrors the real world situation will be deemed as the realistic and sensible projection to be adopted in MYTEM;

- The RES has been clearly defined to cover the full spectrum of processes which includes the primary fuels supplied to the conversion technologies that produces electricity as the energy carrier to meet the end user electricity demand sectors;
- The minimised cost optimisation on future power generation technologies in Malaysia for a period from 2015 until 2050 will be assessed by evaluating several scenarios namely the nuclear scenarios (NUC2 and NUC4) and renewables plus storage scenarios (RNW6S7, RNW6S14, RNW7S7 and RNW7S14) that will be contrasted against the business as usual scenario (BAU);
- Assessing the potential of the available renewable resources of the studied location will provide a realistic renewable energy upper boundary, which is an important step in scenario modelling;
- The combination of different interdisciplinary approaches in delivering MYTEM is a unique and novel approach for modelling the electrical power sector and can be replicated to any other parts of the world at regional, country or even at a localised level.

Chapter 4. Renewable Energy Potential Assessment Approach

4.1 Introduction

This is a foresight study that involves the prediction of future possible scenarios for Malaysia's power sector up to 2050. For this reason, an assessment of Malaysia's renewable energy potential to determine the practical upper boundary needs to be carried out. This chapter describes the methods used in assessing the renewable resources and renewable energy potential in Malaysia.

4.2 Renewable energy potential assessment approach

Malaysia's renewable energy potential will be assessed through the methodological research framework portrayed in Figure 18. Generally, the approaches can be segregated into three clusters, namely via the geographic information system (GIS) satellite databases, theoretical technical estimations and via secondary data from available resources. Explicitly, evaluation for wind, solar and tidal stream energy was made by accessing satellite data. While the valuations for biomass, biogas, and wave were founded on theoretical calculations. Last but not least, the power generation upper boundary for resources such as hydro and geothermal were determined via reviewing the literature, since hydro and geothermal potential relies on scrutiny of hydrological, geophysical and geothermal data which are site dependent and in most cases still not accessible to the public domain.

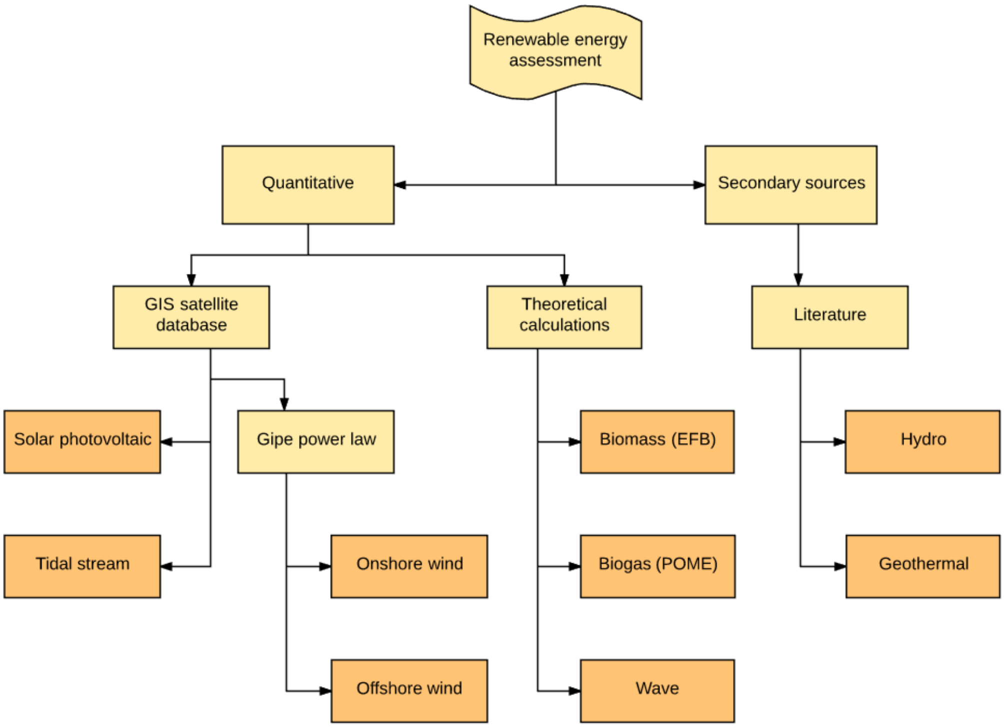


Figure 18. Renewable energy assessment research framework

This aspect of the study will attempt to solve the following research questions:

- What types of renewable energy are potentially viable in Malaysia?
- Can CO_2 emissions from power sector be reduced to mitigate climate change?
- Can the commitments in the Paris Agreement be met by Malaysia?
- Is it cheaper to source power from nuclear or from renewables?
- How do we compare the cost of electricity produced by different technologies?

All the questions listed above eventually form the second research objective which is:

- To assess the renewable energy potential availability in Malaysia

The above objective is vital to determine a sensible upper boundary in terms of power generation capacity for each of the renewable resources that have the potential for implementation in Malaysia. This renewable resource energy and power capacity estimation will serve as a reasonable upper boundary in modeling the MYTEM scenarios.

4.3 Wind

Application of GIS satellite wind database combined with the power law for analyzing wind power potential is still considered a fresh approach for Malaysia as most literature was inclined to statistical distribution function analysis or simulation analysis through on-site meteorological wind speed data collection. Application of satellite wind speed data is useful when on site data are sparse. Furthermore, the wind speed data is reliable because it is based on average wind speed derived from long term daily data collection over a period of many years.

4.3.1 Onshore wind

Monthly mean wind speed data at 50 m above sea level for 8 locations as specified in Table 23 were retrieved from National Aeronautics and Space Administration's (NASA) Langley Research Centre Atmospheric Science Data Centre Surface Meteorological and Solar Energy (SSE). The NASA SSE data was developed through a 10 year averaged wind speed collection from July 1983 to June 1993 [176]. All the chosen locations are marked on the map of Malaysia as shown in Figure 19 [232].

Selection of these locations was mostly driven by past literature which suggested that these areas either possess higher wind speed or higher wind power density and also as a means to validate past findings [11, 165, 172]. Terumbu Layang-Layang (Sparrow Reef) and Pulau Perhentian are islands situated in the South China Sea. However for this assessment, wind speed for Pulau Perhentian will be focused on the Big Island (Pulau Besar) rather than the Small Island (Pulau Kecil) where the two 100 kW wind turbines are currently installed, since it wouldn't make much spatial difference in climatology due to the close distance between this two islands. Whereas Kota Kinabalu, Kuala Terengganu, and Mersing are coastline cities. While Rantau Panjang and Padang Besar are situated near the Thai-Malaysia border zone which is considered by IMPSA, an Argentinien renewable energy company, as a promising area to harness onshore wind energy. Nonetheless, new locations such as Kampung Gua was chosen as it represents the central inland spot for Peninsular Malaysia and these set of coordinates are currently used to reflect Malaysia's position on the global map (refer to Table 23).

Table 23. Coordinates of selected locations for onshore wind assessment

Location	Latitude (°N)	Longitude (°E)
Kota Kinabalu	5.980	116.073
Mersing	2.431	103.836
Kuala Terengganu	5.330	103.137
Rantau Panjang	6.012	101.978
Padang Besar	6.663	100.322
Terumbu Layang-Layang	7.373	113.828
Pulau Perhentian - Pulau Besar	5.904	102.754
Malaysia - Kampung Gua	4.210	101.976

Figure 19. Selected locations for onshore wind assessment

The derived wind speeds at 50 m original hub height (Z_0) [176] are then applied in the power law as in equation (4-1) [178, 179] to extrapolate onshore wind speed at higher hub elevation (Z_1) at 100 m, 150 m, and 200 m. In this formula V_1 refers to wind speed at new height, while V_0 denotes wind speed at original height. The wind shear exponent for plain terrains (α_l) was applied, where α_l equals to 0.143 or better known as the 1/7 power law. Subsequently, wind turbine based on International Electrotechnical Commission (IEC) 61400 standard wind class [233] as per Table 24 will be identified based on the estimated mean annual wind speed range. Hence, it would be interesting to evaluate wind speeds by applying satellite GIS wind speed data [176] combined with Gipe's power law [178] via equation (4-1) that has been advocated by NASA.

$$\frac{V_2}{V_1} = (\frac{Z_2}{Z_1})^{\alpha_l} \tag{4-1}$$

Table 24. IEC 61400 standard wind class [233]

Class	Mean annual wind speed (ms^{-1})
I (High Wind)	8.50 - 10.00
II (Medium Wind	7.50 - 8.50
III (Low Wind)	6.00 - 7.50
IV (Very Low Wind)	≤ 6.00

4.3.2 Offshore wind

Offshore wind speed at 50 m above sea level for the South China Sea region was derived from the monthly averaged QuikSCAT satellite wind database supported by NASA Ocean Vector Wind Science Team [177]. The QuikSCAT wind maps were produced based on 5 years scatterometer readings since 2000 until 2004. A scatterometer is a scientific instrument that is used to measure the return of a beam of light or radar waves scattered by diffusion in a medium such as air. The scatterometer attached to satellites has been able to observe the earth surface wind velocities. After accessing the satellite ocean wind speed data, the same power law as per equation (4-1) was mobilized to calculate wind speeds at higher hub heights of 100 m, 150 m, and 200 m. However, a different value was entered for the wind shear exponent, since the surface has changed from plain terrain to seawater, where α_l is substituted by α_s with corresponding value of 0.09. The appropriate IEC 61400 standard wind class [233] for offshore wind turbines (refer to Table 24) will be identified according to the annual mean wind speed estimations.

4.3.3 Wind power extraction

As a rule of thumb wind turbines generators are governed by the Betz law, there exists an upper limit of 59 % (0.59) in which wind kinetic energy can be converted into electrical energy [234]. In other words, the wind turbine's efficiency (μ) can never exceed the value of 0.59. Commercially available offshore wind turbines are mostly tuned for class I wind speeds with a mean annual stream up to 10 ms^{-1}. However since class I wind sites are becoming more saturated, manufacturers have also developed class II and class III offshore wind turbines to cater for medium to low wind speed zones. Some of the design innovations in medium to low speed wind turbines include larger rotor diameter and lower rated power. Thus, for this assessment in order to theoretically estimate the power density for offshore wind in Malaysia, Vesta's V112-3.08 MW model is selected as a reference wind turbine. Technical specifications of this model are summarized in Table 25 [235] and the power curve is presented in Figure 20

[235]. This turbine has a rotor diameter size of 112 m, hub height of 119 m, the efficiency of the turbine to convert wind energy into electrical energy is 45% , thus μ is fixed at 0.45 and mean wind speed (V) is set at 8.0 ms^{-1}. In order to extract wind power, related constant parameters such as air density (ρ) of 1.225 kgm^{-3} and pi (π) value of 3.14159 were applied in equation (4-2) [234, 236]. The swept area (A) of wind turbine is deciphered by squaring the turbine blade length (r) multiplied with the pi value ($A = \pi r^2$).

$$P = \frac{\rho A V^3 \mu}{2} \tag{4-2}$$

Table 25. Specification of V112- 3.08 MW model [235]

Technical characteristics	Value
Rotor diameter	112 m
Blade length	54.65 m
Swept area (A)	9,852 m²
Rated power	3.075 MW
Efficiency	45%
Cut-in wind speed	3.0 ms^{-1}
Rated wind speed	12.0 ms^{-1}
Cut-out wind speed	25.0 ms^{-1}
Hub height	119 m
Number of blades	3
Grid frequency	50 Hz
Generator	Synchronous permanent
Wind class	IEC Class II

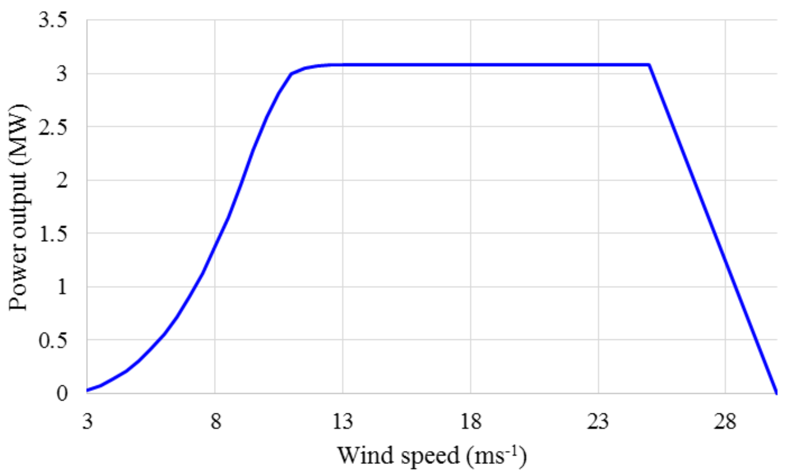


Figure 20. Power curve of V112-3.08 MW offshore wind turbine [235]

The minimum to a maximum number of installed offshore wind turbines is estimated by examining the bathymetry chart and by considering the seawater territorial area within 10 to 22 km (12 km distance) from the shoreline. The east coast of Peninsular Malaysia has a shoreline length of 650 km, while the coastline along Sarawak to Sabah facing the South China Sea is approximately 1,200 km. Hence, the total available area for offshore wind turbine installations in the territorial sea zone is estimated to be a total of 22,200 km^2 (650 km x 12 km + 1200 km x 12 km). The distance between each turbine was placed at 0.75 km (750m) to minimise the wake effect on the neighbouring turbine performance, this complies with the recommended distance of 7 rotor diameters [237]. Based on this assumption the installation area for the wind farm can be appraised, the total installation area would occupy 56.25 km^2 if 100 units of V112 wind turbines were to be fitted.

4.3.4 Wind electricity yield

The annual electricity yield (E_p) attainable from a wind turbine is expressed in equation (4-3) [234] as follows:

$$E_p = P * \hat{n} * AFA \qquad (4\text{-}3)$$

Where $\hat{n}$ stands for the total available hours in a year which is equivalent to 8,760 hours and the availability factor (AFA) of the wind turbine to be operational. Considering the intervals when the wind turbine does not produce power due to insufficient or too high airstream which causes it to automatically shut down and also the down time due to maintenance work, it has been reported that wind turbines have an average availability factor of at least 80% (0.80) [238]. Despite the intermittency characteristic of wind resources, ocean wind tends to replenish faster compared to onshore gust. In this assessment the availability factor for a wind turbine is fixed at 75% (0.75).

4.4 Solar

Malaysia is situated very near to the equator, and therefore receives abundance of sunlight throughout the year. The mean night and day temperature is within the range 24°C to 33°C, while the mean humidity is around 80%. Most literature pertaining to solar energy assessment in Malaysia was through actual onsite PV systems data logger reading, however, in this analysis, another approach will be explored which is tapping on NASA's Surface Meteorological and Solar Energy (SSE) database [176]. One advantage offered by this approach is that it can be replicated to any other locations in the world to assess the solar energy potential for solar-related conversion technologies such as solar photovoltaic (PV), solar thermal, the hybrid photovoltaic-thermal (PVT) and the concentrated solar power (CSP).

4.4.1 Solar radiation

NASA's SSE averaged daily solar radiation data [176] were retrieved for selected locations as labeled on the map in Figure 21 [232] and the coordinates are indicated in Table 26 in order to obtain the mean daily solar radiation value for Malaysia. These locations represent the major cities across Malaysia. Successively, the annual solar radiation is calculated by multiplying the mean daily solar radiation with the total number of days available in a year. The estimated annual solar radiation will be cross-checked with the solar radiation chart of Malaysia [239]. NASA's solar radiation data was established based on the monthly averaged amount of the total solar radiation incident per day measured on a horizontal state at the surface of the earth, averaged for that month over a period of 22 years from July 1983 until June 2005. As Malaysia is situated very near to the equator, the horizontal solar radiation data is sufficient for this assessment since not much difference is observed between the horizontal or slightly tilted surface radiation values. For regions within 15 degrees north or south latitude from the equator, the PV panel is best tilted according to the latitude value. The PV panel should be mounted facing southwards if it is positioned in the northern latitudes and vice versa if the location is in the southern latitudes then the PV array should be facing north.

Figure 21. Selected locations for solar radiation evaluation

Table 26. Coordinates of selected locations for solar radiation evaluation

Location	Latitude (°N)	Longitude (°E)
Kota Kinabalu	5.980	116.073
Kuching	1.607	110.378
Miri	4.399	113.991
Sibu	2.287	111.830
Bintulu	3.171	113.041
Sandakan	5.839	118.117
Tawau	4.244	117.891
Johor Bahru	1.492	103.741
Ipoh	4.597	101.090
Penang	5.416	100.332
Alor Setar	6.124	100.367
Kuala Terengganu	5.329	103.137
Kangar	6.440	100.198
Kuantan	3.763	103.220
Malacca	2.194	102.249
Shah Alam	3.073	101.518
Kota Bahru	6.116	102.277
Malaysia - Kampung Gua	4.210	101.976

4.4.2 PV panel installation area

The total combined area for the PV system is determined based on Malaysia's land usage profile. Currently, about 62% of Malaysia's land is being maintained as forested area, while 23.2% is allocated for agriculture purposes, while the remaining 14.8% is for other uses which include sectors such as mining, industrial, residential, business, and infrastructure [240]. In order not to further compromise land use, photovoltaic installations will be concerted on existing residential, commercial and industrial rooftop which is assumed to be connected to the grid network and taking up 0.15% (492.82 km^2) out of 328,550 km^2 total land area of Malaysia. Correspondingly, it is also assumed that approximately 20% of the rooftops were deemed unfit for PV installations due to shading and other building impediments [185] which leaves the total PV installation area to be further reduced to 394.26 km^2 = 394,260,000 m^2.

4.4.3 Solar energy yield and power extraction

The monocrystalline PV module as specified in Table 27 [241] will be the selected reference PV system to estimate the solar energy potential, electricity yield, and the power extraction.

Equation (4-4) states the formula for estimating the total solar energy (E) potential:

$$E = \overline{H} * A \tag{4-4}$$

While the electricity output (E_p) calculations from a PV system is specified as per equation (4-5) [242]:

$$E_p = \overline{H} * A * \mu * PR \tag{4-5}$$

The power capacity (P) of the PV system is estimated based on equation (4-6):

$$P = \frac{E_p}{\hat{n}} \tag{4-6}$$

Where $\overline{H}$ refers to the annual average solar radiation ($kWhm^{-2}$) on a horizontal plane, A is the total solar PV area (m^2), μ refers to the PV system's efficiency which is fixed at 15.1% (0.151), and PR is the performance ratio of the PV panel in which the standard default value of 0.75 is applied for rooftop modules from mono or polycrystalline silicone [242]. The PR value reflects all the losses of a PV system such as losses through: the AC and DC cables, inverters, fluctuation in temperature, dust and other aspects. The mean hours for a PV to produce optimum power in Malaysia is about 6 hours despite the average daylight hours from sunrise to sunset is 12 hours, this takes into account the time where downpour of rain and heavy clouds frequently occurs in the late afternoon and affects the power generation from a PV system. Hence the total number of hours per annum ($\hat{n}$) that a PV system is able to generate electricity would sum up to 2,190 hours (6 hours multiplied by 365 days).

Table 27. Technical specification of PV panel [241]

Technical characteristics	Value
Manufacturer	Suntech
PV type	Monocrystalline silicone
Module code	STP245S
Rated power (P_{max})	245 W (STC)
Voltage at P_{max}	30.5 V (STC)
Current at P_{max}	8.04 A (STC)
Efficiency	15.1%
Dimension (mm)	1640 x 992 x 50 mm
Frame size	1.63 m^2
Weight	19.1 kg

4.5 Biomass

This assessment will focus on biomass sourced from palm oil waste specifically from EFB. currently EFB is utilized in these proportions: 16% of the EFB is being dumped in palm oil plantations, 62% are used for mulching purposes, 6% are for composting, while 11% are openly incinerated or burned, and 5% are commercially sold as pellets [14]. Lately, the government has banned open burning of EFB. However, in this study these proportions will be optimized in order to set aside 35% of EFB as biomass fuel, while the balance of 65% is utilized for: mulching (55%), composting (5%) and 5% is maintained for commercial trade. This existing and new optimised configuration is illustrated in Figure 22.

The methods in estimating the potential of biomass from EFB includes the following measures: Firstly the yield of EFB per annum needs to be established, this can be founded by identifying the annual yield of Fresh Fruit Bunch (FFB) as 14.6% of dried FFB makes up the yield of EFB [193, 195, 243]. Out of the total yield of EFB, after optimization, approximately 35% of EFB will be allocated as fuel for power generation. Next, the high heating value (HHV) for the agricultural residual of 17 GJ for every tonne of EFB will be applied [244]. The electricity output per annum is estimated based on the steam turbine's efficiency in converting biochemical energy into electricity at 34% ($\mu = 0.34$) and the availability factor of the plant is set at 70% (AFA= 0.70) [104]. Whilst the maximum power capacity is derived by dividing the generated electricity with a function of time in a year that the power plant is in operation.

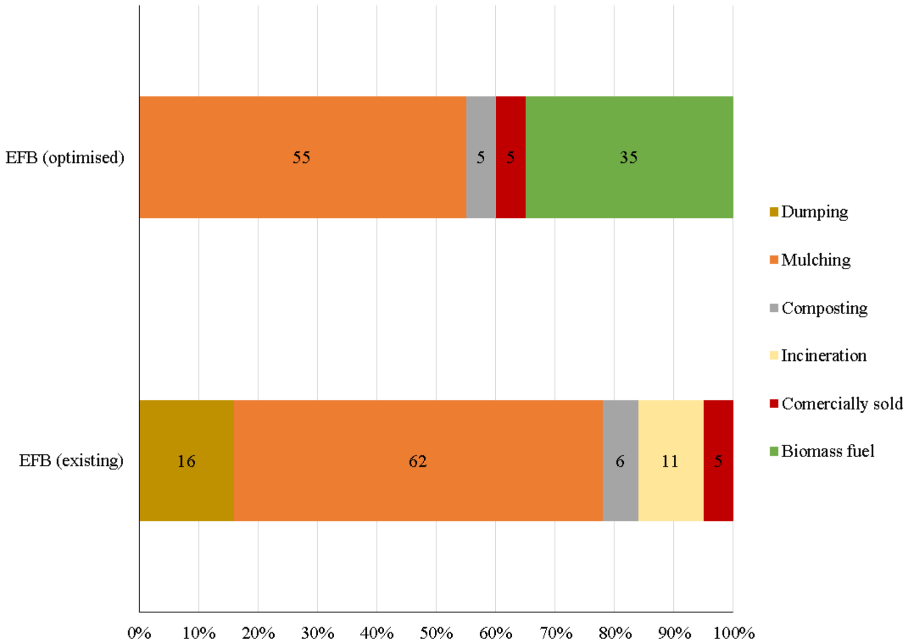


Figure 22. EFB usage before and after optimization

The expansion of palm oil plantation in Malaysia until 2050 is justified by factors such as land availability for palm oil development and based on the global palm oil market demand. Nevertheless, domestic land for palm oil plantation will not likely increase drastically due to competition with other crops and Malaysia's multilateral commitment in the 2015 United Nations 21st Climate Change Conference to maintain at least 50% of land for forest cover. As of 2015, Malaysia's forest cover stands at 67.6% [245] which leaves Malaysia with some limited land for further development. If Malaysia were to retain its status as the second largest palm oil producer up to 2050 and maintain its 35% contribution to the global demand without conceding to further land development, thus existing land for other agricultural crops may need to be sacrificed and partially converted into palm oil plantation. Considering this constraint, projections into the future were done by applying a very minimal annual growth rate on land size expansion for this particular crop as defined in Table 28. This expansion on palm oil crop led to the increment of Fresh Fruit Bunch (FFB) yield [246, 247]. This is also the basis for the increase in EFB yield and Palm Oil Mill Effluents (POME) volume. All relevant data such as the planted area for palm oil and FFB yield were sourced from the Malaysian Palm Oil Board (MPOB) [246, 247].

Table 28. Oil palm plantation expansion growth rates

Period	Growth rates (%)
2016 - 2020	2.9
2021 - 2050	0.4

4.6 Biogas

Biogas from Palm Oil Mill Effluents (POME) is also another energy source that could be leveraged in Malaysia. Bio-methane (CH_4) is the main content of biogas which is equivalent to methane (CH_4) chemical structure in natural gas, it is produced from anaerobic digestion process of organic materials such as dead plants and animal waste which includes POME. The estimations for biogas potential is deduced based on the assumption that 400 m^3 of bio-methane (CH_4) is formed from the anaerobic digestion of 100 tonnes of POME which is a byproduct after processing 20 tonnes of FFB [193]. After ascertaining the total volume of CH_4 based on the annual FFB yield, the energy content of the fuel needs to be estimated by applying the HHV of 38.3 MJ for each m^3 of CH_4 [244]. The electricity output is calculated based on conventional gas turbine's efficiency set at 36% (μ = 0.36) and power plant availability factor of 70% (AFA= 0.70) [104]. The maximum extracted power was deduced by dividing the electricity output by the total number of hours in a year (8760 hours).

4.7 Tidal

Tidal energy potential will be assessed by identifying the tidal stream speed to substantiate if tidal stream converters are suitable to be implemented in Malaysian waters which include the Straits of Malacca, Straits of Johor and the South China Sea. Maximum tidal current velocity will be identified via NOVELTIS TidEA (tidal energy assessment) database [248]. The TidEA database relies on 5-year satellite data as well as procured in-situ observed data from Copernicus Marine service. Tidal velocity will be assessed in 45 selected marine locations as marked on the map shown in Figure 23, 24 and 25 [232] and the coordinates are listed in Table 29 and 30 [248].

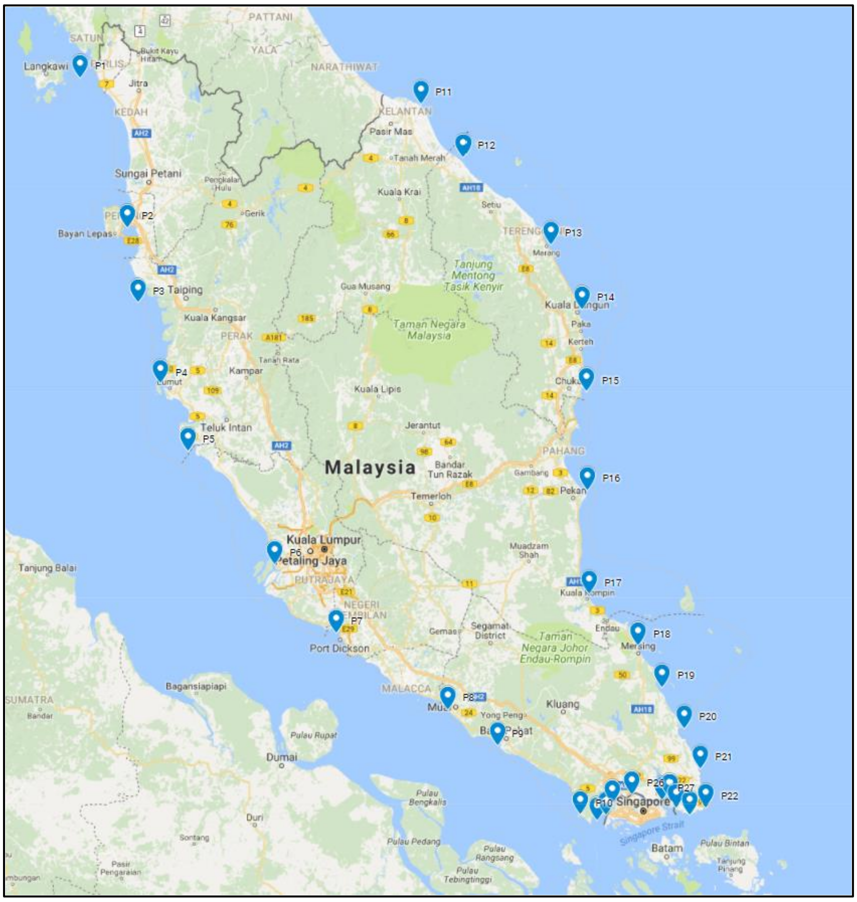


Figure 23. Selected location for tidal current velocity assessment in Peninsular Malaysia

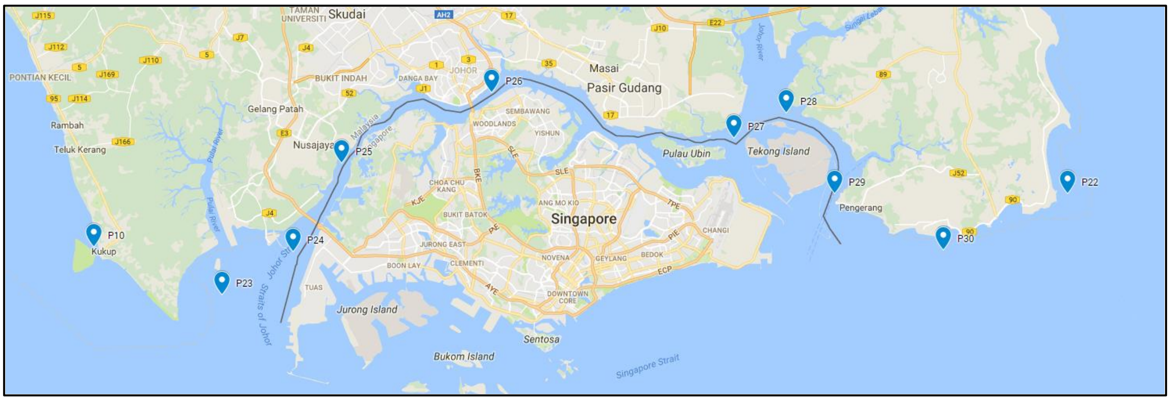


Figure 24. Selected locations for tidal current velocity assessment in Straits of Johor

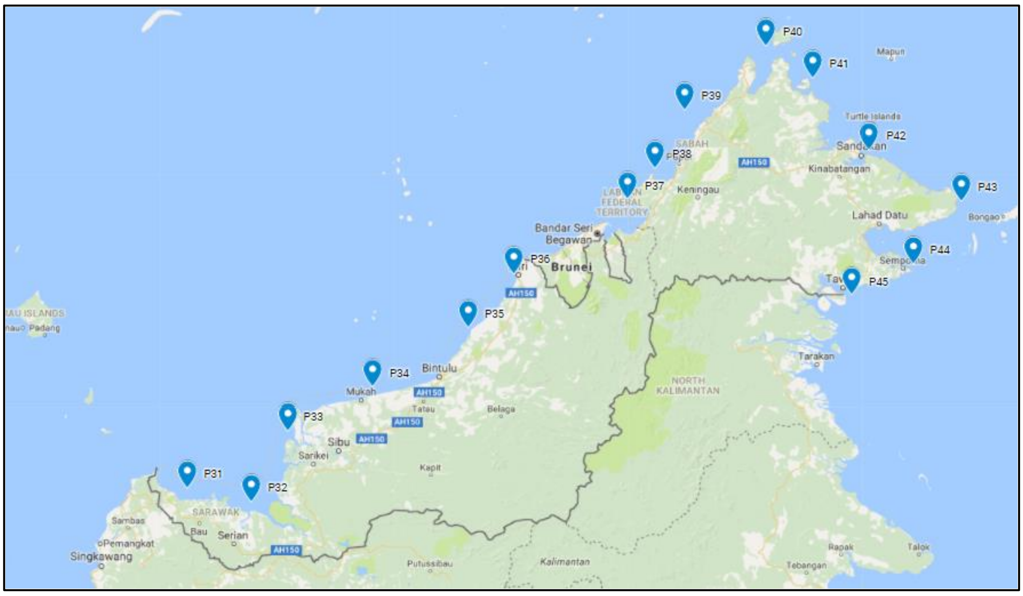


Figure 25. Selected locations for tidal current velocity assessment in East Malaysia

If the tidal stream velocity exceeds the minimum speed requirement of 1.5 ms^{-1} than the tidal power and electricity output will be pursued. Tidal stream converters comply with the same principles as wind turbines. Therefore the same formula as in equation (4-2) is applied for tidal power calculations. The notable difference lies in the density of seawater (1025 kgm^{-3}) which is 836 times much denser compared to air (1.225 kgm^{-3}).

Table 29. Selected locations in Peninsular Malaysia for tidal current velocity valuation

Site	Location	Latitude (°N)	Longitude (°E)
West coast	Point 1	6.3480	100.0195
of Peninsular Malaysia	Point 2	5.3316	100.3381
(Straits of Malacca)	Point 3	4.8173	100.4150
	Point 4	4.2642	100.5688
	Point 5	3.8094	100.7556
	Point 6	3.0335	101.3461
	Point 7	2.5685	101.7649
	Point 8	2.0457	102.5312
	Point 9	1.8014	102.8677
	Point 10	1.3309	103.4359
East coast	Point 11	6.1699	102.3447
of Peninsular Malaysia	Point 12	5.8100	102.6342
(South China Sea)	Point 13	5.2181	103.2302
	Point 14	4.7735	103.4486
	Point 15	4.2108	103.4774
	Point 16	3.5380	103.4857
	Point 17	2.8305	103.4967
	Point 18	2.4835	103.8304
	Point 19	2.1967	103.9965
	Point 20	1.9145	104.1426
	Point 21	1.6437	104.2564
	Point 22	1.3772	104.2916
Southern Peninsular Malaysia	Point 23	1.2887	103.5490
	Point 24	1.3266	103.6110
(Straits of Johor)	Point 25	1.4038	103.6537
	Point 26	1.4659	103.7856
	Point 27	1.4256	103.9986
	Point 28	1.4483	104.0449
	Point 29	1.3769	104.0875
	Point 30	1.3278	104.1826

Table 30. Selected locations in East Malaysia for tidal current velocity valuation

Site	Location	Latitude (°N)	Longitude (°E)
East Malaysia	Point 31	1.8453	110.0006
	Point 32	1.6806	110.7751
	Point 33	2.5315	111.2091
	Point 34	3.0637	112.2308
	Point 35	3.7765	113.3734
	Point 36	4.4176	113.9282
	Point 37	5.3131	115.3001
	Point 38	5.6870	115.6256
	Point 39	6.3808	115.9826
	Point 40	7.1444	116.9631
	Point 41	6.7655	117.5180
	Point 42	5.9029	118.1991
	Point 43	5.2906	119.3005
	Point 44	4.5353	118.7319
	Point 45	4.1656	117.9904

4.8 Wave

Wave energy (J) comprises of both kinetic and potential energy, the formula for combined kinetic and potential energy exerted by a wave can be represented as per equation (4-7) [249]:

$$E = \frac{\rho g h^2}{8} \tag{4-7}$$

Wave power can be expressed mathematically as depicted in equation (4-8) [249]:

$$P = \frac{\rho g^2 T h^2 \mu}{32\pi} \tag{4-8}$$

Malaysia has a total coastline length of 4,675 km (4,675,000 m) [250]. Wave power and energy potential can be estimated by adopting the findings by Muzathik et al. related to South China Sea's mean wave height $h = 1.22$ m and mean wave period $T = 5.87$ s [208]. The following standard values were applied which include seawater density ρ =1,025 kgm^{-3}, $\pi = 3.14159$, and gravitational acceleration $g = 9.81$ ms^{-2}. Currently, wave energy converters generally have an efficiency (μ) of 40% such as the Pelamis model which relies on surface attenuator hydraulic turbines in converting mechanical energy into electrical energy [249].

4.9 Hydro

Hydro energy potential can be estimated by applying equation (4-9):

$$E = mgh \tag{4-9}$$

The power generation potential is appraised based on equation (4-10):

$$P = \frac{mgh}{\hat{n}} \tag{4-10}$$

Whereby E is the potential energy, m refers to mass of water per meter square (kg), g is the gravitational acceleration 9.81 ms^{-2}, and h is vertical height of the dam (m). While P is the potential power and $\hat{n}$ is the number of hours per annum. Hydropower potential relies on the topographic structure of the determined site, the surroundings needs to be considered especially in evaluating the vertical height of the dam. Hydro potential energy can be estimated if information such as the average rain precipitation per annum, dam height, and catchment size or reservoir area have been assessed. Since the data on overall potential sites for hydro development in Malaysia is not accessible. Therefore the upper boundary for hydropower capacity will be concluded based on published secondary data or literature. Nevertheless to demonstrate the application of equation (4-9) and (4-10), the energy potential for the proposed 1,285 MW Baleh Dam will be estimated using the parameters listed in Table 31 [251, 252] and counter checked with the standard energy and power formula.

Table 31. Baleh Dam hydropower estimation inputs [251, 252]

Parameter	Value
dam height (m)	188
average rainfall per annum (mm)	3,600
water density (kgm^{-3})	1,000
catchment area (km^2)	5,625 (5.625×10^9 m^2)
reservoir area (km^2)	588 (5.88×10^8 m^2)

4.10 Geothermal

Geothermal carries the meaning of earth (geo) and heat (thermal) in the Greek language. The earth temperature or geothermal gradient will increase by 3°C with every 100 m descend into the ground [253]. The fundamental principles underlying geothermal energy is that thermal energy reservoirs beneath the earth's crust in the form of steam or hot water will be tapped to drive the turbines that are connected to an electric generator. These thermal reservoirs are heated by hot rocks or molten magma from the earth's core heat. Geothermal in Malaysia is still relatively underdeveloped and data is still sparse as exploration of new geothermal sites requires thorough analysis of thermal, hydrological and geological data. Therefore in this assessment, data from secondary sources will be utilized for determining the upper bound for geothermal power in Malaysia.

4.11 CO_2 emission reduction

As most renewables such as wind, solar, tidal, wave, hydro and geothermal are considered as clean energy resources in which zero GHG are emitted, therefore if power was deployed through renewables then the GHG levels will certainly decline. We could substantiate the annual reduction of CO_2 levels (ktkWh^{-1}) via the formula in equation (4-11) [254]:

$$G = 749E_p \tag{4-11}$$

Where G refers to the annual CO_2 reduction in kilotonnes (kt) per year, while the CO_2 emission factor for every kWh electricity generated is 749 gkWh^{-1}, this emission factor is derived by considering the fossil fuels used in Malaysia for electricity generation such as coal, natural gas and distillate oil (HFO, MFO or diesel) [254], and E_p is the electricity yield . The CO_2 emission reduction percentage is calculated by comparing G to the targeted 45% reduction of CO_2 emissions relative to the 2005 baseline levels which will be calculated by analyzing the CO_2 emission profile for Malaysia. However, biomass and biogas will still continue to emit minimum levels of GHG. Thus United Nations Intergovernmental Panel on Climate Change (IPCC) emission factors will be adopted, whereby the CO_2 emission factor from combustion of solid biomass such as EFB is 360 gkWh^{-1}, while combustion of bio-methane derived from biogas is 202 gkWh^{-1} [230]. Equation (4-12) [230] and (4-13) [230] are applied for estimating the annual CO_2 levels from combustion of biomass and bio-methane gas respectively.

$$G = 360E_p \tag{4-12}$$

$$G = 202E_p \tag{4-13}$$

4.12 Economic analysis

The economic valuation is performed on technologies that have high potential to be implemented in Malaysia. This analysis is to support the investment decision-making process on which technology is more feasible. The selected economic indicators for the feasibility valuation are the Net Present Value (NPV), Internal Rate of Return (IRR) and the Discounted Payback Period (DPP). Besides that, the Levelized Cost of Energy (LCOE) will be valued as well. The aforementioned economic indicators are calculated based on the approach described by Short et al. [224]. The capital cost, fixed operation and maintenance cost (FIXOM) and variable operation and maintenance cost (VAROM) for all the assessed technologies were retrieved from the European Commission's Energy Technology Reference Indicator projections [104].

4.12.1 Net present value

The NPV is an important capital budgeting indicator that reflects whether an investment is economically profitable or not, it is the difference of present value between cash inflows and cash outflows over a period of time. NPV is expressed as per equation (4-14) [224]:

$$NPV = \sum_{r=0}^{R} \frac{F_r}{(1+d)^r} \tag{4-14}$$

Where F_r is the actual cash flow, r is the analysed year, and d is the annual discount rate.

4.12.2 Internal rate of return

IRR is defined as the rate when the NPV achieves zero. Another simpler interpretation for IRR is that it refers to the annualized percentage return when the initial investment cost was made during the period, r = 0. The formula for IRR (%) is specified in equation (4-15) [224]:

$$IRR = 0 = NPV = \sum_{r=0}^{R} \frac{F_r}{(1+d)^r} \tag{4-15}$$

4.12.3 Discounted payback period

The PP denotes the number of years required to recover the initial investment cost while considering the time value for money. In order to calculate the DPP, first the actual cash flow (F_n) needs to be converted into the discounted cash flow (F_d) via equation (4-16) [224]:

$$F_d = \frac{F_r}{(1+d)^r} \tag{4-16}$$

Next, the DPP can be derived by calculating the cumulative discounted cash flow based on the following equation (4-17):

$$DPP = \beta + \frac{\gamma}{\delta} \tag{4-17}$$

Whereby,

β represents the last period with negative cumulative F_d;

γ is the absolute value of cumulative F_d at period β;

δ denotes the F_d after period β.

4.12.4 Levelized cost of energy

The LCOE is quite a useful indicator when contrasting the cost of electricity produced by different types of power plants or technologies, it can be derived from equation (4-18) [224]:

$$LCOE = TLCC \div \sum_{n=0}^{N} \frac{Q_n}{(1+d)^n} \tag{4-18}$$

Where Q_n represents the electricity output in year, while N is the number of years in the analysis period. The after tax total life cycle cost (TLCC) needs to be determined first before estimating the LCOE using equation (4-19) [224]:

$$TLCC = INVCOST - (IT \times PVDEP) + PVOM(1 - IT) \tag{4-19}$$

Where $INVCOST$ represents the investment cost, IT is the income tax rate (%), $PVDEP$ refers to the depreciated present value, and $PVOM$ is the present value of operations and maintenance cost.

4.12.5 *Economic inputs by technology*

As wind energy is not currently included as a renewable resource eligible for the FiT scheme in the 2011 Renewable Energy Act [13], therefore Germany's existing offshore FiT of €150 per MWh (USD 177 per MWh) is applied in this valuation. The period eligible for the FiT coverage is set for 20 years. The wind farm has a lifespan of 25 years with 75% (0.75) plant availability [104]. Malaysia's average electricity tariff in 2016 was MYR0.3853 per kWh or MYR385.30 per MWh (USD 117.42 per MWh). The parameters applied for the 100 MW offshore wind farm valuation are detailed in Table 32.

Table 32. Economic valuation input for 100 MW offshore wind farm

Parameter	Unit	Value	Reference
Capital cost	USD/kW	4,094.60	[104]
Fixed O&M	USD/kW	151.50	[104]
Lifetime	Year	25	[104]
Depreciation rate	%	4	
Interest rate	%	3, 7, 9	
Capacity	MW	100	
Availability factor	%	75	[238]
Electricity tariff	USD/MWh	117.42	[255]
Feed-in tariff	USD/MWh	177.00	[5]
Feed-in tariff period	Year	20	[5]
Exchange rate	1 € to USD	1.18	[256]
	1 MYR to USD	0.3047	[257]

The solar PV FiT covers a period of 21 years and the existing rate effective since January 2017 for energy companies is MYR 604.10 per MWh (USD 184.07 per MWh) and for individual applications is MYR 824.30 per MWh (USD 251.16 per MWh) on a condition that locally manufactured or assembled inverters and PV modules are utilised [258].The inputs used for the economic analysis of a 100 MW utility-scale solar PV farm and 8 kW residential rooftop PV installations are summarized in Table 33.

Table 33. Economic valuation input for solar PV

Parameter	Unit	Solar PV (energy company)	Solar PV (individual)	Reference
Capital cost	USD/kW	1,298.00	1545.80	[104]
Fixed O&M	USD/kW	32.45	30.92	[104]
Lifetime	Year	25	25	[104]
Depreciation rate	%	4	4	
Interest rate	%	3, 7, 9	3, 7, 9	
Capacity	MW	100	0.008	
Availability factor	%	25	25	[104]
Electricity tariff	USD/MWh	117.42	117.42	[255]
Feed-in tariff	USD/MWh	184.07	251.16	[13]
Feed-in tariff period	Year	21	21	[13]
Exchange rate	1 € to USD	1.18	1.18	[256]
	1 MYR to USD	0.3047	0.3047	[257]

The existing FiT rate for biomass power plants with steam-based technology and efficiency exceeding 20% is fixed at MYR 318.50 per MWh (USD 97.05 per MWh) [258] which is slightly lower than the average electricity tariff of MYR 385.30 per MWh (USD 117.42 per MWh) and covers a duration of 16 years. Usually, biomass residues or waste are priced as a function of the transportation fuel cost, since biomass waste needs to be transferred to the power plant location. Nevertheless, for EFB, the transportation cost does not need to be accounted since the EFB waste is already available at the mill site. The economic analysis for biomass-fueled power plant was based on the parameters described in Table 34.

Table 34. Economic valuation input for 10 MW biomass power plant

Parameter	Unit	Value	Reference
Capital cost	USD/kW	3,410.20	[104]
Fixed O&M	USD/kW	75.02	[104]
Variable O&M	USD/MWh	4.13	[104]
Lifetime	Year	25	[104]
Depreciation rate	%	4.00	
Interest rate	%	3, 7, 9	
Capacity	MW	10	
Availability factor	%	70	[104]
Electricity tariff	USD/MWh	117.42	[255]
Feed-in tariff	USD/MWh	97.05	[13]
Feed-in tariff period	Year	16	[13]
Exchange rate	1 € to USD	1.18	[256]
	1 MYR to USD	0.3047	[257]

Whereas for biogas, the inputs for the economic valuation are detailed out in Table 35. The current FiT allocated for biogas from agricultural waste is MYR 377.10 per MWh (USD 114.90 per MWh) and holds for a period of 16 years from the commencement date.

Table 35. Economic valuation input for 5 MW biogas power plant

Parameter	Unit	Value	Reference
Capital cost	USD/kW	4,578.40	[104]
Fixed O&M	USD/kW	187.71	[104]
Variable O&M	USD/MWh	3.66	[104]
Lifetime	Year	20	[104]
Depreciation rate	%	5.00	
Interest rate	%	3, 7, 9	
Capacity	MW	5	
Availability factor	%	70	[104]
Electricity tariff	USD/MWh	117.42	[255]
Feed-in tariff	USD/MWh	114.90	[13]
Feed-in tariff period	Year	16	[13]
Exchange rate	1 € to USD	1.18	[256]
	1 MYR to USD	0.3047	[257]

Two different baseload technologies with 2,000 MW power capacity, namely hydro and nuclear power plant will be assessed to substantiate which is more feasible. This comparison is of relevance because the Malaysian government is keen to connect the grid network with a 2 GW nuclear power by 2030. The inputs used for the appraisal of these two power plants are summarised in Table 36.

Table 36. Economic valuation input for 2,000 MW hydro vs nuclear power plant

Parameter	Unit	Hydro	Nuclear	Reference
Capital cost	USD/kW	2,596.00	4,838.00	[104]
Fixed O&M	USD/kW	25.96	91.92	[104]
Variable O&M	USD/MWh	3.54	2.95	[104]
Fuel cost	USD/MWh	0.00	2.80	[227]
Lifetime	Year	60	60	[104]
Depreciation rate	%	1.60	1.60	
Interest rate	%	3, 7, 9	3, 7, 9	
Capacity	MW	2,000	2,000	
Availability factor	%	91	90	[104]
Electricity tariff	USD/MWh	117.42	117.42	[255]
Exchange rate	1 € to USD	1.18	1.18	[256]

The FiT mechanism also extends to geothermal technology, Malaysia has deployed its first 30 MW geothermal power plant based on binary Organic Rankine Cycle technology in Apas Kiri, Tawau. Drilling efforts at this location at a depth of 1,449 meters had verified heat over 200^0C. Therefore, it would be interesting to examine how the existing FiT (MYR 0.45 per kWh) influence the investment perspective. The considered inputs for the economic appraisal on a 30 MW Geothermal plant is presented in Table 37.

Table 37. Economic valuation input for 30 MW geothermal power plant

Parameter	Unit	Value	Reference
Capital cost	USD/kW	8,224.60	[104]
Fixed O&M	USD/kW	172.72	[104]
Lifetime	Year	30	[104]
Depreciation rate	%	3.33	
Interest rate	%	3, 7, 9	
Capacity	MW	30	
Availability factor	%	95	[104]
Electricity tariff	USD/MWh	117.42	[255]
Feed-in tariff	USD/MWh	140.00	[13]
Feed-in tariff period	Year	21	[13]
Exchange rate	1 € to USD	1.18	[256]
	1 MYR to USD	0.3047	[257]

4.13 Chapter summary

In summary:

- The comprehensive renewable energy assessment will shed a deeper understanding of Malaysia's renewable energy resources in meeting the future electricity demand and finding the answer to how much fossil fuels can be substituted with renewable resources;
- This is also an important step for the TIMES simulation as it provides a sensible upper boundary for renewables which is essential to create the relevant scenarios under MYTEM;
- The economic valuation is essential to aid investors in their technology investment decision-making process as power plants and electricity generating converters are procured in advance;
- The described approaches in assessing renewable energy potential for wind, solar, tidal stream, biomass, biogas, wave and hydro are provided in detail in this chapter which can be universally replicated to any other locations in the world at regional or country level or even for a specific locality.

Chapter 5. Electricity Demand Projection

5.1 Introduction

The ability to ascertain in advance the prospective electricity demand is central to long term power sector planning. Hence this concept is also extended in simulation works involving long term predictions for the power sector, whereby the electricity demand requirement throughout the study period needs to be determined ahead of time. In this chapter, the electricity demand projections from 2016 until 2050 derived from several selected methods will be presented. The purpose of testing a few forecasting methods is to produce a sensible electricity demand projection which aligns with the world's electricity outlook. Ultimately, the electricity demand forecast that is deemed optimal will be input in the Malaysia TIMES Electricity Model (MYTEM) development.

5.2 Simple growth

The electricity demand forecast using the growth model is presented in Table 38, while the predictions during the holdback period are revealed in Table 39. The electricity consumption is expected to rise to 247,860 GWh by 2050, which is an increment by a factor of 1.87 compared to 132,199 GWh in 2015.

A clear upward curve as in Figure 26 is derived when the estimated projections which include the values during the forecast period (2016-2050) and the holdback period (2011-2015) are plotted alongside the true data (1973-2015).

Table 38. Electricity demand projection via the growth model

Year	Forecasted value (GWh)
2016	136,297
2017	140,522
2018	144,879
2019	149,370
2020	154,000
2021	158,004
2022	162,112
2023	166,327
2024	170,652
2025	175,089
2026	177,540
2027	180,026
2028	182,546
2029	185,102
2030	187,693
2031	190,321
2032	192,985
2033	195,687
2034	198,427
2035	201,205
2036	204,021
2037	206,878
2038	209,774
2039	212,711
2040	215,689
2041	218,708
2042	221,770
2043	224,875
2044	228,023
2045	231,216
2046	234,453
2047	237,735
2048	241,063
2049	244,438
2050	247,860

Table 39. Holdback estimation via the growth model

Year	Holdback value (GWh)
2011	107,341
2012	111,313
2013	115,431
2014	119,702
2015	124,131

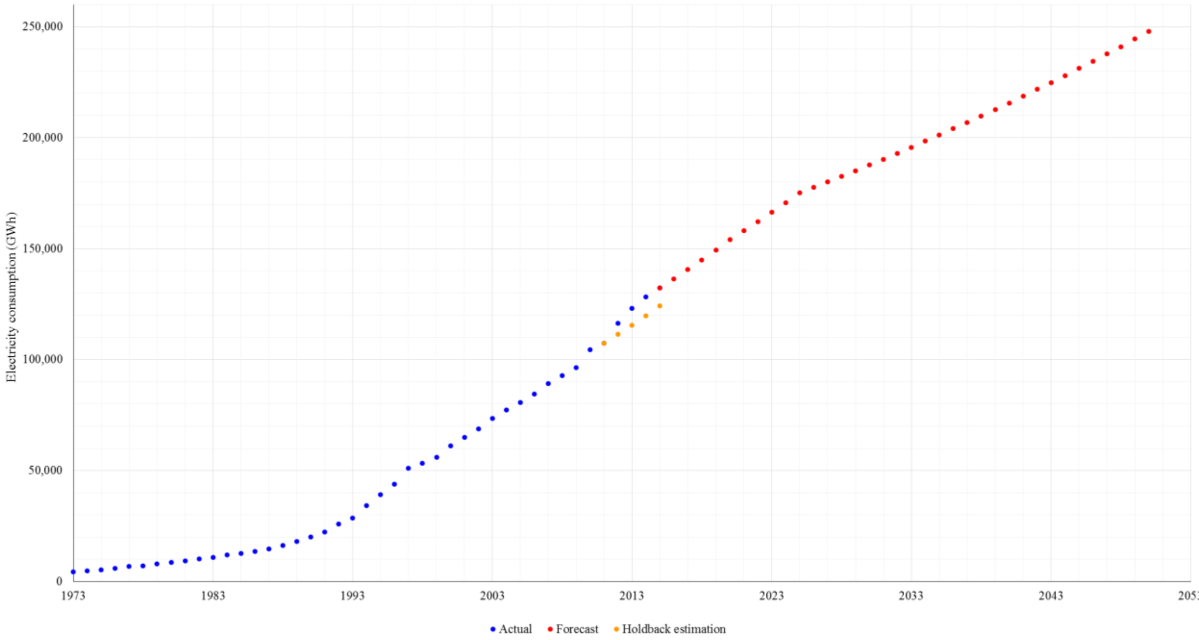


Figure 26. Electricity demand forecast via the growth model

5.3 Linear regression

Electricity consumption can be projected based on the following simple linear regression as per equation (5-1) derived from analyzing 43 electricity consumption annual historical data from 1973 until 2015 as follows:

$$y_t = 3{,}107.936x_t - 6{,}149{,}726 \quad (5\text{-}1)$$

Here the dependent variable y_t represent electricity consumption and the independent variable x_t denotes the period in years, while the intercept b_0 falls at point $-6{,}149{,}726$ when $x_t = 0$ and the slope b_1 refers to the rate of change of electricity consumption per annum. The model adequacy is evaluated by referring to the coefficient of determination denoted as R squared or R^2, which measures how close the data are fitted to the regression line. Here the R^2 obtained a value of 92.6% which signifies a good model fit. The regression output is attached in **Appendix F**. The projected electricity consumption figures based on the simple regression model is presented in Table 40 and the holdback period estimates are as per Table 41.

Table 40. Electricity demand projection via the linear regression model

Year	Forecasted value (GWh)
2016	115,873
2017	118,981
2018	122,089
2019	125,197
2020	128,305
2021	131,413
2022	134,521
2023	137,628
2024	140,736
2025	143,844
2026	146,952
2027	150,060
2028	153,168
2029	156,276
2030	159,384
2031	162,492
2032	165,600
2033	168,708
2034	171,816
2035	174,924
2036	178,032
2037	181,140
2038	184,248
2039	187,355
2040	190,463
2041	193,571
2042	196,679
2043	199,787
2044	202,895
2045	206,003
2046	209,111
2047	212,219
2048	215,327
2049	218,435
2050	221,543

Table 41. Holdback estimation via the linear regression model

Year	Holdback value (GWh)
2011	100,333
2012	103,441
2013	106,549
2014	109,657
2015	112,765

The slope produced by plotting the actual, holdback and predicted data appears as per Figure 27. It is noted that by 2050, the electricity demand would amplify by a factor of 1.67 in contrast to the figures in 2015, by which the trajectory will reach 221,543 GWh.

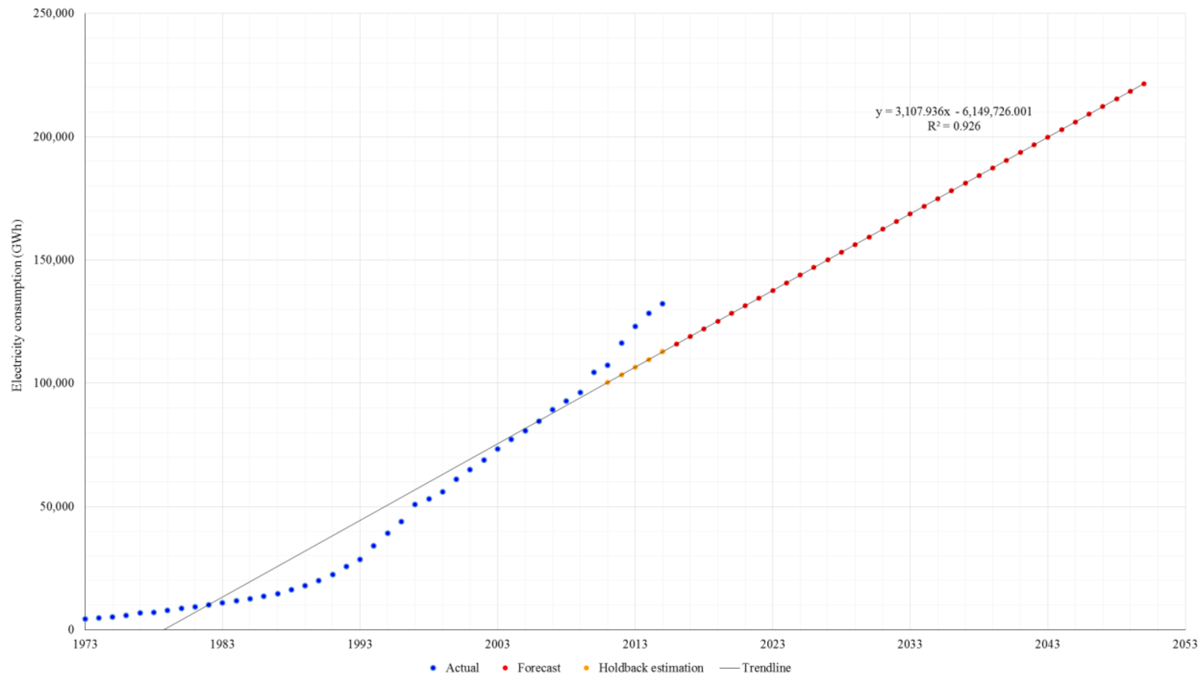


Figure 27. Electricity demand forecast via the linear regression model

5.4 Multiple linear regression

A multiple linear regression analysis was conducted to predict electricity consumption (y_t) based on regressors such as GDP (x_1) and population (x_2) as these two economic and demographic variables are commonly applied in prior related studies [126, 127, 131] to estimate electricity consumption. A significant multiple regression formula was founded as per equation (5-2):

$$y_t = 0.064099x_1 + 0.003193x_2 - 39{,}738.3 \qquad (5\text{-}2)$$

Where the intercept $b_0 = -39{,}738.3$, the coefficient for x_1 is $b_1 = 0.064099$, and the coefficient for x_2 is $b_2 = 0.003193$. The coefficient of multiple determination R^2 for this model obtained a value of 99.2% which indicates that the model has a high goodness of fit. The multiple regression output is included in **Appendix G**. The forecast estimates from 2016 until 2050 are listed in Table 42 and the estimates for the holdback period are as per Table 43.

Table 42. Electricity demand projection via the multiple linear regression model

Year	Forecasted value (GWh)
2016	116,178
2017	119,300
2018	122,421
2019	125,543
2020	128,665
2021	131,787
2022	134,909
2023	138,030
2024	141,152
2025	144,274
2026	147,396
2027	150,518
2028	153,639
2029	156,761
2030	159,883
2031	163,005
2032	166,127
2033	169,248
2034	172,370
2035	175,492
2036	178,614
2037	181,736
2038	184,857
2039	187,979
2040	191,101
2041	194,223
2042	197,345
2043	200,466
2044	203,588
2045	206,710
2046	209,832
2047	212,954
2048	216,075
2049	219,197
2050	222,319

Table 43. Holdback estimation via the multiple linear regression model

Year	Holdback value (GWh)
2011	100,569
2012	103,691
2013	106,812
2014	109,934
2015	113,056

It is noted that by 2050, the expected electricity consumption figures has scaled up to 222,319 GWh which is an increment by a factor of 1.68 as of 2015. The slope of the actual, holdback and the projected electricity consumption based on the multiple linear regression approach is illustrated in Figure 28.

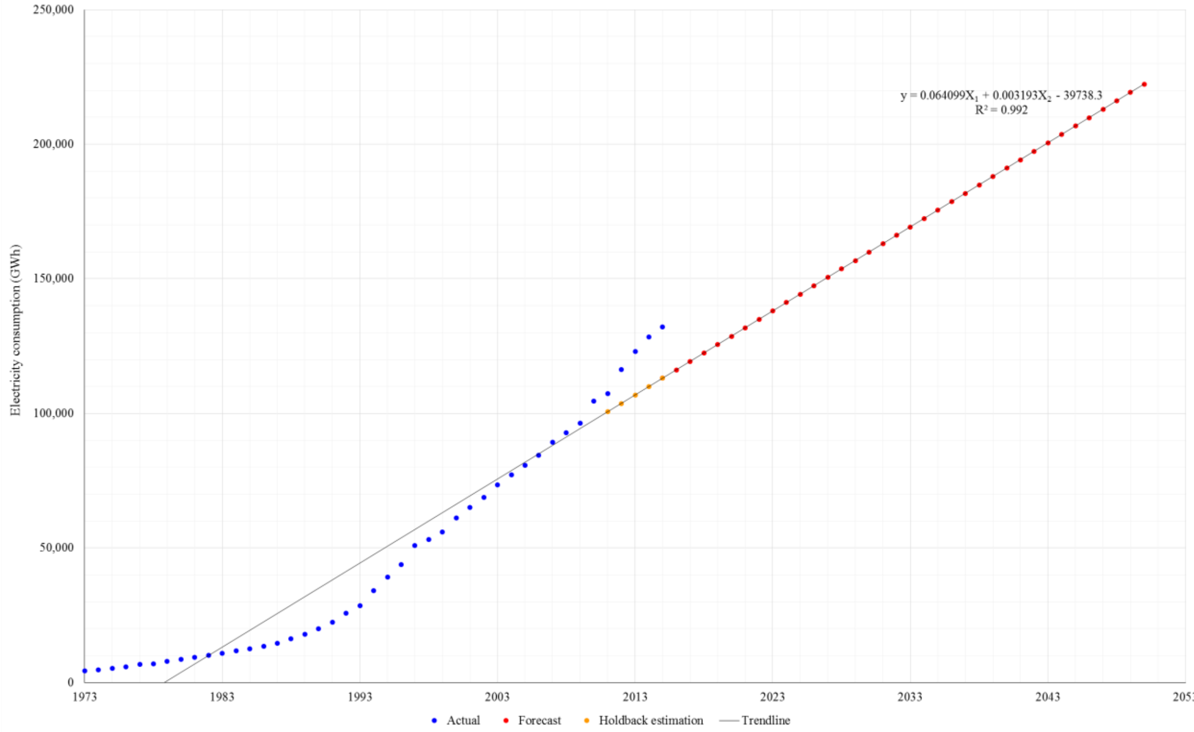


Figure 28. Electricity demand forecast via the multiple linear regression model

5.5 Auto regressive integrated moving average

The ARIMA modeling projection for Malaysia's electricity demand from 2016 until 2050 was computed by deploying EViews package and will be presented based on the following sequence, namely the Box and Jenkins three-step procedure which includes identification, estimation and diagnostic checking [259], followed with the forecast process and the forecast performance evaluation.

5.5.1 Identification

To enable visual examination, the actual electricity consumption time series data in Malaysia since 1973 until 2015 in its level form (CO) has been plotted in the form of a line graph as shown in Figure 29. The CO data seems to exhibit a non-stationary characteristics due to: (i) an upscaling trend over time; (ii) the mean and variance do not appear to be constant, which suggest for transformation operations; (iii) the series kept a persistent increase throughout the 43 years and it took a steeper disposition especially in the 1990s. If the data were stationary, then the graph should be similar to Figure 30, this is the transformed CO series, which has undergone the natural logarithmic and the first difference operations (DLCO).

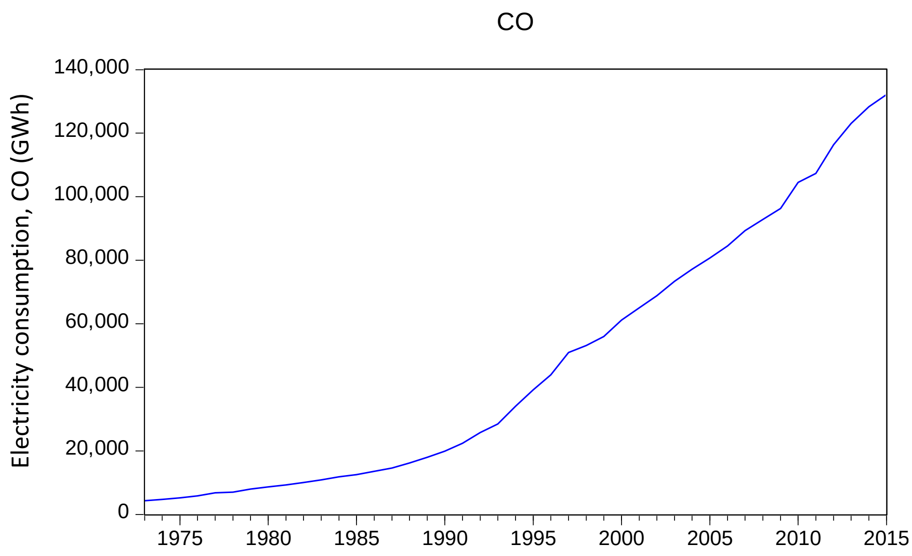


Figure 29. Line graph for the level series CO

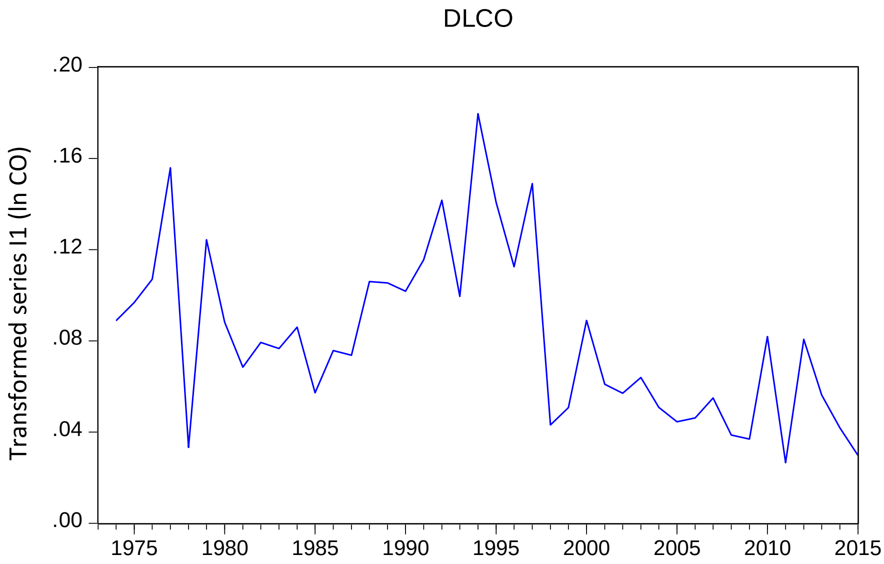
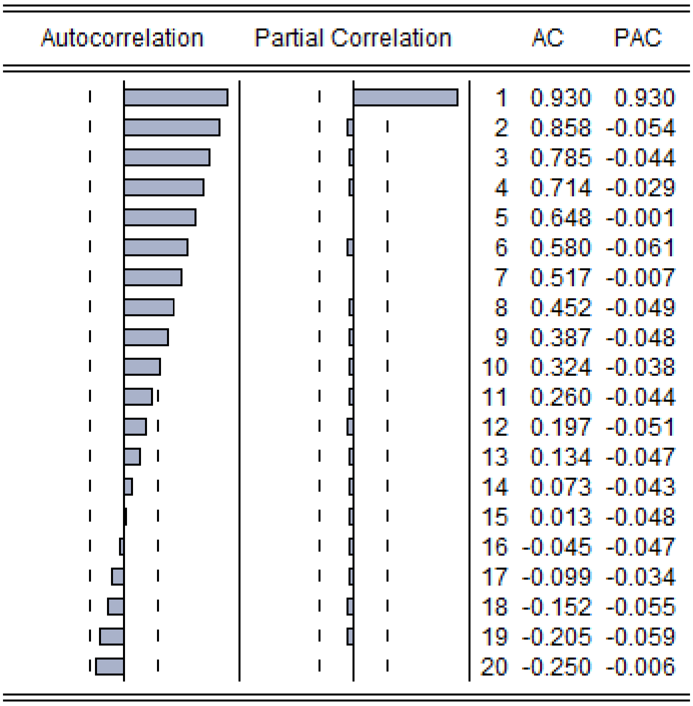


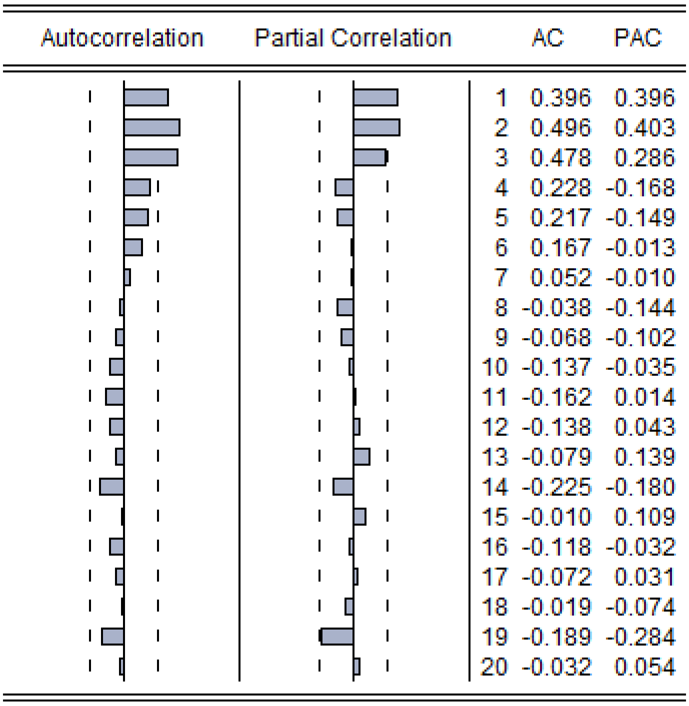
Figure 30. Line graph for the transformed series DLCO

Another means of visual screening is by observing the correlogram graphs, which includes both the autocorrelation (AC) and partial correlation (PAC) functions. If series were stationary than spikes of the AC and PAC would indicate a diminishing trend where most of the spikes would be within the standard error bands. However, if the series are non-stationary then a lot of spikes will exceed the error bands. The correlogram for the level series CO as shown in Figure 31, has quite a number of AC spikes that exceeded the positive standard error bands, while most of the PAC spikes were within the error bands except for the spike at lag 1. Conversely, the correlogram of the transformed series DLCO as per Figure 32 has most of the spikes positioned within the error margins. Thus it can be deduced that most likely CO is a non-stationary series and there is a possibility that DLCO is a stationary series. Nevertheless, these findings are still just estimates, it needs to be verified based on the statistical evaluation that will be deliberated next.



	AC	PAC
1	0.930	0.930
2	0.858	-0.054
3	0.785	-0.044
4	0.714	-0.029
5	0.648	-0.001
6	0.580	-0.061
7	0.517	-0.007
8	0.452	-0.049
9	0.387	-0.048
10	0.324	-0.038
11	0.260	-0.044
12	0.197	-0.051
13	0.134	-0.047
14	0.073	-0.043
15	0.013	-0.048
16	-0.045	-0.047
17	-0.099	-0.034
18	-0.152	-0.055
19	-0.205	-0.059
20	-0.250	-0.006

Figure 31. The correlogram for the level series CO



	AC	PAC
1	0.396	0.396
2	0.496	0.403
3	0.478	0.286
4	0.228	-0.168
5	0.217	-0.149
6	0.167	-0.013
7	0.052	-0.010
8	-0.038	-0.144
9	-0.068	-0.102
10	-0.137	-0.035
11	-0.162	0.014
12	-0.138	0.043
13	-0.079	0.139
14	-0.225	-0.180
15	-0.010	0.109
16	-0.118	-0.032
17	-0.072	0.031
18	-0.019	-0.074
19	-0.189	-0.284
20	-0.032	0.054

Figure 32. The correlogram for the transformed series DLCO

To ascertain this statistically, high powered tests such as the Elliot Rothenberg and Stock (ERS) [218] and the Phillips-Perron (PP) [217] tests were performed on the level series CO and transformed series DLCO. These tests are designed to rule out the presence of unit roots in the data series. The established hypothesis for these unit root tests is defined by the null hypothesis, H_0 which states that the series has a unit root, whereas the alternative hypothesis, H_1 entails that the series does not have a unit root. The principle in these tests is if the tested series has a unit root then the data is inferred as non-stationary. Nevertheless, if there is no presence of unit root, then the data is considered to achieve stationarity.

The results of the ERS and PP test has been summarised in Table 44 and are interpreted in absolute values. For the level series CO, the value of t statistics at 10% critical value (CV) is higher than the ERS and PP statistics, this suggests that the CO series does have a unit root and is serially correlated, which implies that the data is non-stationary and therefore the null hypothesis cannot be rejected. When the same test is implemented on the transformed series DLCO, the results indicated that data is stationary since the value of t statistics at 10 % CV is less than the ERS and PP statistics, thus this statistically infers that the data set is not serially correlated and does not have a unit root. Hence, the DLCO series has accomplished stationarity condition and is integrated of order one, or denoted I (1).

Table 44. ERS and PP test on level series CO and transformed series DLCO

Series	ERS stats	10% CV	Analysis	H_0	State
CO	-1.744	-2.890	ERS stats < 10% CV	Do not reject	Non-Stationary
DLCO	-1.890	-1.611	ERS stats > 10% CV	Reject	Stationary

Series	PP stats	10% CV	Analysis	H_0	State
CO	-1.023	-3.191	PP stats < 10% CV	Do not reject	Non-Stationary
DLCO	-4.314	-2.605	PP stats > 10% CV	Reject	Stationary

5.5.2 Estimation

At this stage, the ARIMA (p, q) models, are all estimated on the DLCO data based on the parsimonious model condition $p + q \leq 6$, where the autoregressive function contains p lags and the moving average consists of q lags,. The principles of parsimony brings the concept of scarcity in which a model shouldn't be over parameterised. Hence, this condition allows for 15 combinations of ARIMA models to be estimated. Consecutively, the parsimonious models will be selected based on the smallest Schwarz Bayesian Criterion (SBC) value. The SBC is being utilized as a measure to identify the plausible models with best fit, since SBC is found to be more consistent in selecting a parsimonious model [213, 259] compared to the Akaike Information Criterion (AIC). Nonetheless, the model selection will be counter checked with the AIC values as well. If both SBC and corresponding AIC selected the same models, this indicates consistency in model selection and thus is a form of assurance that the correct models have been chosen for the forecast. For ease of comparison, all the SBC and AIC values for each of the estimated models are tabulated as per Table 45 and 46. The lowest SBC values depicted here are -4.153 followed with -4.090 which corresponds to ARIMA (3,2), and ARIMA (3,3). While the least AIC values are -4.408 and -4.388, which reflects the same models, namely ARIMA (3,2) and ARIMA (3,3). Thus, the models ideal to perform the forecast have been narrowed down to two parsimonious model, namely ARIMA (3,2) and ARIMA (3,3).

Table 45. SBC values of the estimated models

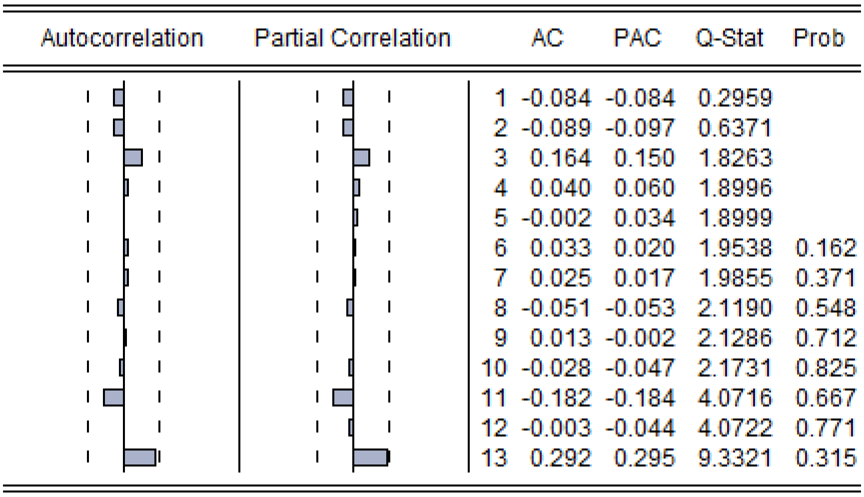
q \ p	**0**	**1**	**2**	**3**
0		-3.744	-3.833	-3.837
1	-3.690	-3.845	-3.808	-3.943
2	-3.837	-3.972	-3.887	**-4.153**
3	-4.038	-3.998	-3.939	**-4.090**

Table 46. AIC values of the estimated models

q \ p	**0**	**1**	**2**	**3**
0		-3.828	-3.960	-4.007
1	-3.773	-3.971	-3.977	-4.157
2	-3.961	-4.139	-4.099	**-4.408**
3	-4.203	-4.207	-4.193	**-4.388**

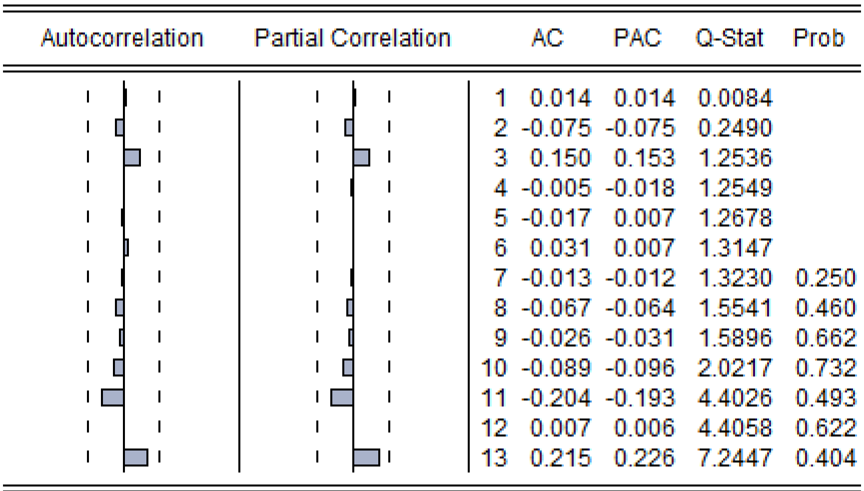
5.5.3 Diagnostics check

To avoid a spurious forecast, the residuals need to be confirmed whether it has the white noise process. White noise refers to the state of a sequence of residuals (ε_t) whereby each value have a zero mean, a constant variance, and are not correlated. According to the residual correlogram shown in Figure 33 and 34, the AC and the PAC of the two models indicate no signs of correlation since all of the spikes are within the standard error band (positive and negative). While both models have an insignificant residual autocorrelation and partial autocorrelation because the values are all nearing zero. This can be statistically proven, the final lag (lag 13) of the Ljung-Box Q statistics [219] for both models are significant because the probability ($\hat{p}$) value of the Q statistics at 95% confidence level are $\hat{p}$=0.315 [ARIMA (3,2)] and $\hat{p}$=0.404 [ARIMA (3,3)] respectively, which is greater than the 5% significance level (0.05). Therefore, we can concur that both models have passed the residual checks and both models have white noise characteristics.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.084	-0.084	0.2959	
		2	-0.089	-0.097	0.6371	
		3	0.164	0.150	1.8263	
		4	0.040	0.060	1.8996	
		5	-0.002	0.034	1.8999	
		6	0.033	0.020	1.9538	0.162
		7	0.025	0.017	1.9855	0.371
		8	-0.051	-0.053	2.1190	0.548
		9	0.013	-0.002	2.1286	0.712
		10	-0.028	-0.047	2.1731	0.825
		11	-0.182	-0.184	4.0716	0.667
		12	-0.003	-0.044	4.0722	0.771
		13	0.292	0.295	9.3321	0.315

Figure 33. Residual correlogram and the Ljung-Box Q statistics of ARIMA (3,2)



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.014	0.014	0.0084	
		2	-0.075	-0.075	0.2490	
		3	0.150	0.153	1.2536	
		4	-0.005	-0.018	1.2549	
		5	-0.017	0.007	1.2678	
		6	0.031	0.007	1.3147	
		7	-0.013	-0.012	1.3230	0.250
		8	-0.067	-0.064	1.5541	0.460
		9	-0.026	-0.031	1.5896	0.662
		10	-0.089	-0.096	2.0217	0.732
		11	-0.204	-0.193	4.4026	0.493
		12	0.007	0.006	4.4058	0.622
		13	0.215	0.226	7.2447	0.404

Figure 34. Residual correlogram and the Ljung-Box Q statistics of ARIMA (3,3)

At this point, it is a good practice to include a stability test known as the Chow test [220] to rule out structural breaks. The null hypothesis, H_0 in the Chow test assumes that there are no breaks at the specified breakpoint. Whereas the alternative hypothesis, H_a assumes that there is a breakpoint at the tested period. The identified test year for the Chow test was set to 1984, this year was chosen due to the occurrence of an economic slowdown which impacted Malaysia from 1984 to 1986. Besides 1984 also serves as a cut-off point to maintain a meaningful forecast by having at least 30 annual observed data (1985-2015) in case a break does occur in 1984. The outcomes of the Chow test on both models indicated that there was no occurrence of a breakpoint in 1984. This is because the probability ($\hat{p}$) values of the F-statistics for both models at 95% confidence level were greater than 0.05 significance level as shown in Table 47, therefore the null hypothesis cannot be rejected. Nevertheless, just to ensure consistency that no breaks ensued, the Chow test was arrayed for 1986 as well and the outcomes as reflected in Table 48 has confirmed that no breaks had transpired in that year. Nevertheless, if a structural break indeed had occurred in 1986, this break has to be omitted due to an insufficient number of observed data to produce a significant ARIMA forecast.

Table 47. Chow test results for structural break in 1984

	F-statistic	$\hat{p}$ **value**
(3,2)	0.825	0.560
(3,3)	0.120	0.996

Table 48. Chow test results for structural break in 1986

	F-statistic	$\hat{p}$ **value**
(3,2)	0.844	0.546
(3,3)	0.214	0.978

5.5.4 Forecast process

The forecast results in its level form for ARIMA (3,2) and ARIMA (3,3) are presented in Table 49, while the estimated values during the five year holdback period are specified in Table 50. As demonstrated in Figure 35, it is obvious that ARIMA (3,2) produced a higher forecast than the ARIMA(3,3) model. It is obvious that these two models showed a noticeable increase in electricity demand over time, by 2050 the forecast value of ARIMA (3,2) was expanded by a factor of 10.34, whereas ARIMA (3,3) amplified by 7.95 times against the 2015 data. The forecast curves seem to show a symmetrical ascend at the early stage and starts to diverge from 2020 onwards.

A forecast appraisal is performed to isolate the ARIMA model with the better forecast. Performance measures such as the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are the commonly referred error statistics to determine the more reliable forecast model. Based on the forecast performance measures shown in Table 51, both models have the same RMSE value, however, the MAE value for ARIMA (3,3) is lower than ARIMA(3,2). Hence, it can be deduced that ARIMA (3,3) has the better forecast.

Table 49. Electricity demand projection via the ARIMA model

Year	(3,2)	(3,3)
2016	138,553	138,539
2017	143,808	143,518
2018	151,107	150,164
2019	160,392	158,179
2020	169,306	165,709
2021	179,752	174,349
2022	191,968	184,321
2023	204,381	194,418
2024	218,174	205,445
2025	233,687	217,775
2026	249,882	230,675
2027	267,509	244,533
2028	286,934	259,724
2029	307,492	275,841
2030	329,681	293,067
2031	353,858	311,730
2032	379,629	331,641
2033	407,350	352,895
2034	437,363	375,771
2035	469,474	400,219
2036	503,969	426,317
2037	541,184	454,302
2038	581,076	484,221
2039	623,912	516,165
2040	670,033	550,349
2041	719,520	586,888
2042	772,655	625,906
2043	829,799	667,615
2044	891,146	712,185
2045	957,016	759,779
2046	1,027,812	810,628
2047	1,103,833	864,948
2048	1,185,464	922,954
2049	1,273,171	984,908
2050	1,367,359	1,051,077

Table 50. Holdback estimates via the ARIMA model

Year	(3,2)	(3,3)
2011	109,182	108,888
2012	116,405	115,934
2013	126,481	125,217
2014	135,038	133,142
2015	144,891	142,240

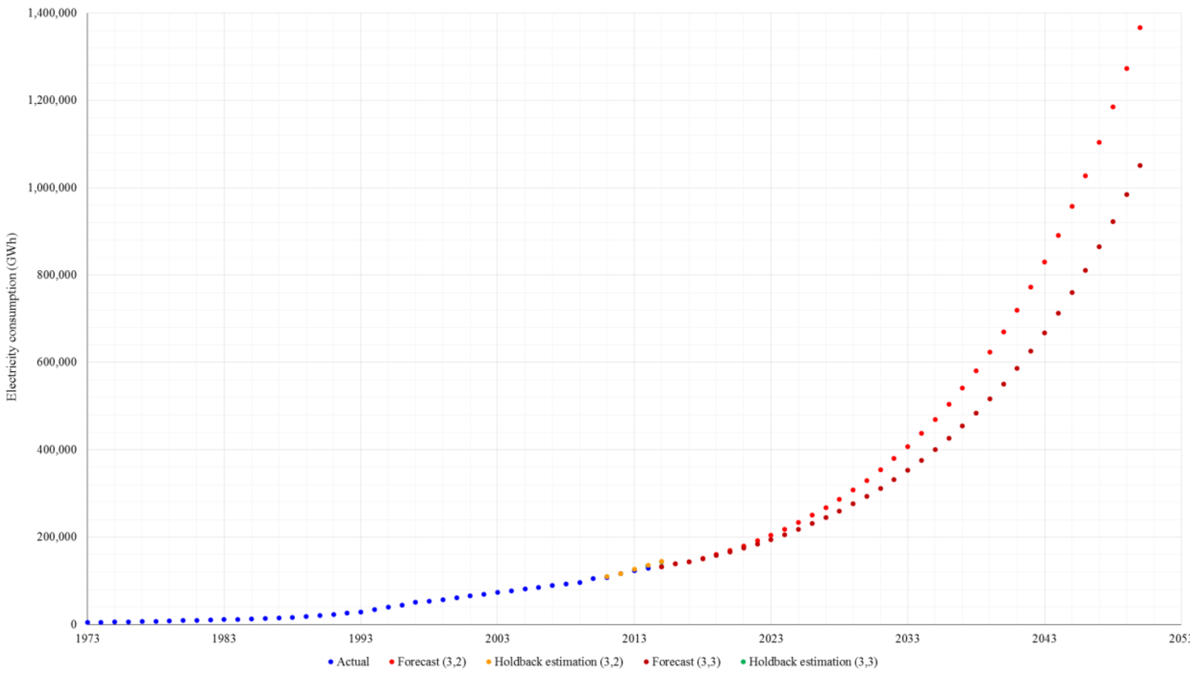


Figure 35. Electricity demand forecast via the ARIMA (3,2) and ARIMA (3,3) model

Table 51. Forecast performance measures

	MAE	RMSE
(3,2)	0.028	0.035
(3,3)	0.026	0.035

5.6 Validation

All the tested models were validated by delivering an in-sample forecast with a 5 year holdback period (2011-2015). The sample size had to be reduced from 43 (1973 -2015) to 38 annual observations (1973 - 2010) to produce the estimated value during the 5 years withheld period. The plots for the forecast during the holdback period alongside the actual data for all tested models are shown in Figure 36. Since different forecast approaches are being compared, thus the forecast accuracy measure is better reflected with the Mean Absolute Percentage Error (MAPE). Results showed that the model with the best fit in terms of accuracy would be the ARIMA (3,3), succeeded with ARIMA (3,2) and the growth model, this is guided by the smaller MAPE value as indicated in Table 52. The MAPE of each of the aforementioned models is 2.98%, 3.87%, and 4.68% respectively. The linear regression and multiple linear regression models both gave a higher error value which was above 10%.

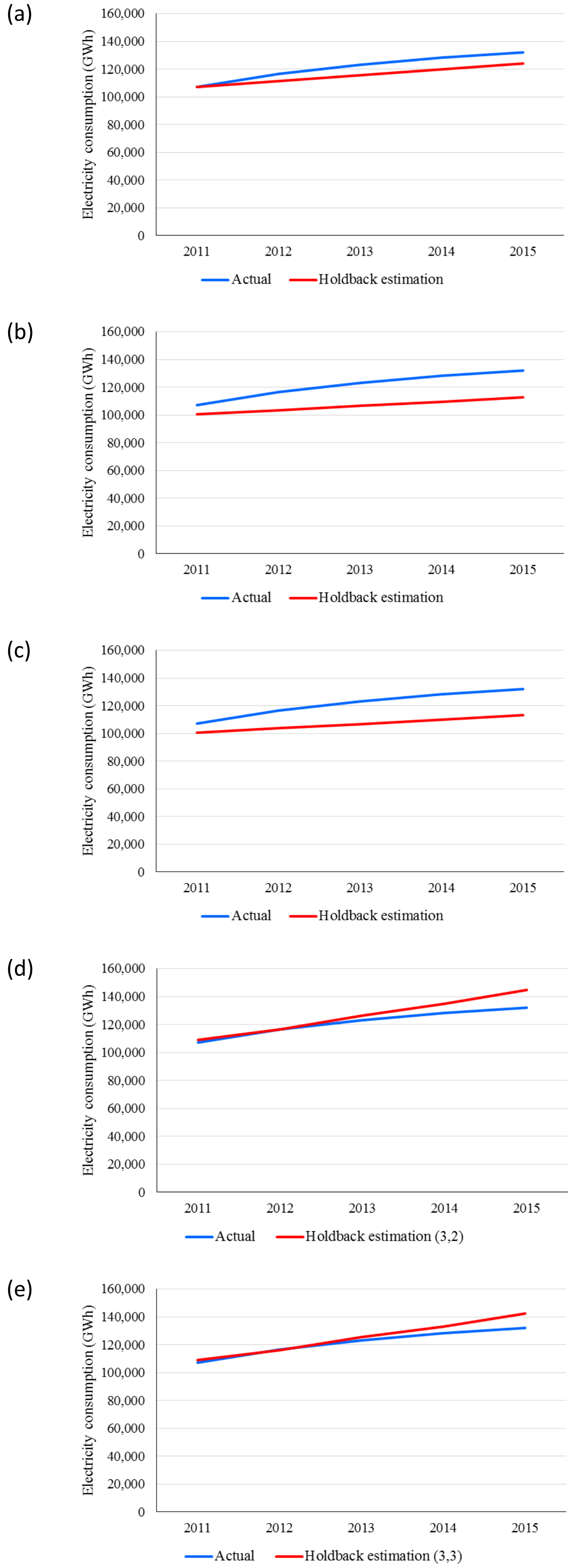


Figure 36. Five year holdback validation plots vs. actual data for (a) Growth; (b) Linear regression; (c)Multiple linear regression; (d) ARIMA (3,2) and (e) ARIMA (3,3)

Table 52. Comparison of forecast accuracy measures for all tested models

Model	Growth	Linear regression	Multiple linear regression	ARIMA (3,2)	ARIMA (3,3)
MAPE (%)	4.68	12.06	11.84	3.87	2.98

5.7 Discussion

There are several models that can be applied for forecasting purposes, the applications of the simple growth rate, the econometric founded regression analysis as well as the more sophisticated univariate time series ARIMA model have been demonstrated. These models were chosen mainly because they were prevalent in studies related to energy demand forecasting [40, 48, 107, 108, 116, 118-120, 128, 260, 261]. The pros and cons of the tested models are summarised in Table 53.

At this point, after deriving several forecasts via different approaches, the challenge lies in identifying the ideal forecast that can be deployed in the Malaysia TIMES Electricity Model (MYTEM). There is actually no straightforward answer to this since all of these forecasts are statistically correct based on the prescribed methodology. If it were solely based on statistics, then naturally the forecast with the highest forecast accuracy would be selected, this can be identified by assigning the model with the minimum MAPE value. However, forecasting is not merely a quantitative exercise, more often than not a qualitative element is attached to it [262].

Forecasting is also sometimes considered as an art by itself since the choice of selecting a forecast is not something that is carved in stone. In scenario modelling, it is emphasized that the projection must mirror the real world situation as closely as possible in order to create more realistic scenarios. Hence, the researcher must weigh each of the forecasts and evaluate whether the results produced are sensible and logical to accommodate the overall research perspective. Fortunately, electricity demand projections at global or regional level have been explored by experts and presented as electricity demand outlooks. Therefore it is a prudent to benchmark the available global and regional electricity demand outlooks to get a better understanding of the expected growth pattern throughout 2050. According to the International Energy Agency (IEA) outlook (refer Figure 37), by 2040 the electricity demand for Southeast Asia will increase to 1,997 TWh from 837 TWh in 2016, this is an increase by a factor of 2.38 [263]. While another outlook by the World Energy Council (WEC) as shown in Figure 38 suggested that throughout 2010 to 2050, Southeast Asia and the Pacific region under moderate economic circumstances will experience a rise in electricity production by a factor of 3.40 from 1,000 to 3,400 TWh, however this assertion is quite sensible since it covers countries in the pacific region such as Australia and New Zealand apart from Southeast Asia. Even at the global level, the electricity production is projected to achieve a twofold increase by 2050 as portrayed in Figure 39 [264]. In fact, the Asia-Pacific Economic Cooperation (APEC) anticipated that the electricity consumption for Southeast Asia by 2040 will more than double as indicated in Figure 40 [265]. Whereas the Association of Southeast Asian Nations (ASEAN) expects that the cumulative electricity consumption by all ASEAN member states will rise from 82 Mtoe (953 TWh) to 207 Mtoe (2,407 TWh) within a time frame from 2015 to 2040 which is a growth factor of 2.52 [266]. Thus, it can be concluded that the electricity demand for Southeast Asia based on the various outlooks are likely to more than double by 2050.

Table 53. Pros and cons of all tested models

Model	Simple growth	Linear regression	Multiple linear regression	ARIMA
Pros	• simplest approach; • base year data is sufficient to do the forward projection; • growth rates can be fixed at a constant rate for the whole duration; • different growth rates can be set for different periods based on the assumptions.	• simple approach; • measures the influence of one independent variable to the dependent variable; • an econometric based approach.	• relies on two or more independent variables in establishing the association to the dependent variable; • an econometric based approach.	• depends on a single-variable (univariate); • effective when there is data constraint on other determinants; • the established method backed with economic theory; • contains wide literature on method application; • high accuracy for short-term forecast
Cons	• a constant growth rate may not reflect the real world situation; • sensible growth rates relies on historical data; • forecast accuracy level may be lower.	• relies on historical or sample data to develop a regression line; • forecast accuracy level may be lower.	• relies on historical or sample data for all variables; • forecast accuracy level may be better than the linear regression model.	• lengthy approach; • forecast accuracy deteriorates for a longer stretch of time.

If contrasted to the amplifying factor of all the tested models as summarised in Table 54, the closest would be the growth model with a factor of 1.87. The lower factor value is still reasonable as this is an electricity demand projection for a single individual country. Therefore, the two ARIMA models will be ruled out despite having the lowest MAPE value since ARIMA (3,2) and ARIMA (3,3) both have a high amplifying factor of 10.34 and 7.95 respectively. Despite the fact that ARIMA models provides a forecast based on historical data that has been modified to reach a state of statistical equilibrium, it has been demonstrated through this study that there exist some limitations to the ARIMA model when deployed for long term electricity demand projections. One of the clear limitations of ARIMA is that the produced forecast values are unreasonably high and unrealistic to represent the future electricity demand requirements. Although literature has acknowledged that ARIMA model could provide an accurate short-term forecast [262] and this finding has been confirmed in this study whereby the MAPE for ARIMA models during the 5 year holdback validation period presented the lowest value in comparison to the other methods (refer Table 52). Nevertheless when ARIMA is mobilised for long term projections, the uncertainty level increases as forecast period extends longer into the future. The ARIMA derived electricity demand forecasts are found to have high amplifying factors (refer Table 54) compared to the other models. This similar observation was also noted in forecasting the installed power capacity for Malaysia using the ARIMA model whereby within a span from 2013 to 2050, the expansion factor grew by 22.51 folds from 29,748 MW to 669,726 MW [267], which is rationally unjustifiable in the context of power engineering.

Table 54. Amplifying factor measured from 2015 to 2050 for all models

Model	Growth	Linear regression	Multiple linear regression	ARIMA (3,2)	ARIMA (3,3)
Amplifying factor	1.87	1.67	1.68	10.34	7.95

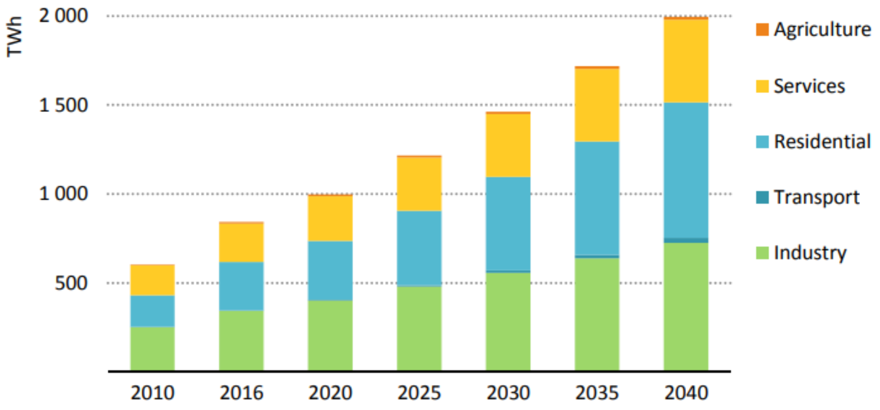


Figure 37. Southeast Asia's electricity demand (IEA)

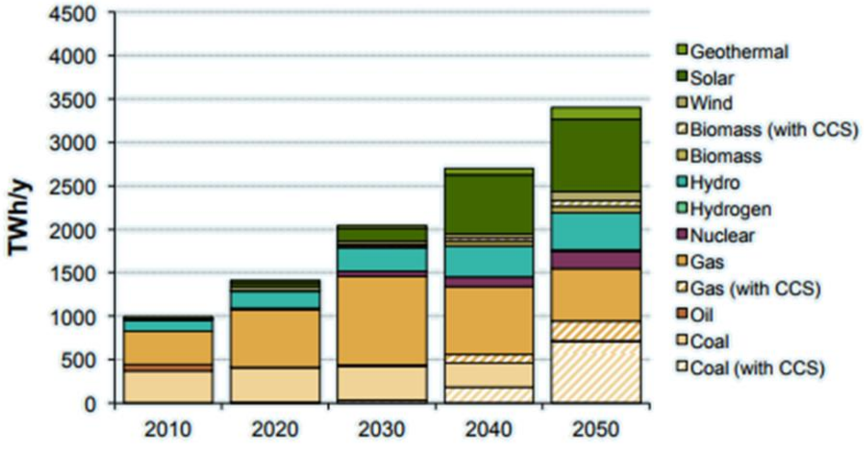


Figure 38. Southeast Asia and Pacific electricity production (WEC)

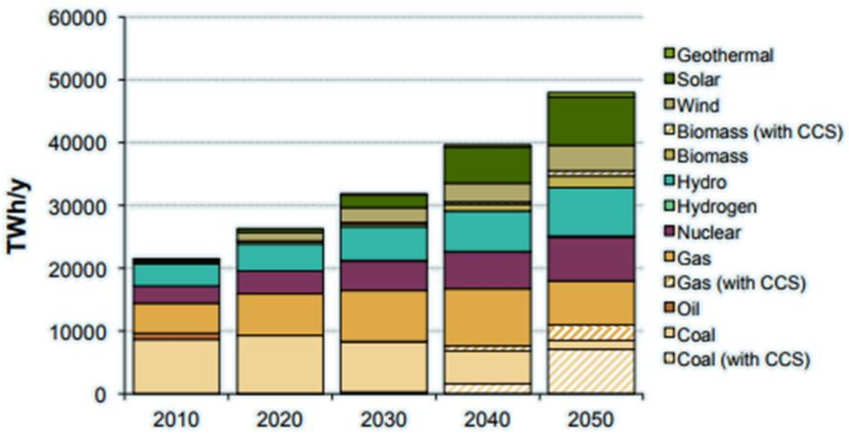


Figure 39. Global electricity production (WEC)

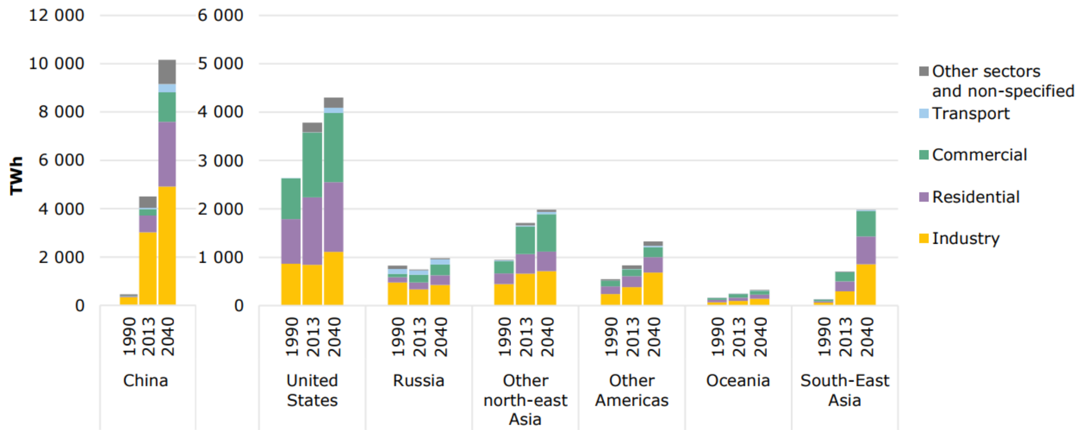


Figure 40. Electricity consumption by region (APEC)

Another reason why the growth model is deemed appropriate over the rest of the models is that the growth rates by the Energy Commission are derived by analyzing historical data on multiple variables through a multiple regression analysis. In recent times, despite the positive economic growth in Malaysia, the electricity demand seems not to correspond in accordance with the economic progress but instead moves slower than the GDP. Thus, the Energy Commission of Malaysia had to consider other variables in the multiple regression analysis such as the slowdown of electricity sales especially in the industrial sector specifically the steel industry, structural transformation in the economy, consumer reaction to higher electricity tariffs, energy efficiency initiatives, implementation of the feed-in tariff mechanism, and also declining demographic factors. Therefore, it is believed that the forecast delivered based on the growth model would be more conclusive because it entails additional variables in which the data are exclusive to the utility company. With the above rationalizations, the forecasts deduced by the linear regression and multiple linear regression shall be laid back to give way to the growth model forecast which considered more data as independent variables in their regression analysis. Ultimately, the preferred forecast to be deployed for MYTEM is the forecast derived from the simplest approach explicitly the growth model.

In the TIMES model, the energy units are set in Peta Joule (PJ). Thus, the electricity demand projections resulting from the growth model needs to be converted from GWh into the specified unit PJ. The conversion factor of 1 GWh equals 0.0036 PJ was applied and the converted figures in PJ appears in Table 55.

Table 55. Electricity demand projections for MYTEM

Year	Electricity demand (GWh)	Electricity demand (PJ)
2015	132,199	476
2020	154,000	554
2025	175,089	630
2030	187,693	676
2035	201,205	724
2040	215,689	776
2045	231,216	832
2050	247,860	892

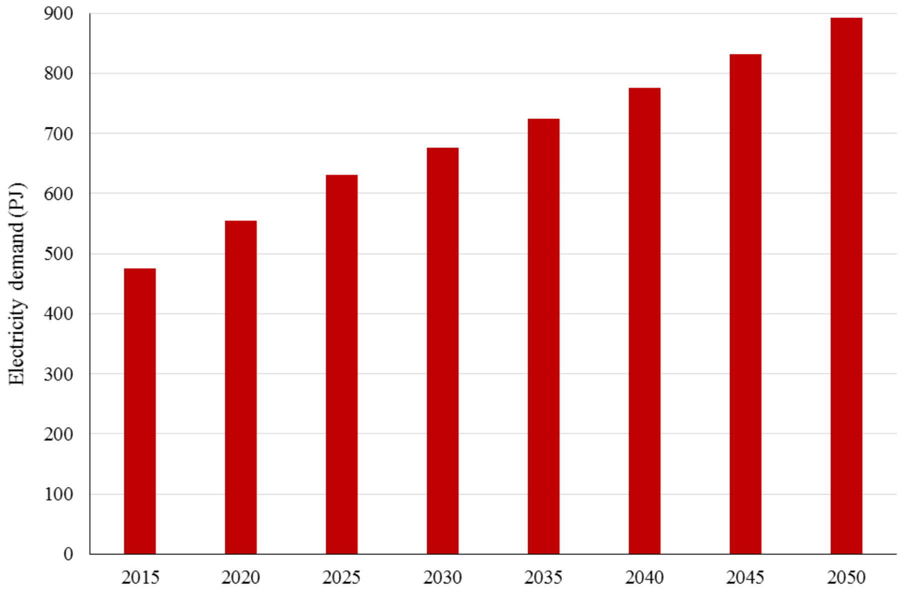


Figure 41. Electricity demand projection for Malaysia 2015-2050

Based on the growth model forecast result as presented in Figure 41, the electricity demand will gradually increase. As a consequence of the rise in electricity demand, certain policy implications need to be thoroughly considered by Malaysia, which includes:

i) an effective power capacity succession plan to accommodate the increase in electricity demand needs to be strategized;

ii) reducing foreign fuel imports to enhance Malaysia's energy security and leverage more on indigenous energy resources that are sustainable; and,

iii) finding the appropriate conversion technologies that would not lead to the uncontainable release of carbon emissions which may breach International Agreements related to climate change mitigation.

5.8 Limitations

Data for annual electricity consumption could only be sourced until 2015 as the latest national energy balance released by the Energy Commission of Malaysia was as of 31st December 2015. Data for 2016 and 2017 are still unavailable.

5.9 Chapter summary

The key findings from this assessment are summarized as below:

- There are different options for projecting electricity demand, however, in futuristic power sector modeling, the embedded forecast must be sensible to mirror the real world situation as close as possible;
- Sometimes the forecast by the simplest method is more practical to be applied in scenario analysis rather than the more complex approach;
- Uncertainty of a forecast is directly proportionate with time;
- The electricity demand projection based on the growth model has been chosen as inputs for MYTEM development as it aligns with the world and regional electricity demand outlooks, the MAPE is within ± 4.68% which serves as the upper and lower forecast error boundary;
- With the depletion of fossil fuel reserves in the near future, alternative pathways need to be explored to replace the high dependency on fossil fuels for power generation, hence the development MYTEM is crucial and timely.

Chapter 6. Potential Power Generation Using Renewable Energy

6.1 Introduction

According to latest production to a reserve ratio of oil and gas, oil may hold for 24 years and gas for another 43 years [6]. Malaysia is ranked the third biggest CO_2 emitter in South East Asia, just within 10 years since 2003 CO_2 emission grew drastically from 158.3 Mt to 236.5 Mt in 2013 and power sector contributed about 54.8% out of the aforementioned figure [7]. Malaysia has ratified the Paris agreement to reduce 45% of greenhouse gas (GHG) concentration relative to 2005 levels by 2030, in which 35% reduction is on a voluntary basis and 10% is upon conditional terms [8] on receipt of international finances.

To overcome the challenges of depleting fossil reserves and to mitigate GHG emissions, it is high time for Malaysia to explore unconventional energy resources to reduce its hydrocarbon dependence as the main source for power generation in order to ensure a sustainable power sector. Thus, it is essential to comprehend the technical potential of available renewable resources that could complement the national grid.

In this chapter, potential energy from renewable resources such as onshore and offshore wind, solar photovoltaics, biomass sourced from Empty Fruit Bunch (EFB), biogas from anaerobic digestion of Palm Oil Mill Effluent (POME), tidal and wave energy will be explored in the perspective of power generation. For renewables such as hydro and geothermal that are dependent on topographic and geological factors will be reviewed through literature review or secondary sources. This assessment is important in establishing a sensible upper boundary for power generation capacity through renewable energy resources. This identified upper boundary for renewables will be input in the Malaysia TIMES Electricity Model (MYTEM) that will be described in the next chapter.

The results for Malaysia's renewable energy potential assessment will be presented in the following order: onshore and offshore wind, solar photovoltaic, tidal, biomass, biogas, wave, hydro and geothermal.

6.2 Wind

It is observed that wind speed increases with altitude, this is connected to friction that interacts with the earth surface and causes wind speed to reduce, however, it is noted that friction is inversely proportional to the increment in altitude, thus giving a rise in wind speed at higher elevations. In fact, wind speed has always been a crucial aspect in evaluating wind power as it is factored as a cubic function in the wind power equation.

It is expected that in the following section, this context will be covered: the onshore and offshore wind maps for Malaysia; the monthly and annual mean onshore and offshore wind speed at 50 m, 100 m, 150 m and 200 m height;, the minimum to maximum wind power and electricity output estimations derived based on available wind farm installation area and through a referenced wind turbine with specified parameters; and, the avoided CO_2 emissions will be estimated as well.

6.2.1 Onshore wind

The onshore and 30 km oceanfront wind map at 50 m altitude [268] is presented in Figure 42, based on this map, the onshore wind speed in Malaysia generally falls in the range from 3.0 to 4.0 ms^{-1}. While seafront area facing the South China Sea indicates a higher wind streaming between 5.0 to 6.0 ms^{-1}.

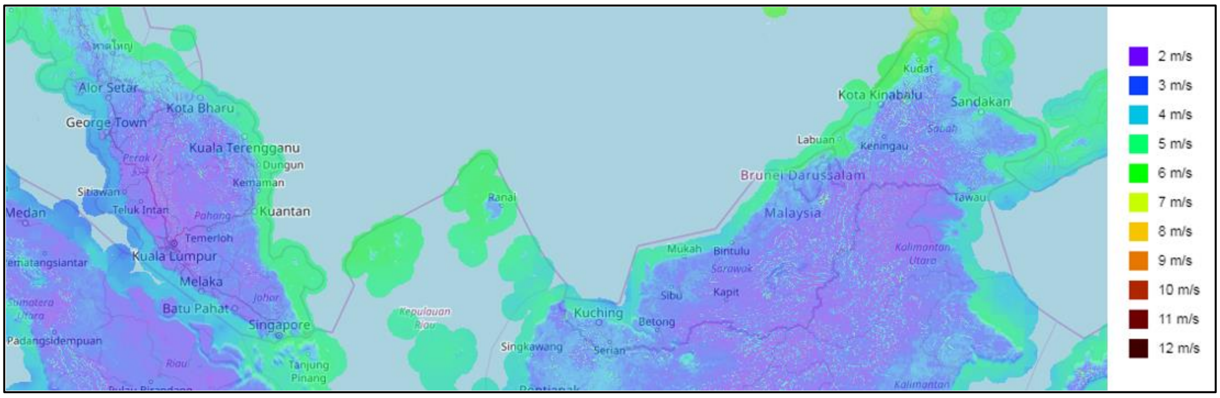


Figure 42. Onshore wind map for Malaysia at 50 m altitude [268]

NASA Langley Research Centre Atmospheric Science Data Centre Surface Meteorological and Solar Energy (SSE) monthly and annual mean wind speed data at 50 m elevation for 8 assessed locations are presented in Table 56, these results indicate that the mean annual wind speeds for these locations falls in the low wind speed range varying between 2.80 to 5.43 ms^{-1}.

Table 56. Annual mean onshore wind speed at 50 m for assessed locations

Month	Kota Kinabalu (KK) (ms^{-1})	Mersing (M) (ms^{-1})	Rantau Panjang (RP) (ms^{-1})	Padang Besar (PB) (ms^{-1})
January	4.01	4.34	4.16	3.72
February	3.73	3.73	3.61	3.22
March	3.36	2.97	3.17	2.82
April	2.38	1.94	2.36	2.14
May	2.10	2.12	2.39	2.35
June	3.27	3.23	3.21	3.01
July	3.34	3.24	3.15	2.92
August	3.92	3.55	3.53	3.40
September	3.03	2.72	3.09	2.90
October	3.18	2.18	2.60	2.50
November	3.10	2.87	3.47	3.19
December	3.48	4.19	4.62	4.26
Mean	**3.24**	**3.08**	**3.28**	**3.03**

Month	Kuala Terengganu (KT) (ms^{-1})	Pulau Perhentian (PP) (ms^{-1})	Terumbu Layang-Layang (TLL) (ms^{-1})	Malaysia-Kg Gua (MY) (ms^{-1})
January	5.36	4.17	7.43	3.88
February	4.40	3.50	6.33	3.24
March	3.74	3.00	5.47	2.80
April	2.60	2.08	3.84	1.99
May	2.38	1.97	3.34	1.91
June	3.49	2.89	5.70	2.67
July	3.51	2.89	5.21	2.70
August	3.78	3.11	6.24	2.94
September	3.26	2.72	5.04	2.46
October	2.70	2.19	4.86	2.17
November	3.83	3.17	5.25	2.89
December	5.49	4.33	6.59	3.97
Mean	**3.71**	**3.00**	**5.43**	**2.80**

As Malaysia's weather is governed by two monsoon seasons throughout the year, namely the Southwest Monsoon that begins from late May to September, and the Northeast Monsoon that falls from late October to March, therefore a visible pattern across all 8 locations can be distinguished whereby wind speeds tend to be higher during the months where the monsoon seasons prevails as presented in Figure 43. It is observed that the declining slopes are visible in the months of April and October. The monthly and annual mean wind speed based on estimations derived from equation (4-1) at variable hub heights of 100 m, 150 m and 200 m for all 8 locations are summarised in Table 57. Figure 44 presents the radar charts to illustrate the rise in wind speed at different altitudes which takes place during the monsoon months. The results revealed that only Terumbu Layang-Layang (Sparrow reef) has wind speeds exceeding 6.00 ms^{-1} above 100 m height, all other locations presented very low wind speeds, even at 200 m above sea level wind streams were between 3.43 to 4.54 ms^{-1}. This indicates that utility-scale onshore wind development in Malaysia is technically not viable as the annual mean onshore wind speed does not surpass the minimum requirement of 6.0 ms^{-1} [269].

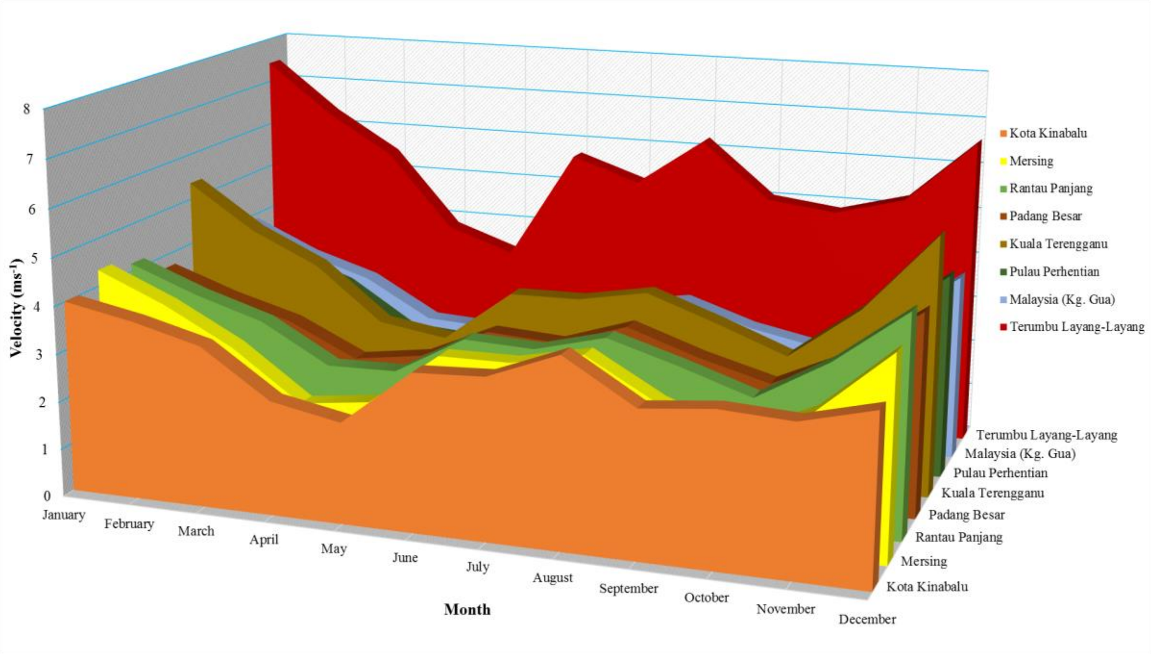


Figure 43. Mean monthly wind speed for assessed locations

Despite Terumbu Layang-Layang's higher mean annual wind speed as shown in Figure 45, small-scale off-grid IEC class IV or class III wind turbine may be installed. However, a grid-connected onshore wind farm is not feasible since a 300 km undersea high voltage direct current interconnector cable needs to be fitted to link Terumbu Layang-Layang and Kota Kinabalu which is too costly. Furthermore, Sparrow reef is part of the on-going disputed Spratly islands being claimed over ocean territory and sovereignty by several countries at the International Tribunal.

Table 57. Onshore mean annual wind speed at 100 m, 150 m and 200 m alleviation for assessed locations

Location	Jan	Feb	Mac	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
KK100	4.46	4.13	3.72	2.64	2.33	3.62	3.70	4.34	3.36	3.52	3.43	3.86	**3.59**
KK150	4.74	4.39	3.96	2.80	2.47	3.85	3.93	4.62	3.57	3.74	3.65	4.10	**3.82**
KK200	4.92	4.56	4.11	2.92	2.57	4.00	4.09	4.79	3.71	3.89	3.79	4.26	**3.97**
M100	4.82	4.13	3.29	2.15	2.35	3.58	3.59	3.93	3.01	2.41	3.18	4.64	**3.42**
M150	5.12	4.39	3.50	2.28	2.49	3.80	3.82	4.18	3.20	2.57	3.38	4.94	**3.64**
M200	5.32	4.56	3.63	2.37	2.59	3.95	3.96	4.34	3.32	2.66	3.51	5.12	**3.78**
RP100	4.61	4.00	3.51	2.61	2.65	3.56	3.49	3.91	3.42	2.88	3.85	5.12	**3.63**
RP150	4.90	4.25	3.73	2.78	2.81	3.78	3.71	4.16	3.64	3.06	4.09	5.44	**3.86**
RP200	5.09	4.42	3.88	2.88	2.93	3.93	3.85	4.32	3.78	3.18	4.25	5.65	**4.01**
PB100	4.12	3.57	3.12	2.37	2.60	3.33	3.23	3.77	3.21	2.77	3.53	4.72	**3.36**
PB150	4.38	3.79	3.32	2.52	2.77	3.54	3.44	4.00	3.41	2.94	3.76	5.02	**3.58**
PB200	4.55	3.94	3.45	2.62	2.87	3.68	3.57	4.16	3.54	3.06	3.90	5.21	**3.71**
KT100	5.94	4.88	4.14	2.88	2.64	3.87	3.89	4.19	3.61	2.99	4.24	6.09	**4.11**
KT150	6.32	5.18	4.41	3.06	2.80	4.11	4.13	4.45	3.84	3.18	4.51	6.47	**4.37**
KT200	6.56	5.39	4.57	3.18	2.92	4.27	4.30	4.63	3.99	3.30	4.68	6.72	**4.54**
PP100	4.62	3.88	3.32	2.30	2.18	3.20	3.20	3.45	3.01	2.42	3.51	4.80	**3.32**
PP150	4.91	4.12	3.53	2.45	2.32	3.40	3.40	3.66	3.20	2.58	3.73	5.10	**3.53**
PP200	5.10	4.28	3.67	2.54	2.41	3.53	3.53	3.81	3.32	2.67	3.88	5.30	**3.67**
TLL100	8.24	7.02	6.06	4.26	3.70	6.32	5.78	6.92	5.59	5.39	5.82	7.31	**6.03**
TLL150	8.76	7.46	6.44	4.52	3.93	6.72	6.14	7.35	5.94	5.73	6.19	7.77	**6.41**
TLL200	9.10	8.24	6.69	4.70	4.09	6.98	6.38	7.64	6.17	5.95	6.43	8.07	**6.70**
MY100	4.30	3.59	3.10	2.20	2.11	2.96	2.99	3.26	2.72	2.40	3.20	4.40	**3.10**
MY150	4.57	3.82	3.30	2.34	2.25	3.14	3.18	3.46	2.90	2.55	3.40	4.68	**3.30**
MY200	4.75	3.96	3.42	2.43	2.33	3.27	3.30	3.60	3.00	2.65	3.53	4.86	**3.43**

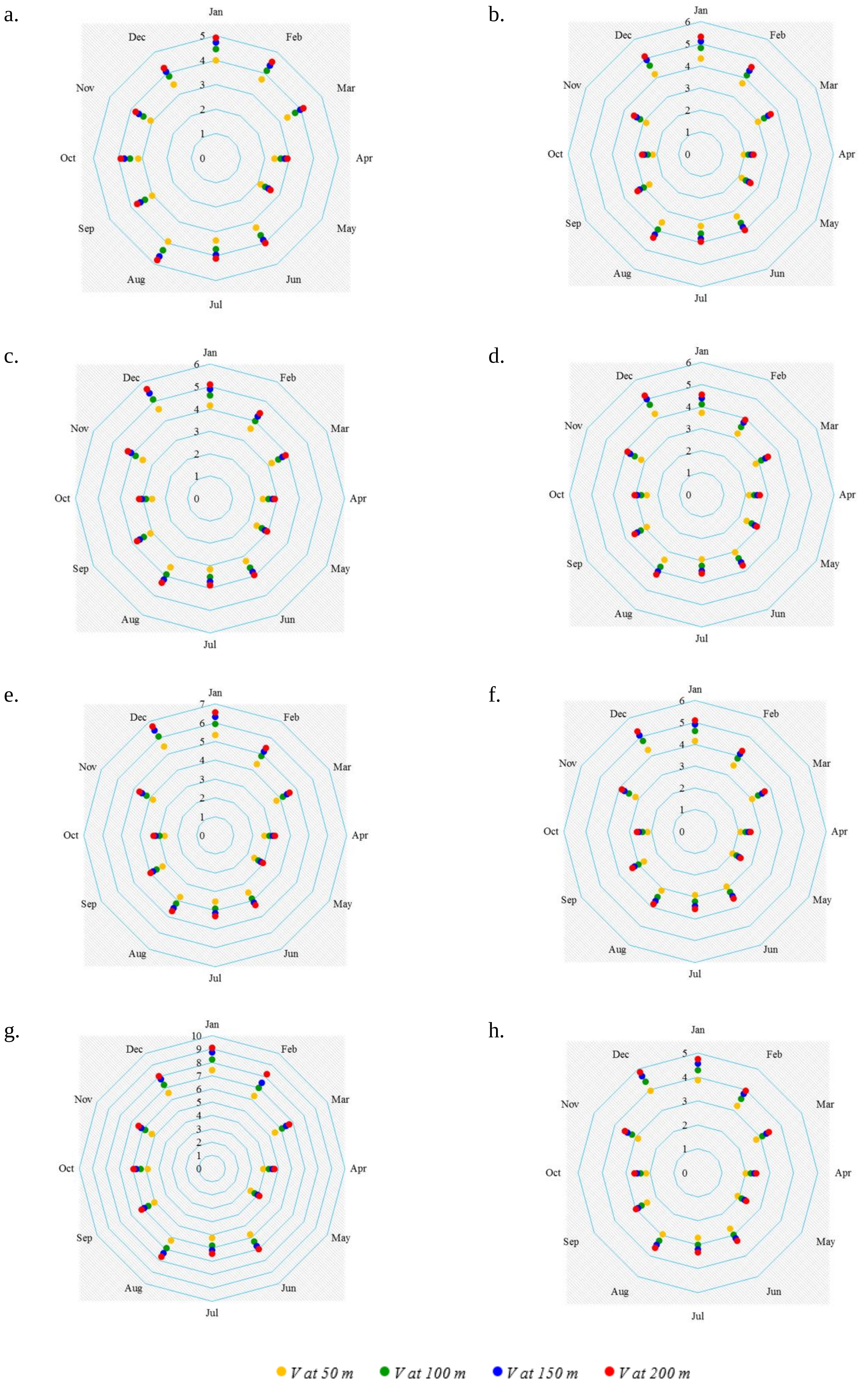


Figure 44. Onshore monthly mean wind speed at variable heights for locations: a. Kota Kinabalu; b. Mersing; c. Rantau Panjang; d.Padang Besar; e. Kuala Terengganu; f. Pulau Perhentian; g. Terumbu Layang-Layang; and h. Malaysia (Kg. Gua)

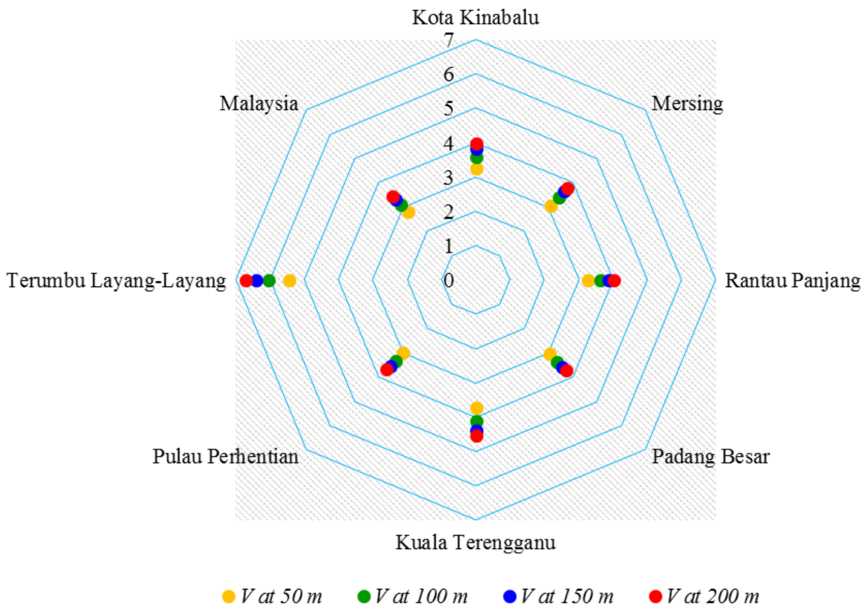


Figure 45. Annual mean onshore wind speed at variable heights for assessed locations

6.2.2 Offshore wind

South China Sea's mean monthly and annual wind speed as per Table 58 were retrieved from analyzing QuikSCAT monthly ocean maps at 50 m elevation as in Figure 46 [177]. After substituting wind speed values at 50 m in equation (4-1) using the sea surface wind shear (α_s = 0.09), wind speeds for altitudes of 100 m, 150 m, and 200 m were deduced using the power law approach and the results appear in Table 59.

Table 58. Mean monthly and annual offshore wind speed at 50 m

Month	wind speed at 50 m (ms^{-1})
January	9.00
February	8.00
March	6.50
April	6.00
May	6.00
June	7.00
July	8.00
August	8.50
September	7.00
October	7.00
November	8.00
December	9.00
Mean	**7.50**

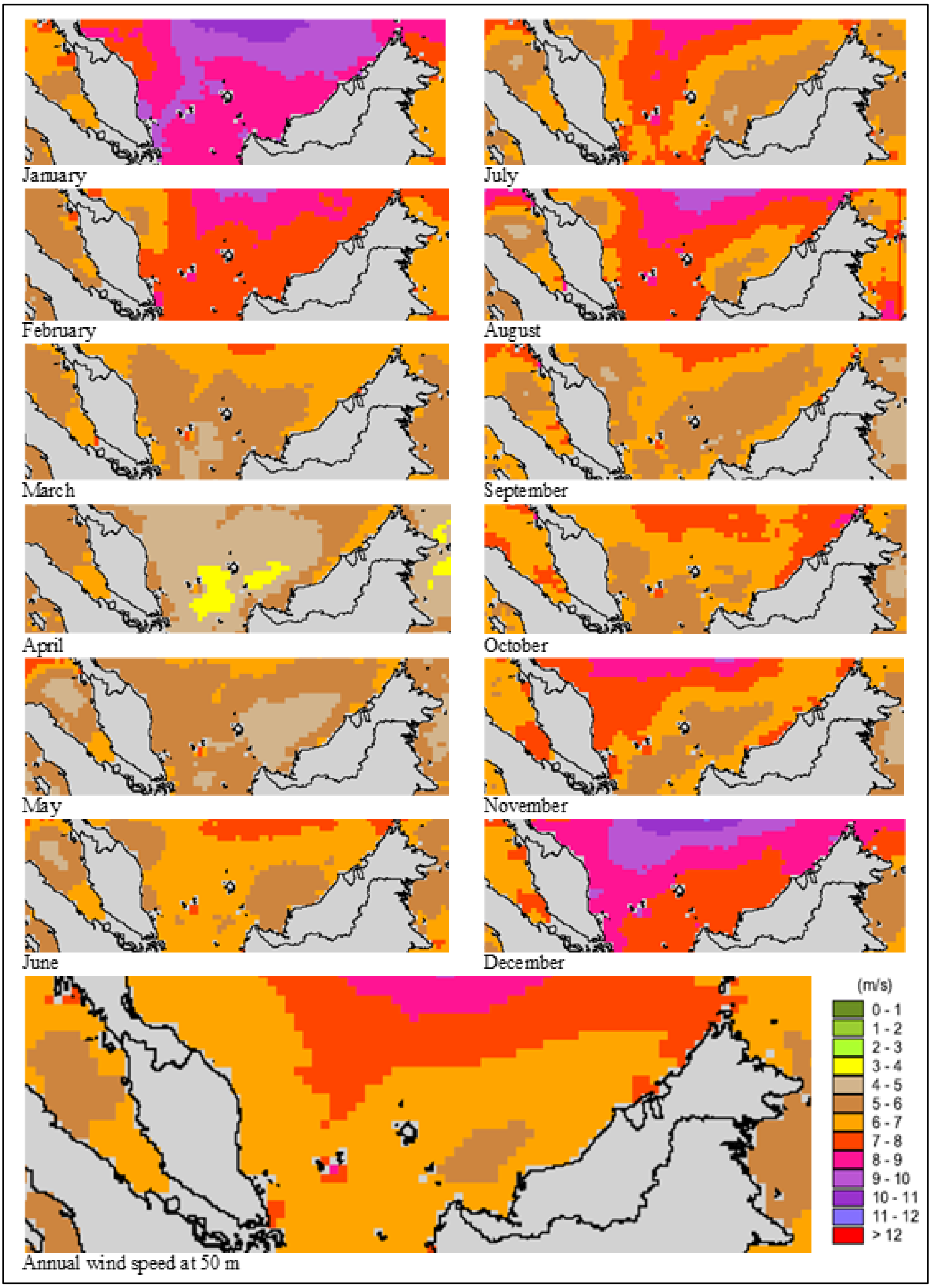


Figure 46. Offshore wind map for Malaysia at 50 m [177]

Based on the derived wind speed data, Malaysia has the potential to harness wind energy from offshore wind farms as the annual average offshore wind speed for Malaysia falls in the medium speed range between 7.5 to 8.5 ms^{-1}.

Table 59. Offshore annual mean wind speed at 100 m, 150 m, and 200 m alleviation

Month	wind speed 100 m (ms^{-1})	wind speed 150m (ms^{-1})	wind speed 200m (ms^{-1})
January	9.58	9.94	10.20
February	8.51	8.83	9.06
March	6.92	7.18	7.36
April	6.39	6.62	6.80
May	6.39	6.62	6.80
June	7.45	7.73	7.93
July	8.51	8.83	9.06
August	9.05	9.38	9.63
September	7.45	7.73	7.93
October	7.45	7.73	7.93
November	8.51	8.83	9.06
December	9.58	9.94	10.20
Mean	**7.98**	**8.28**	**8.50**

Hence, based on the mean monthly wind speed map for altitudes within 50 to 200 m shown in Figure 47, IEC class II wind turbines are technically feasible to be implemented near the coastal shoreline facing the South China Sea.

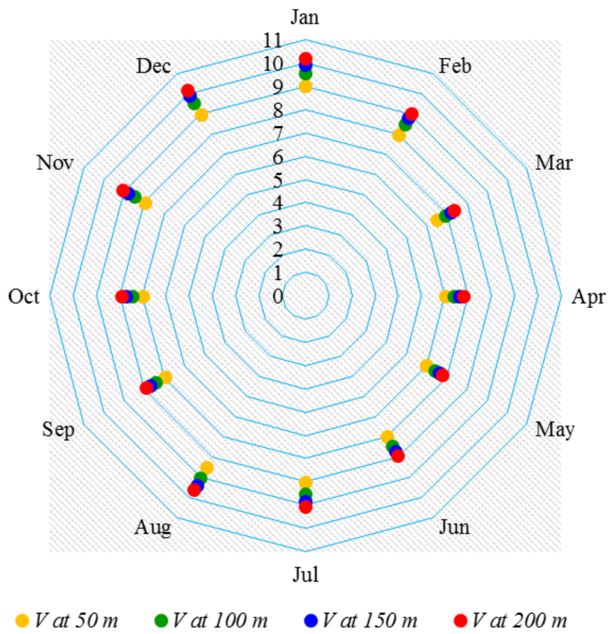


Figure 47. Offshore monthly mean wind speed at variable heights

Currently, offshore wind farms are limited to regions where sea depth does not exceed 60 m, however floating wind turbines may be a future option for deeper zones. Malaysia's ocean depth is at the shallower front, which permits construction of oil and gas platforms for oil and gas upstream activities. According to the bathymetry charts for Peninsular Malaysia and East Malaysia [270] in Figure 48 and 49 specified that Malaysia holds a generous stretch of seabed with depth less than 50 m which makes it perfect for offshore wind installations. As wind is an unlimited resource, the number of wind farms will be influenced by factors such as availability of installation areas, attractive feed-in tariff rates, and the investment cost on commissioning an offshore wind farm.

Figure 48. Bathymetry map for Peninsular Malaysia [270]

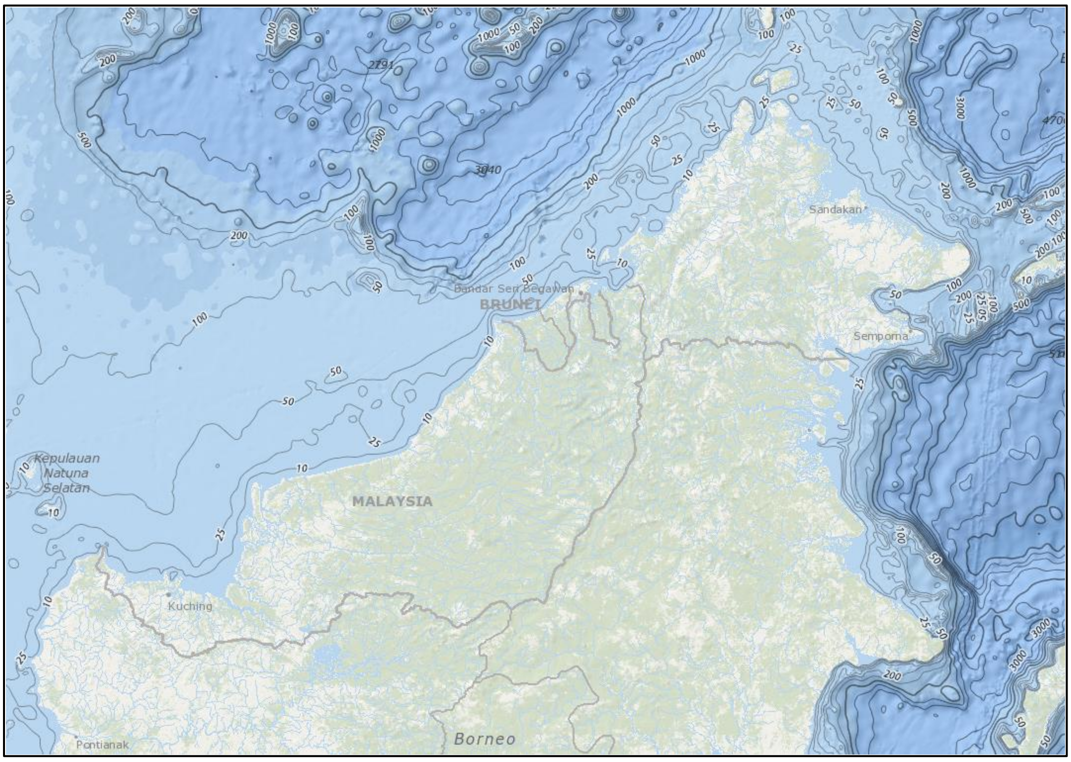


Figure 49. Bathymetry map for East Malaysia [270]

In this assessment, a total of 22,200 km^2 of the Malaysian territorial waters facing the South China Sea was explored as suitable installation space for offshore wind farms, therefore under this constraint, the minimum to maximum extracted wind power and electricity output was estimated in Table 60. Apart from that, the avoided CO_2 emission were also determined.

Table 60. Offshore wind power potential

Wind turbines (unit)	Territory sea area (km^2)	Territory sea area (%)	Swept area (m^2)	Power (MW) Equation (4-2)	Electricity yield (GWh/year) Equation (4-3)	Avoided CO_2 emission (kt/year) Equation (4-11)	CO_2 reduced (based on 45% 2005 level) (%)
1	1	0.0	9,852	1.39	9.13	6.84	0.01
500	281	1.3	4,926,013	695.16	4,567.19	3,420.11	4.36
1,000	563	2.5	9,852,026	1,390.32	9,134.39	6,840.22	8.71
1,500	844	3.8	14,778,039	2,085.48	13,701.58	10,260.33	13.07
2,000	1,125	5.0	19,704,052	2,780.64	18,268.78	13,680.44	17.42
2,500	1,406	6.3	24,630,066	3,475.79	22,835.97	17,100.55	21.78
3,000	1,688	7.6	29,556,079	4,170.95	27,403.17	20,520.65	26.13
3,500	1,969	8.9	34,482,092	4,866.11	31,970.36	23,940.76	30.49
4,000	2,250	10.0	39,408,105	5,561.27	36,537.56	27,360.87	34.85
5,920	3,330	15.0	58,323,995	8,230.68	54,075.58	40,494.09	51.57
9,867	5,550	25.0	97,206,659	13,717.80	90,125.97	67,490.15	85.95
11,479	**6,457**	**29.1**	113,067,815	**15,956.13**	104,831.78	**78,519.00**	**100.00**
19,733	11,100	50.0	194,413,318	27,435.61	180,251.94	134,980.30	171.91
29,600	16,650	75.0	291,619,977	41,153.41	270,377.91	202,470.45	257.86
39,467	22,200	100.0	388,826,636	54,871.21	360,503.88	269,960.61	343.82

The estimations reveal that at the maximum cumulated power of 54,871.21 MW, would allow for 360,503.88 GWh generated electricity per annum which is 281% in excess of supply compared to the electricity consumption record in 2014. If each residential customer in Malaysia consumes about 4,194 kWh of electricity per annum [271], then the maximum electricity generation from offshore wind resource would be sufficient to cater for 85.9 million customers, which is 2.75 folds higher than the current 31.2 million population. Nevertheless, if only 10% (2,250 km^2) of the allocated area is developed into offshore wind farms, this would fulfill 28.5% (36,538 GWh) of the electricity demand requirements of 2014 and could reduce the dependence on fossil fuels such as coal and natural gas. The 2005 baseline reduction levels can be substantiated by analyzing the CO_2 emission data of Malaysia as shown in Table 61 [7]. The 45% reduction target based on 2005 baseline levels is equivalent to 78,519 kt of CO_2 savings as presented in Figure 50. An upward trend is clearly detected in Malaysia's CO_2 emission profile.

Table 61. CO_2 emission data for Malaysia from 1970 -2014

Year	CO_2 emissions (kt)	Year	CO_2 emissions (kt)	Year	CO_2 emissions (kt)
1970	14,602	1985	36,237	2000	125,734
1971	16,678	1986	39,985	2001	135,620
1972	17,913	1987	40,762	2002	133,743
1973	17,514	1988	42,724	2003	158,257
1974	19,050	1989	49,882	2004	163,827
1975	19,446	1990	56,593	2005	174,487
1976	23,894	1991	68,591	2006	167,703
1977	22,611	1992	75,298	2007	184,817
1978	23,238	1993	91,723	2008	204,032
1979	27,279	1994	94,011	2009	198,803
1980	27,998	1995	121,132	2010	218,476
1981	30,825	1996	125,375	2011	220,405
1982	30,572	1997	124,821	2012	218,707
1983	37,972	1998	114,187	2013	236,510
1984	34,697	1999	107,934	2014	242,821

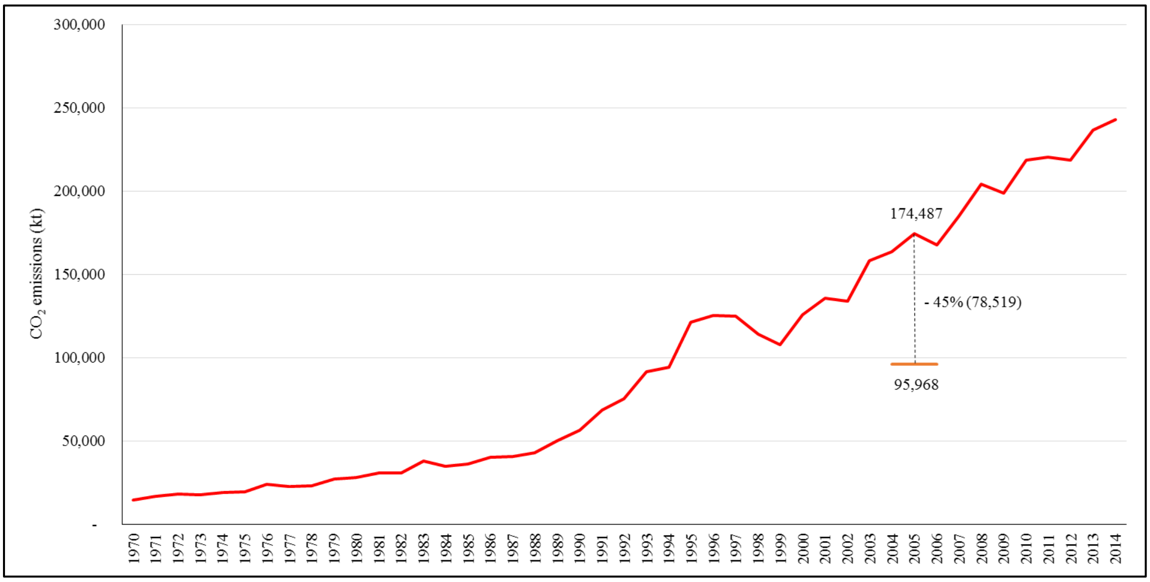


Figure 50. CO_2 emission profile for Malaysia 1970 - 2014

As wind is an unlimited resource and considered as a clean energy which is emission free, it can be one of the options that could aid the fulfillment of Malaysia's commitment in the Paris Agreement namely to reduce 45% or 78,519 kt of CO_2 emissions relative to the 2005 baseline levels by 2030. In order to achieve this pledge by relying on wind energy alone, approximately 29.1% of territorial sea space has to be installed with offshore wind farms with cumulated power capacity totaling 15,956 MW. This assessment indicated that offshore wind has the technical potential to substantially contribute to the electricity generation mix since the corresponding mean power density and the annual mean energy density per square meter swept area are 141.12 Wm^{-2} and 927.16 $kWhm^{-2}$ respectively.

The economic analysis presented in Table 62 indicated that the 100 MW wind farm is perceived to be a viable project since it has a positive net present value (NPV). In this study, Germany's FiT for offshore wind is adopted since offshore wind is not listed in the Malaysian FiT scheme. This analysis indicated that the internal rate of return (IRR) and the discounted payback period (DPP) seems to be sensitive to FiT and the variable interest rates offered by the central or commercial banks. It is observed that when FiT is introduced, the IRR and DPP becomes more attractive as the recovery period on investment cost is greatly reduced between 4.9 to 7.3 years. In contrast to the analysis without FiT, it is clear that the discounted payback period gets deferred between 9.4 to 22.2 years subject to the interest rates.

Table 62. Economic valuation of 100 MW offshore wind farm

Indicator	Unit	3%	7%	9%
NPV	USD	978,224,744	669,662,026	570,120,044
IRR	%	10.59	6.45	4.5
DPP	years	9.4	15.5	22.2
NPV (FiT)	USD	1,498,475,013	1,049,414,447	900,919,593
IRR (FiT)	%	20.33	15.83	13.71
DPP (FiT)	years	4.9	6.3	7.3
LCOE	USD per kWh	0.05	0.06	0.07

6.2 Solar photovoltaics

Solar PV generates electrical power by converting solar radiation into direct current (DC) and can be installed at locations where the solar radiation is above 1,000 kWh per annum. Therefore many temperate countries in Europe have installed solar PV systems despite the lower annual radiation range. The climatic condition in Malaysia makes solar photovoltaics the perfect technology choice for generating electricity. The mean daily radiation in all the assessed locations falls between 4.55 to 5.28 $kWhm^{-2}$ as per Table 63, while the annual mean solar radiation received by Malaysia is about 1,795.27 $kWhm^{-2}$ as shown in Table 64.

Table 63. Mean daily solar radiation for assessed locations

Daily solar radiation ($kWhm^{-2}$)	Kota Kinabalu	Kuching	Miri	Sibu	Bintulu	Sandakan
January	4.72	3.96	5.16	4.26	4.78	4.28
February	5.09	4.36	5.65	4.91	5.19	4.66
March	5.57	4.68	6.09	5.11	5.44	5.30
April	5.72	4.99	5.80	5.30	5.34	5.68
May	5.33	4.87	5.27	5.14	5.25	5.39
June	5.23	4.93	5.22	5.14	5.23	5.17
July	5.21	4.84	5.19	5.12	5.23	5.24
August	5.16	4.87	5.27	4.80	5.08	5.36
September	5.25	4.68	4.96	4.50	5.01	5.34
October	4.92	4.59	4.66	4.67	4.82	4.93
November	4.76	4.48	4.40	4.51	4.68	4.59
December	4.51	4.16	4.43	4.23	4.55	4.20
Mean	**5.12**	**4.62**	**5.17**	**4.80**	**5.04**	**5.01**

Daily solar radiation ($kWhm^{-2}$)	Tawau	Johor Bahru	Ipoh	Penang	Alor Setar	Kuala Terengganu
January	4.55	4.48	4.59	5.62	5.26	4.61
February	4.76	5.22	5.20	6.09	5.86	5.55
March	5.09	5.05	5.29	5.93	5.81	5.92
April	5.25	4.87	5.27	5.69	5.65	5.99
May	5.00	4.57	4.93	5.07	5.05	5.49
June	4.95	4.41	4.84	4.97	4.82	5.26
July	4.90	4.30	4.81	4.92	4.84	5.20
August	4.99	4.33	4.68	4.71	4.68	5.20
September	5.12	4.53	4.67	4.67	4.65	5.29
October	4.91	4.57	4.47	4.53	4.37	4.67
November	4.80	4.34	4.11	4.76	4.23	3.87
December	4.49	4.07	4.05	5.00	4.42	3.81
Mean	**4.90**	**4.55**	**4.73**	**5.15**	**4.96**	**5.06**

Daily solar radiation ($kWhm^{-2}$)	Kangar	Kuantan	Malacca	Shah Alam	Kota Bahru	Malaysia (Kg. Gua)
January	5.26	4.24	4.48	4.79	5.14	4.59
February	5.86	5.09	5.12	5.37	5.95	5.20
March	5.81	5.24	5.09	5.42	6.23	5.29
April	5.65	5.42	5.09	5.27	6.28	5.27
May	5.05	5.15	4.76	5.11	5.54	4.93
June	4.82	5.01	4.61	4.98	5.33	4.84
July	4.84	4.96	4.58	4.92	5.35	4.81
August	4.68	5.05	4.61	4.87	5.30	4.68
September	4.65	5.12	4.71	4.88	5.42	4.67
October	4.37	4.71	4.76	4.76	4.76	4.47
November	4.23	3.89	4.34	4.36	3.98	4.11
December	4.42	3.55	4.00	4.17	4.24	4.05
Mean	**4.96**	**4.78**	**4.67**	**4.90**	**5.28**	**4.73**

Table 64. Mean annual solar radiation for Malaysia

Month	Daily mean solar radiation ($kWhm^{-2}$)	Days per month (days)	Monthly solar radiation ($kWhm^{-2}$)
January	4.71	31	146.01
February	5.29	28	148.12
March	5.46	31	169.26
April	5.47	30	164.10
May	5.11	31	158.41
June	4.99	30	149.70
July	4.96	31	153.76
August	4.91	31	152.21
September	4.90	30	147.00
October	4.66	31	144.46
November	4.36	30	130.80
December	4.24	31	131.44
Mean	**4.91**	-	-
Total	-	**365**	**1,795.27**

A more detailed observation on the monthly radiation as per Figure 51 indicated that the minimum mean monthly radiation of 130.80 $kWhm^{-2}$ occurs in November and the maximum mean monthly radiation is 169.26 $kWhm^{-2}$ which transpire in March.

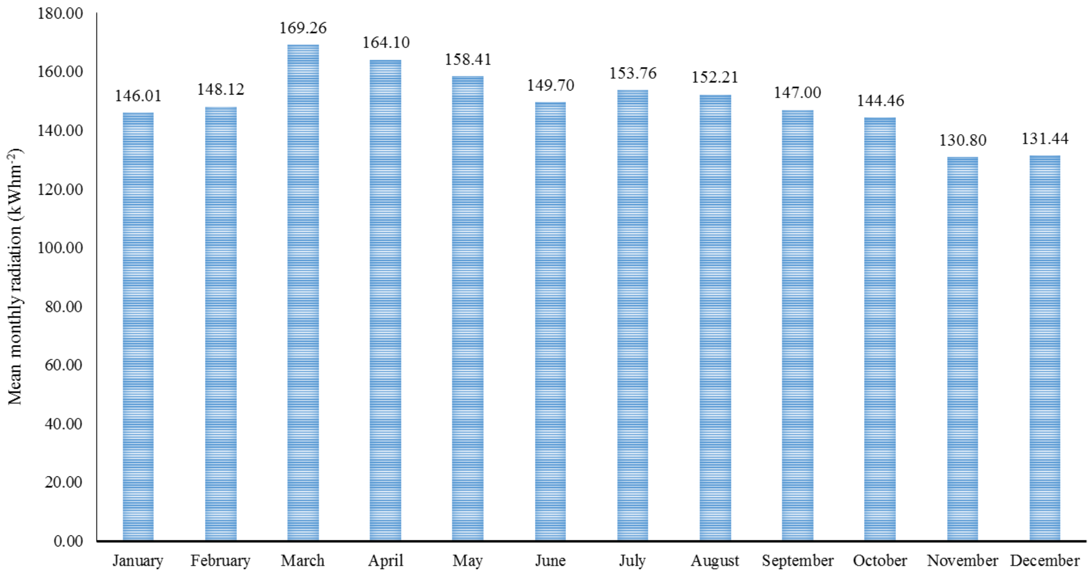


Figure 51. Mean monthly radiation

When the approximated annual mean solar radiation of 1,795.27 $kWhm^{-2}$ is contrasted with the solar radiation map of Peninsular and East Malaysia [239] as shown in Figure 52 and 53, the annual solar radiation range is within 1,700 to 1,900 $kWhm^{-2}$. Therefore, solar PV should be maximized and connected to the grid as it is a promising power conversion technology for Malaysia.

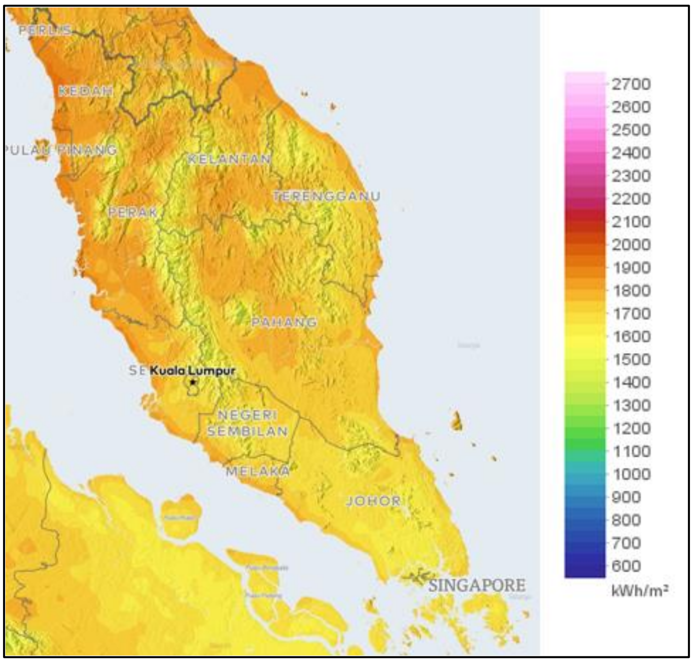


Figure 52. Solar radiation map for Peninsular Malaysia [239]

Figure 53. Solar radiation map for East Malaysia [239]

In order not to compromise new land usage, solar PV panels for rooftops facades or building integrated photovoltaics is a sensible option for Malaysia and estimates were accounted for an upper limit of 0.15% out of Malaysia's total land area assumed for existing residential, commercial and industrial rooftops. This upper limit is equivalent to 394,260,000 m^2 after considering 20% of unfit roof area for PV installations. Hence, Table 65 presents the minimum to maximum solar energy potential, the extracted power as well as the electricity yield from

PV. Furthermore, the carbon footprint savings are also projected and compared to the 2005 baseline levels of 45% (78,519 kt) CO_2 reductions.

Upon 100% installation coverage, the cumulative annual electricity output from 36,602.15 MW solar power would generate 80,158.71 GWh per year which is approximately 60.64% of the total electricity consumption in 2015. While this electricity yield could accommodate 32.34% of the demand by 2050. In Malaysia, the period where electricity is optimally produced from PV coincides with the daytime peak load which occurs in the afternoon which is much required for building cooling (air-conditioning), industrial use, and manufacturing purposes. Therefore, solar energy through PV technology has the potential to contribute to the peak load demands that occurs during the day. Besides that, solar PV is a clean energy source since no GHG is released into the atmosphere. The CO_2 savings coming from solar PV could only fulfil 76.46% (60,038 kt) of the targeted pledge in the Paris Agreement by 2030. Hence, this technology needs to be combined with other carbon-free energy resources.

Table 65. PV power potential

Number of PV panels (unit)	PV surface area (m^2)	PV area (%)	Solar energy potential (GWh/year) Equation (4-4)	Electricity yield (GWh/year) Equation (4-5)	Extracted power (MW) Equation (4-6)	Avoided CO_2 emission (kt/year) Equation (4-11)	CO_2 reduced (based on 45% 2005 level) (%)
1	1.63	0.0	0.00	0.00	0.00	0.00	0.00
2,418,773	3,942,600	1.0	7,078.03	801.59	366.02	600.39	0.76
12,093,865	19,713,000	5.0	35,390.16	4,007.94	1,830.11	3,001.94	3.82
24,187,730	39,426,000	10.0	70,780.32	8,015.87	3,660.21	6,003.89	7.65
36,281,595	59,139,000	15.0	106,170.47	12,023.81	5,490.32	9,005.83	11.47
48,375,460	78,852,000	20.0	141,560.63	16,031.74	7,320.43	12,007.77	15.29
60,469,325	98,565,000	25.0	176,950.79	20,039.68	9,150.54	15,009.72	19.12
72,563,190	18,278,000	30.0	212,340.95	24,047.61	10,980.64	18,011.66	22.94
84,657,055	137,991,000	35.0	247,731.10	28,055.55	12,810.75	21,013.60	26.76
96,750,920	157,704,000	40.0	283,121.26	32,063.48	14,640.86	24,015.55	30.59
108,844,785	177,417,000	45.0	318,511.42	36,071.42	16,470.97	27,017.49	34.41
120,938,650	197,130,000	50.0	353,901.58	40,079.35	18,301.07	30,019.44	38.23
133,032,515	216,843,000	55.0	389,291.73	44,087.29	20,131.18	33,021.38	42.06
145,126,380	236,556,000	60.0	424,681.89	48,095.22	21,961.29	36,023.32	45.88
157,220,245	256,269,000	65.0	460,072.05	52,103.16	23,791.40	39,025.27	49.70
169,314,110	275,982,000	70.0	495,462.21	56,111.09	25,621.50	42,027.21	53.52
181,407,975	295,695,000	75.0	530,852.36	60,119.03	27,451.61	45,029.15	57.35
193,501,840	315,408,000	80.0	566,242.52	64,126.97	29,281.72	48,031.10	61.17
205,595,706	335,121,000	85.0	601,632.68	68,134.90	31,111.83	51,033.04	64.99
217,689,571	354,834,000	90.0	637,022.84	72,142.84	32,941.93	54,034.98	68.82
229,783,436	374,547,000	95.0	672,412.99	76,150.77	34,772.04	57,036.93	72.64
241,877,301	394,260,000	100.0	707,803.15	80,158.71	36,602.15	60,038.87	76.46

The power variability or intermittency issue caused by solar PV can be resolved if small-scale storage systems such as lithium ion batteries or on a larger scale whereby the grid is networked with the mature pumped hydro storage (PHS) system. There are plans to establish an 800 MW utility-scale photovoltaic solar farms by 2020 [152] which will further increase the PV potential up to 37,402.15 MW.

The economic analysis on a 100 MW solar PV farm as in Table 66 revealed that the return on investments can be recovered between 4.1 to 5.8 years depending on the selected interest rate which is an attractive business venture since it requires less than 7 years to break even. While the 8 kW rooftop PV system for individual application in Table 67 seems to give an even shorter payback period, just within 3.4 to 4.4 years the initial capital cost can be redeemed. For both application namely company and individual, the NPV is sensitive to the interest rates because it declines in value with higher interest rates (inversely proportional relationship between discount rate and the NPV).

Table 66. Economic valuation of 100 MW solar PV farm (company)

		Include FiT		
Indicator	Unit	3%	7%	9%
NPV	USD	552,783,017	386,105,538	331,148,850
IRR	%	24.23	19.59	17.39
DPP	years	4.1	5.1	5.8
LCOE	USD per kWh	0.04	0.06	0.07

Table 67. Economic valuation of 8 kW solar PV on residential rooftop (individual)

		Include FiT		
Indicator	Unit	3%	7%	9%
NPV	USD	67,634	46,480	39,550
IRR	%	29.64	24.79	22.50
DPP	years	3.4	4.0	4.4
LCOE	USD per kWh	0.04	0.06	0.08

6.3 Tidal

The tidal current speed obtained from NOVELTIS TidEA satellite data [248] for identified locations are revealed in Table 68 and 69.

Table 68. Tidal velocity for selected locations in Peninsular Malaysia

Site	Location	Max. tidal velocity (ms^{-1})
West coast of Peninsular Malaysia (Straits of Malacca)	Point 1	0.4892
	Point 2	0.2042
	Point 3	0.7143
	Point 4	1.0599
	Point 5	0.9860
	Point 6	0.6460
	Point 7	0.9024
	Point 8	0.7513
	Point 9	0.8428
	Point 10	0.7936
East coast of Peninsular Malaysia (South China Sea)	Point 11	0.6715
	Point 12	0.3630
	Point 13	0.3013
	Point 14	0.2877
	Point 15	0.3315
	Point 16	0.3268
	Point 17	0.1285
	Point 18	0.3527
	Point 19	0.3376
	Point 20	0.3904
	Point 21	0.6589
	Point 22	1.4031
Southern Peninsular Malaysia (Straits of Johor)	Point 23	0.8069
	Point 24	0.3877
	Point 25	0.3198
	Point 26	1.0483
	Point 27	0.5690
	Point 28	0.5847
	Point 29	0.7401
	Point 30	1.4516

Table 69. Tidal velocity for selected locations in East Malaysia

Site	Location	Max. tidal velocity (ms^{-1})
East Malaysia (South China Sea)	Point 31	0.4521
	Point 32	0.5085
	Point 33	0.6396
	Point 34	0.3849
	Point 35	0.2696
	Point 36	0.1104
	Point 37	0.1939
	Point 38	0.0830
	Point 39	0.1107
	Point 40	0.2283
	Point 41	0.1633
	Point 42	0.1839
	Point 43	1.2788
	Point 44	0.5855
	Point 45	0.1042

The tidal velocity map for Peninsular Malaysia and East Malaysia are presented in Figure 54 and 55 [248]. It can be concluded that Malaysia's tidal velocity generally falls in the lower range and is not sufficient for currently available commercial tidal stream converters which requires a minimum tidal stream flow of at least 1.5 ms^{-1}. If this technology can be modified to accommodate lower tidal stream flow ranging from 0.7 – 1.4 ms^{-1}, then Malaysia would be able to harness tidal stream energy in future in which tidal stream technology has a competitive edge since the availability factor of 90% is similar to hydropower, geothermal and fossil-fueled power plants.

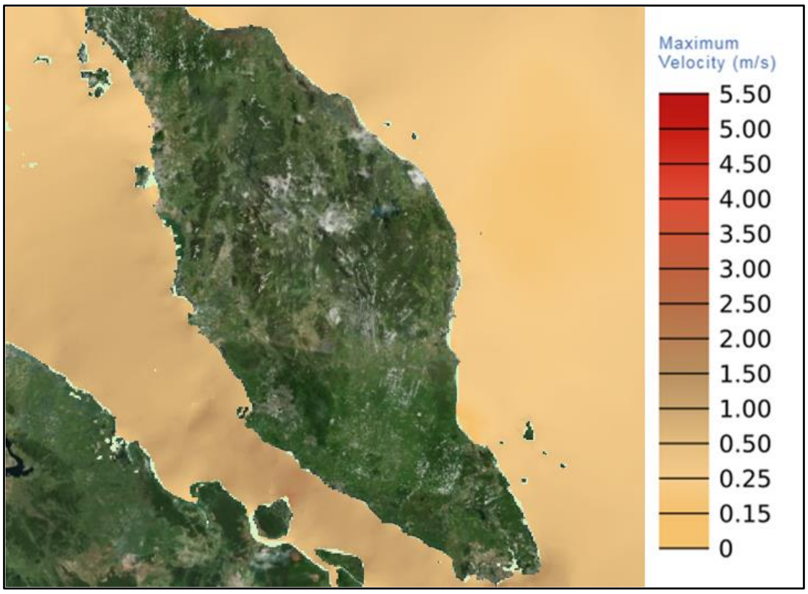


Figure 54. Tidal velocity map for Peninsular Malaysia [248]

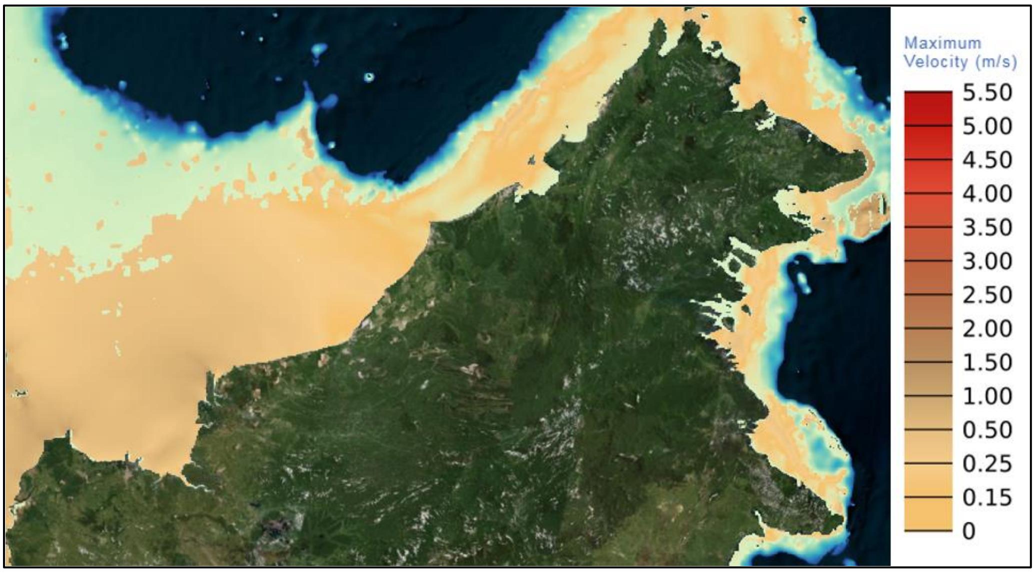


Figure 55. Tidal velocity map for East Malaysia [248]

6.4 Biomass

Malaysia ranks as the second largest palm oil producer in the world after Indonesia, contributing 35% share to the world's crude palm oil demand. The total land used for palm oil plantation in 2016 was 5,737,985 hectares [246] as shown in Table 70 which is equivalent to 17.5% of Malaysia's total land area. While the total yield for Fresh Fruit Bunch (FFB) in 2016 as recorded by palm oil mills in Table 71 was 86,325,309 tonnes [247]. Dried Empty Fruit Bunch (EFB) has higher potential to be used as a biomass fuel, at present, about 68% of EFB is used as mulch and composts. Dry EFB is equivalent to 14.6% weight of dry FFB [193], if 35% of the untapped dried EFB is consumed as biomass fuel, power potential derived from EFB would be as estimated in Table 72. The projected power capacity and the generated electricity from EFB throughout 2016 until 2050 with plant availability factor (AFA) set at 70% are shown in Figure 56.

Table 70. Oil palm planted area as of 31 December 2016 [246]

State	Land area (Hectares)	%
Johor	745,630	13.0
Kedah	87,786	1.5
Kelantan	155,458	2.7
Malacca	56,149	1.0
Negeri Sembilan	178,958	3.1
Pahang	732,052	12.8
Perak	397,908	6.9
Perlis	652	0.0
Penang	14,135	0.2
Selangor	138,831	2.4
Terengganu	171,943	3.0
Peninsular Malaysia	**2,679,502**	**46.7**
Sabah	1,551,714	27.0
Sarawak	1,506,769	26.3
East Malaysia	**3,058,483**	**53.3**
Total	**5,737,985**	**100.0**

Table 71. Fresh fruit bunch harvested from January until December 2016 [247]

Month	FFB yield (tonnes)
January	5,558,538
February	5,282,514
March	6,074,990
April	6,492,052
May	6,981,344
June	7,838,041
July	7,948,680
August	8,273,740
September	8,470,098
October	8,142,065
November	7,876,810
December	7,386,437
Total	**86,325,309**

Table 72. Biomass power potential

Year	Units	2016	2020	2025	2030
FFB	tonne	86,325,309	110,494,169	112,953,141	115,466,837
14.6% of dry FFB mass is equal to dry EFB	tonne	12,603,495	16,132,149	16,491,159	16,858,158
35% of dry EFB	tonne	4,411,223	5,646,252	5,771,906	5,900,355
each tonne of dry EFB contains 17 GJ energy	GJ	74,990,796	95,986,284	98,122,394	100,306,041
Convert GJ to GWh	GWh	20,831	26,663	27,256	27,863
Maximum electricity produced at 0.34 efficiency	GWh	7,083	9,065	9,267	9,473
Power	MW	809	1,035	1,058	1,081
Electricity generation (AFA 0.70)	GWh	4,958	6,346	6,487	6,631

Year	Units	2035	2040	2045	2050
FFB	tonne	118,036,473	120,663,294	123,348,574	126,093,613
14.6% of dry FFB mass is equal to dry EFB	tonne	17,233,325	17,616,841	18,008,892	18,409,667
35% of dry EFB	tonne	6,031,664	6,165,894	6,303,112	6,443,384
each tonne of dry EFB contains 17 GJ energy	GJ	102,538,284	104,820,204	107,152,906	109,537,521
Convert GJ to GWh	GWh	28,483	29,117	29,765	30,427
Maximum electricity produced at 0.34 efficiency	GWh	9,684	9,900	10,120	10,345
Power	MW	1,105	1,130	1,155	1,181
Electricity generation (AFA 0.70)	GWh	6,779	6,930	7,084	7,242

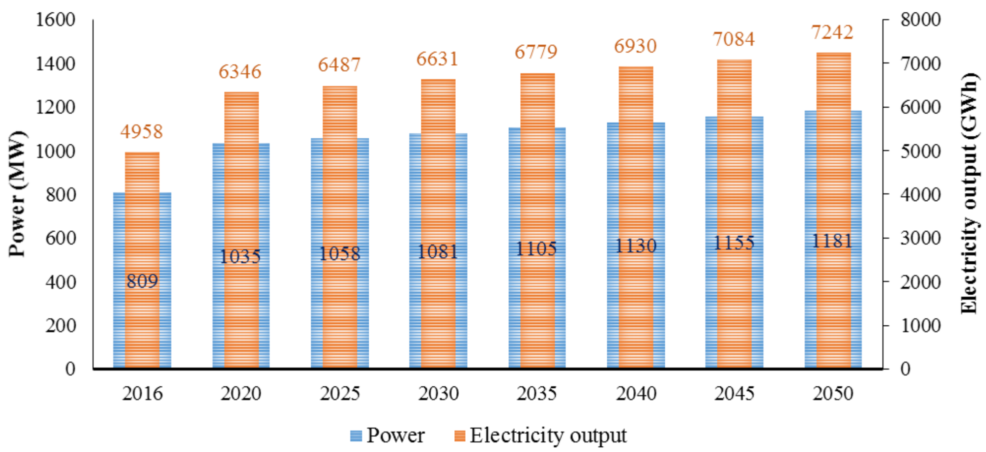


Figure 56. Biomass power and electricity projection 2016 -2050

It is observed that biomass fuel will still release considerable levels of CO_2 emissions despite being categorized as renewables, nonetheless, there are opinions put forth by scholars that biomass has a net zero carbon worth or assumed as carbon neutral since the sequestered CO_2 absorbed during photosynthesis approximately equals the emitted CO_2 during biomass combustion [272]. The CO_2 emissions from combustion of EFB from 2016 until 2050 is estimated as per Table 73.

Table 73. Annual CO_2 produced from biomass combustion

Year	Emitted CO_2 (kt) Equation (4-12)
2016	1,784.88
2020	2,284.56
2025	2,335.32
2030	2,387.16
2035	2,440.44
2040	2,494.80
2045	2,550.24
2050	2,607.12

It is observed that the existing FiT rate set for biomass are slightly lower than the averaged electricity selling tariff, hence as a consequence, this does affect the payback period. Investment cost will take longer to break even. Even at 3% interest rate offered by the Central Bank, it would take around 9.8 years to recover the initial investment. Upon implementation of higher interest rates such as 7% or 9% which are the common rates applied by the commercial banks will cause the rate of returns to decrease and inflate the payback period to an extent where it becomes economically unfeasible as shown in Table 74. If the government were really serious in considering biomass power, then the FiT needs to be increased to a price higher than the average electricity tariff to ensure a payback period lesser than 7 years as an acceptable payback benchmark. Otherwise, investors may find that the current FiT rate is just not worth for venture.

Table 74. Economic valuation of 10 MW biomass power plant

		Include FiT		
Indicator	Unit	3%	7%	9%
NPV	USD	82,741,538	55,577,405	46,962,894
IRR	%	10.21	6.09	4.14
DPP	years	9.8	16.4	24.2
LCOE	USD per kWh	0.04	0.05	0.06

6.5 Biogas

The estimations for biogas energy potential from POME is presented in Table 75. Capturing methane gas as a useful fuel for power generation will curb global warming, as methane is 28 times more potent than CO_2 over a century and is 84 times more lethal in 20 years span [273]. Besides that, the odor pollution caused by methane gas mixtures can be resolved which would lead to a harmonized environment and better air quality.

Table 75. Biogas power potential

Year	Units	2016	2020	2025	2030
FFB	tonne	86,325,309	110,494,169	112,953,141	115,466,837
20 t FFB (100 t POME) = 400 m^3 Bio-Methane produced	m^3	1,726,506,180	2,209,883,374	2,259,062,828	2,309,336,736
1 m^3 Methane is equal to 38.3 MJ	MJ	66,125,186,694	84,638,533,226	86,522,106,296	88,447,597,005
Convert MJ to GWh (1GWh = 3600 GJ)	GWh	18,368	23,511	24,033	24,569
Maximum electricity produced at 0.36 efficiency	GWh	6,613	8,464	8,652	8,845
Power	MW	755	966	988	1,010
Electricity generation (AFA 0.70)	GWh	4,629	5,925	6,057	6,191

Year	Units	2035	2040	2045	2050
FFB	tonne	118,036,473	120,663,294	123,348,574	126,093,613
20 t FFB (100 t POME) = 400 m^3 Bio-Methane produced	m^3	2,360,729,457	2,413,265,888	2,466,971,481	2,521,872,256
1 m^3 Methane is equal to 38.3 MJ	MJ	90,415,938,203	92,428,083,496	94,485,007,717	96,587,707,389
Convert MJ to GWh (1GWh = 3600 GJ)	GWh	25,115	25,674	26,245	26,830
Maximum electricity produced at 0.36 efficiency	GWh	9,041	9,243	9,448	9,659
Power	MW	1,032	1,055	1,079	1,103
Electricity generation (AFA 0.70)	GWh	6,329	6,470	6,614	6,761

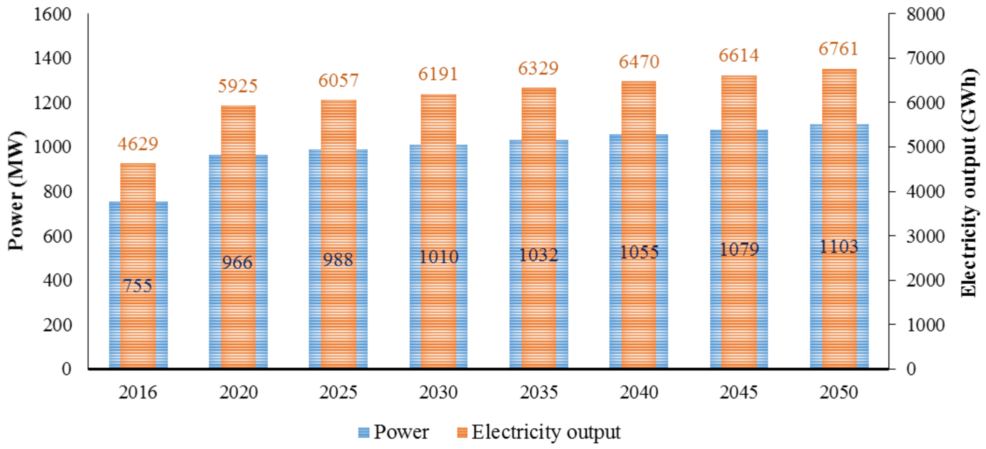


Figure 57. Biogas power and electricity projection 2016 -2050

The projected power capacity and electricity output from biogas are depicted in Figure 57 and the emitted CO_2 levels from the combustion of methane gas is shown in Table 76 which is still minimal in contrast to coal and distillate fuel oil.

Table 76. Annual CO_2 produced from bio-methane combustion

Year	Emitted CO_2 (kt) Equation (4-13)
2016	935.06
2020	1,196.85
2025	1,223.51
2030	1,250.58
2035	1,278.46
2040	1,306.94
2045	1,336.03
2050	1,365.72

Based on the economic valuation for a 5 MW biogas power plant as per Table 77, the outlook for biogas power is perceived to be bleak because the current FiT rates for biogas is not satisfactory to establish a viable rate of return and payback period. Even at a low-interest rate of 3%, because the discounted payback period approaches the biogas power plant lifetime of 20 years.

Table 77. Economic valuation of 5 MW biogas power plant

		Include FiT		
Indicator	Unit	3%	7%	9%
NPV	USD	34,805,912	25,070,705	21,714,019
IRR	%	5.09	1.16	NA
DPP	years	19.6	86.2	NA
LCOE	USD per kWh	0.07	0.09	0.10

6.6 Wave

Wave energy and power potential estimates for Malaysia is estimated as per Table 78.

Table 78. Wave power potential

Parameters	Results
Energy per metre (kWh/m)	A metre of crest holds energy
Equation (4-7)	$= 1025 \times 9.81 \times (1.22)^2 / 8$
	= 1870.78 J/m
	= 1.871 kJ/m
	= 0.0052 kWh/m
Power per metre (kW/m)	A metre of crest holds power
Equation (4-8)	$= 1025 \times (9.81)^2 \times 5.87 \times (1.22)^2 / 32 \times 3.14159$
	= 861826.1 / 100.53088
	= 8572.75 W/m
	= **8.57 kW/m**
Total wave power potential (GW)	= power per metre crest x total coastline length
	= 8.57 x 4,675,000
	= 40064750kW
	= 40.06 GW
Total wave exergy potential at 0.40 efficiency (TWh) (energy converted into electricity)	= total wave power x total hours per year x efficiency
	= 40.065 x 8760 x 0.40
	= 140,387.76 GWh
	= 140.39 TWh
Total wave power capacity at 0.40 efficiency (GW)	= electricity output/ total hours per year
	= 140,387.76 / 8760
	= 16.03 GW

The findings that every metre of crest holds 8.57 kWm^{-1} power aligns with the global annual mean wave power distribution map as portrayed in Figure 58 [249]. A closer observation into Malaysia's wave power distribution map as in Figure 59 concurs with the theoretical assessment findings that the wave power per metre crest falls in the lowest range between 0 to 10 kWm^{-1} which is not practical for wave energy exploitation. Apparently, the idyllic condition to harness wave energy is at locations with power densities ranging between 40 to 60 kWm^{-1} [249]. Furthermore, wave energy converters are still vigorously undergoing research and development phase. Therefore it can be inferred that this technology is still going through an evolutionary phase and has not reach convergence as a commercial technology.

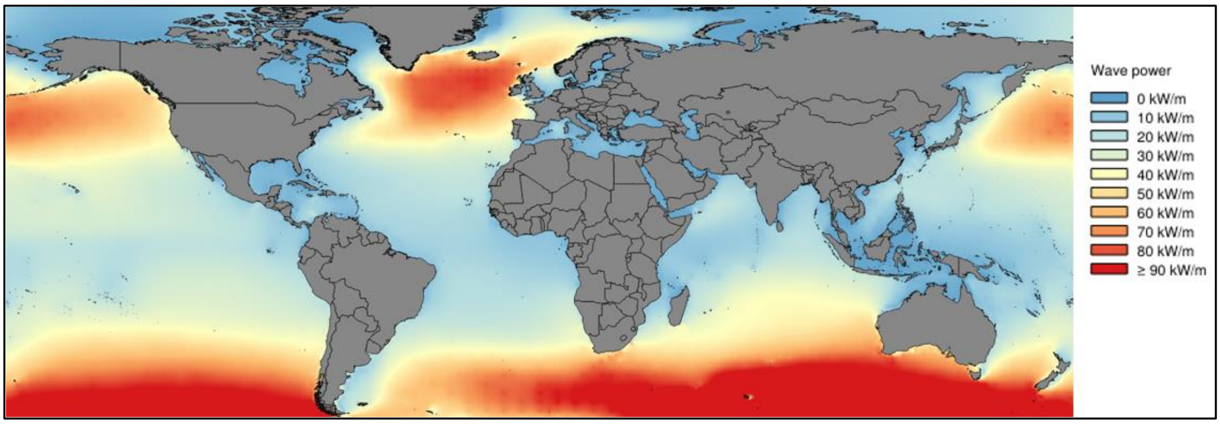


Figure 58. Wave power global distribution map [249]

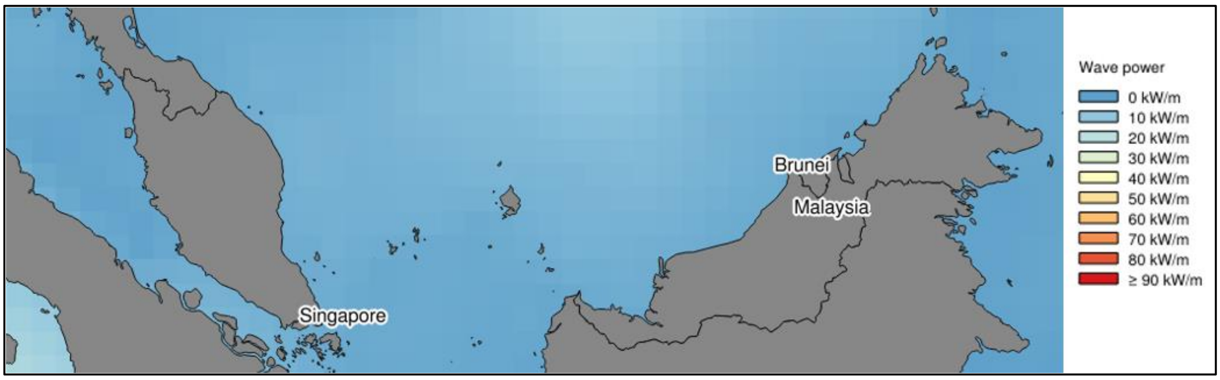


Figure 59. Wave power distribution map for Malaysian seas [249]

6.7 Hydro

As a tropical country, Malaysia's overall average precipitation of rain per annum is above 2,600 mm and the mean terrestrial elevation is 300 m above sea level. As shown in Figure 60, the lowest to highest averaged rain precipitation distribution per annum varies depending on location from a range of 1,800 mm to 4,600 mm [251].

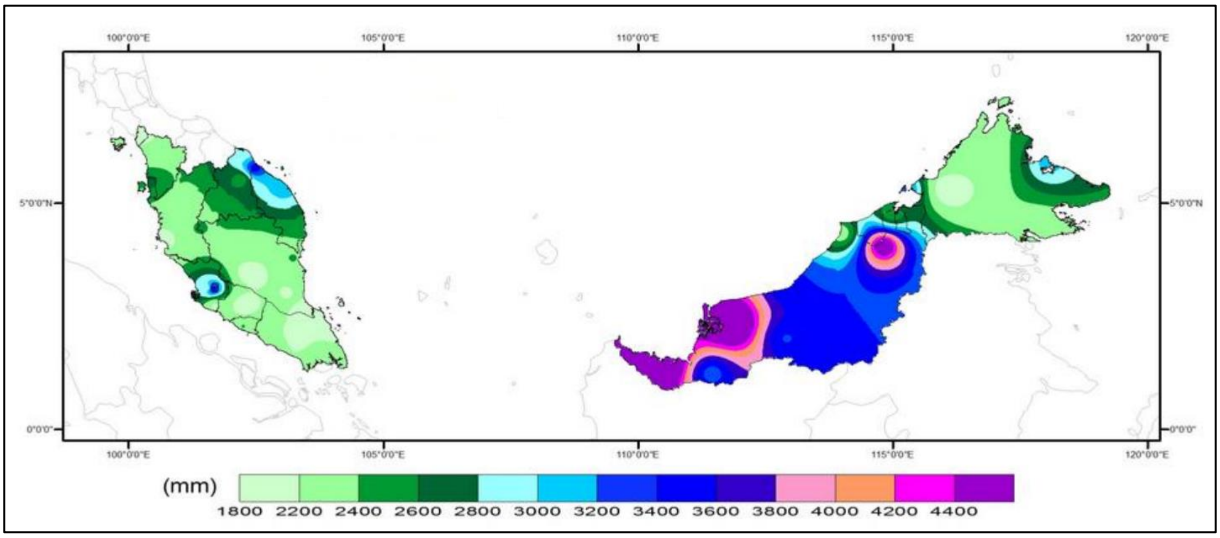


Figure 60. Distribution of rain precipitation from January until December 2016 [251]

Sarawak has a few large hydro projects in the pipeline such as the dams in Baleh, and Pelagus each with planned capacities of 1,285 MW and 562 MW. Most of the potential sites to develop hydro projects are in East Malaysia with a ratio of 85 % and the remaining 15 % is in the Peninsular [11]. The largest hydropower plant currently in operation in Malaysia is the Bakun project with 2,400 MW power capacity.

Estimations for hydro potential is closely related to the topographic high and hydrological data at site whereby the surroundings need to be considered especially in assessing the potential vertical height of the dam. Hydro potential energy can be estimated if information such as the average rain precipitation per annum, dam height, and catchment size or reservoir area have been determined in the specified location. The hydro potential energy estimations for the proposed 1,285 MW Baleh Dam is depicted in Table 79, whereby the technical calculations are compared to the standard power and electricity output calculations with plant availability factor of 90%. The results are the same in both calculations for estimated power per metre square which is 0.21 Wm^{-2}.

Table 79. Baleh Dam hydropower potential

Hydro potential estimation as per equation (4-9)	Standard energy formulas at 90% availability factor
Average rainfall per annum = 3,600 mm = 3.6 m^3	Energy generated, E = 1,285 MW x 8,760 h x 0.90
Density of water, ρ =1000 kg/m	= 10,130,940 MWh
Mass of water, m_w = 3.6 m^3 x 1,000 kg/m^3 =3,600 kg	= 10,130,940,000 kWh
Energy, E_{pot} = 3,600 kg x 9.8 m/s^2 x 188 m	Catchment area = 5.625 x10^9 m^2
= 6,639,408 J	Energy per square metre,
= 6639.408 kJ	E = 10,130,940,000 kWh/5.625 x10^9 m^2
= 1.84428 kWh/m^2/year	= 1.8011 kWh/m^2/year
Power per metre square, P =1.84428 kWh/ 8760 h	Power per metre square, P = 1.8011 kWh/ 8760h
= **0.21W/m^2**	= **0.21 W/m^2**
Firm power based on catchment area	
= 0.21W/m^2 x 5.625 x 10^9 m^2	
=1181.25 MW	

Hydropower potential via Sarawak Corridor of Renewable Energy (SCORE) project is valued at 20,000 MW [210, 211]. Mini-hydro potential estimates for Malaysia is 490 MW [14] and total large hydropower potential is estimated at 23,844.6 MW [151, 152]. As of 31st December 2015 about 23.7% large hydro capacity has already been exploited with cumulated capacity of 5,656 MW. Therefore Malaysia still has about 76.3% of untapped large hydropower potential. Whereas mini hydro has only utilized 6.1% (29.6 MW) out of the 490 MW total potential. Therefore the upper bound for hydropower after adding mini hydro would account to 24,334.6 MW with electricity output estimated at 202,306 GWh. The availability factor for hydropower plants to operate are usually at the upper edge around 90 to 95 %. While the efficiency to convert hydro potential energy into electricity in large hydropower plants could reach up to 95%, and 90% for small hydro [226].

Based on the literature, it can be substantiated that Malaysia does have great potential in harnessing hydropower. Hydropower is considered a clean energy resource which does not add to the carbon footprint. Above and beyond that, hydropower can cater for the base load as well as peak load. If Peninsular Malaysia wanted to tap on Sarawak's rich hydro resources than an underwater HVDC interconnector needs to be fitted to enable transmission of electricity from Kuching to Johor Bahru whereby the two grid networks of Peninsular and East Malaysia gets connected.

The economic valuation of the two base load power plants depicted in Table 80 implies that hydropower is economically more viable than nuclear power as the discounted payback period (DPP) can be retrieved within 3.4 to 4.4 years. While the DPP for nuclear power will entail 8 to 15.8 years to gain back the principal investment cost. Moreover, the LCOE from hydropower is still cheaper than nuclear power despite pioneer status being granted to both hydro and nuclear power utility companies in which corporate tax is exempted for the first 10 years from the commencement date.

Table 80. Economic valuation of 2,000 MW hydro and nuclear power plant

		Hydro		
Indicator	Unit	3%	7%	9%
NPV	USD	40,767,142,364	21,813,147,510	17,539,791,885
IRR	%	29.63	24.79	22.50
DPP	years	3.4	4.0	4.4
LCOE	USD per kWh	0.02	0.03	0.03

		Nuclear		
Indicator	Unit	3%	7%	9%
NPV	USD	38,058,566,565	20,264,918,650	16,263,887,178
IRR	%	12.54	8.33	6.34
DPP	years	8.0	12.0	15.8
LCOE	USD per kWh	0.03	0.05	0.07

6.8 Geothermal

There are 40 hot water springs in the Peninsular as shown in Figure 61 [274], Tenaga Nasional Berhad (TNB) the main utility company in Peninsular Malaysia has plans to generate a total of 2 MW of electricity from steam released at 4 potential sites. While in East Malaysia, a geothermal source with 67 MW capacity was discovered in Apas, a town nearby Tawau [11].

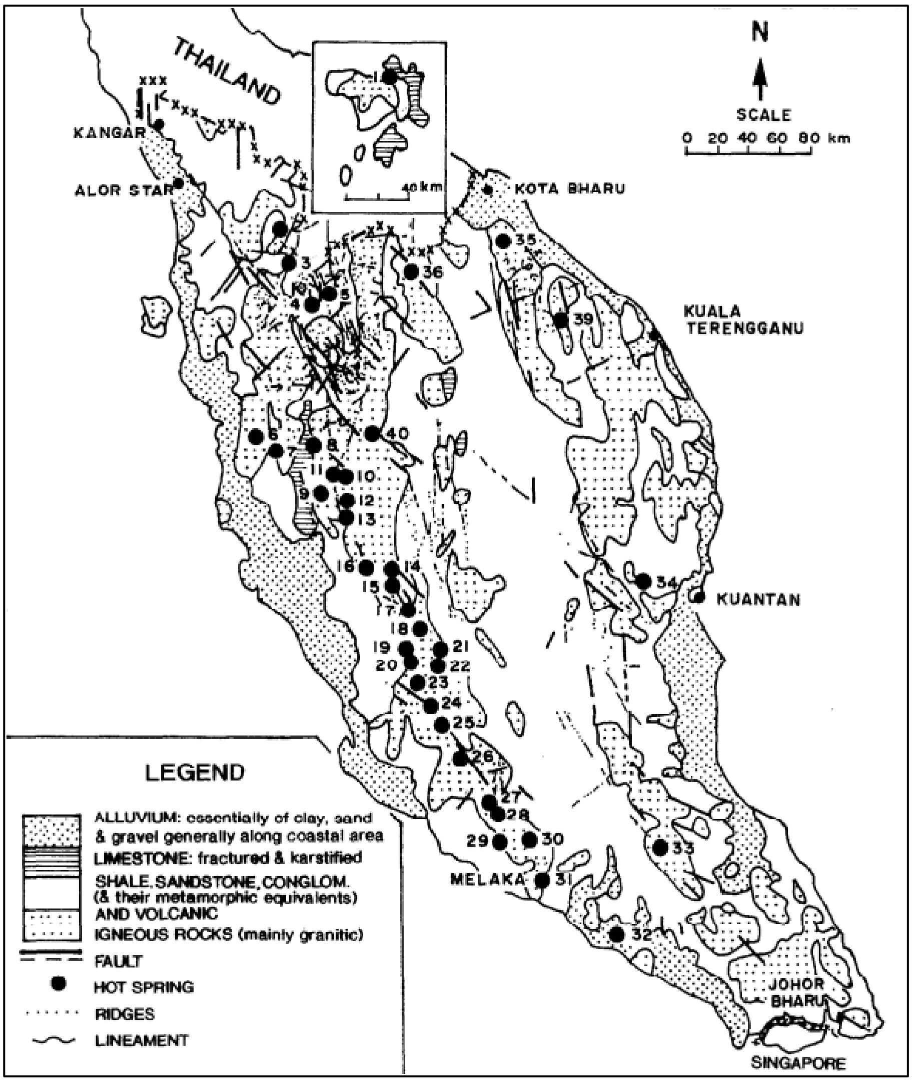


Figure 61. Hot spring sites in Peninsular Malaysia [274]

Therefore, the known total potential for geothermal power generation in Malaysia at present totals to 69 MW. Geothermal power plants are known to provide a stable generation output, hence plant availability factor is placed at a higher end of 95%. For this reason, the electricity output per annum is estimated to be 574.22 GWh. The CO_2 emission savings from geothermal plants is approximately 430.09 kt per year.

Given the economic appraisal on the 30 MW Binary Organic Rankine Cycle geothermal technology as per Table 81. The results suggest that despite the project having positive net present values, nevertheless the discounted payback period turns out to be economically unfeasible even at 3% interest rate.

Table 81. Economic valuation of 30 MW geothermal power plant

		Geothermal		
Indicator	Unit	3%	7%	9%
NPV	USD	505,966,894	333,654,498	280,855,702
IRR	%	7.46	3.44	1.54
DPP	years	13.4	29.1	64.9
LCOE	USD per kWh	0.06	0.09	0.10

6.9 Discussion

Wave energy converters and tidal stream converters are still considered immature technologies, there is still continuous research and development being undertaken on these technologies. Therefore, tidal and wave energy converters will not be reflected in the development of MYTEM scenarios. Thus, the annual upper boundary for the assessed renewables is summarised in Table 82.

Table 82. Annual upper boundary for renewables

Renewable technology	Power capacity (MW)	Electricity output (GWh)
Offshore wind	54,871	360,503
Solar PV	36,602	80,159
Biomass	809	4,958
Biogas	755	4,629
Large hydropower	23,845	198,443
Mini hydropower	490	3,863
Geothermal	69	574
Total	**117,441**	**653,129**

In this assessment, the cumulative power generation capacity from renewables is estimated to reach 117,441 MW, which exceeds the available capacity in 2015 of 25,064 MW by approximately 4.7 fold. As for the annual electricity output, achievable through renewables is approximated at 653,129 GWh, which is 4.9 times higher compared to the electricity consumption in 2015 with the corresponding value of 132,199 GWh.

According to the electricity demand projection described in Chapter 5, by 2050 electricity consumption in Malaysia would increase by a factor of 1.87 fold to reach 247,860 GWh. This renewable energy analysis indicated that Malaysia is an energy self-sufficient country with vast indigenous renewable resources that is able to satisfy 100% of the electricity demand by 2050. The variability issue of renewables can be stabilized with the integration of grid connected storage systems, a mature technology would be the Pumped Hydro Storage (PHS) which is suitable for implementation in Malaysia. The ideal scenario would be if Malaysia could substitute all of its fossil resources with renewables for power generation. Countries such as Iceland have achieved 99.9% electricity generation from renewables [275] and Norway is following suit with 98% renewable electricity [276]. With proper strategic planning and implementation, Malaysia could achieve the same status in the next two to three decades since Malaysia has diverse supply of renewable resource.

If each resident in Malaysia consumed approximately 4,194 kWh of electricity per year [271], then the annual electricity generated from renewables alone would be sufficient to cater for 155.7 million people. Currently, Malaysia has a population size of 31.1 million and according to the World Bank projection, by 2050 Malaysia's population is expected to reach 41.7 million [277]. Hence, Malaysia has an excess of renewable energy supply which may be traded with neighboring countries.

The findings of this study are consistent with the prevailing view that integration of renewables in the electricity generation mix could significantly reduce the CO_2 emission levels which will help mitigate climate change. Most renewable energy such as solar, wind, wave, tidal, hydro and geothermal are emission free energy resources. Whereas renewables like biomass and biogas will still contribute to the carbon footprint. This assessment can provide estimations of how a single renewable resource could contribute in meeting the obligations of the Paris Agreement. However, this procedure could not provide the collective estimations of all the renewables in fulfilling the commitments of the Paris Agreement. This perspective will be addressed by the MYTEM optimisation model.

Levelized Cost of Energy (LCOE) is an indicator generally used to compare the cost of electricity produced by different technologies. To comprehend the cost dynamics, it is vital to note that cost of technology will depreciate over time, however, commodity cost such as coal, oil, natural gas, and uranium will likely appreciate according to market forces. Based on Table 83, the LCOE from hydropower plants turns out to be the most feasible and electricity produced from biogas and geothermal technology have a slightly higher LCOE. The influence of technology capital cost on LCOE is indisputable since it directly relates with maturity and complexity of the technology involved.

Table 83. LCOE of assessed technologies

LCOE (USD per kWh)	3%	7%	9%
Offshore wind	0.05	0.06	0.07
Solar PV (Company)	0.04	0.06	0.07
Solar PV (Individual)	0.04	0.06	0.08
Biomass	0.04	0.05	0.06
Biogas	0.07	0.09	0.10
Hydro	0.02	0.03	0.03
Nuclear	0.03	0.05	0.07
Geothermal	0.06	0.09	0.10

The discounted payback period (DPP) for all assessed technologies is contrasted in Table 84. Generally, the acceptable payback period for energy-related technologies is relatively less than 7 years. From this evaluation, it is apparent that offshore wind, solar PV, and hydro systems are feasible as the breakeven period seems to be in a reasonable range despite the levied interest rates. The payback period for nuclear power still can be argued as acceptable in the perspective that the project lifetime extends to 60 years. However, biomass, biogas, and Geothermal exceeded the 7 years acceptable target period despite FiT being factored in the assessment. This is because the current FiT rates for biomass and biogas are much lower than the average electricity selling tariff. One way to overcome this issue is to revise the FiT rates to a higher rate. The government must ensure that the new introduced FiT rates must be appealing enough to venture capitalist. While for geothermal, the investment may still be amortized at 3% interest rate if a long term power purchase agreement has been secured with the main utility supplier. The payback period becomes unfeasible when the interest rate is above 7% because it surpasses the 30 years project life.

Table 84. DPP of assessed technologies

DPP (years)	3%	7%	9%
Offshore wind	4.9	6.3	7.3
Solar PV (Company)	4.1	5.1	5.8
Solar PV (Individual)	3.4	4.0	4.4
Biomass	9.8	16.4	24.2
Biogas	19.6	86.2	NA
Hydro	3.4	4.0	4.4
Nuclear	8.0	12.0	15.8
Geothermal	13.4	29.1	64.9

This assessment revealed that there are other sustainable choices of energy that Malaysia could tap on rather than deploying nuclear energy in the electricity mix, as peak and base load generation respectively can be supplied from hydro and solar PV. Another disadvantage of nuclear energy is that it requires consistent imports of uranium fuel because uranium extraction from Malaysian granites bodies is found to be impossible in the near future as there are no signs of leaching properties in the granite host stones. This process may take millions of years before the uranium mineral deposit becomes practical for extraction [278]. Furthermore, nuclear power has other issues such as the treatment of radioactive nuclear waste which will incur additional cost.

6.10 Limitations

Municipal Solid Waste (MSW) is considered a good source for biomass and bio-methane gas production, however, assessment for biomass from MSW and methane from landfill sites could not be performed due to constraints in obtaining the overall MSW and detailed landfill data. Therefore biomass from MSW and landfill biogas potential is set aside for future research when data becomes permissible. Hydropower potential and geothermal potential had to rely on published secondary data as assessing these resources requires access to detailed geological, thermal and hydrological data which are unavailable.

6.11 Chapter summary

The key findings from this assessment are summarized as below:

- onshore wind development is generally not feasible in Malaysia as the wind speeds are relatively at the lower end, even at 200 m above sea level wind speed are between 3.43 to 4.54 ms^{-1};
- class II offshore wind speed turbines can be deployed at the territorial waters facing the South China Sea as mean offshore wind speed for Malaysia falls in the range between 7.5 to 8.5 ms^{-1}. Offshore wind power is estimated to reach 54,871.21 MW and would produce 360,503.88 GWh of electricity;
- The daily and annual mean solar radiation for Malaysia are approximated to reach 4.91 $kWhm^{-2}$ and 1,795.27 $kWhm^{-2}$ respectively. If 0.15% of Malaysia's total land area were installed with rooftops PV applications, then generated power capacity would be 36,602.15 MW with electricity yield of 80,158.71 GWh per annum;

- The tidal speed for Malaysian waters are mostly in the lower speed range between 0.7 – 1.4 ms^{-1}, which does not meet the minimum speed requirement of 1.5 ms^{-1} for existing commercial tidal energy. Hence, tidal energy will not be envisioned in MYTEM;
- In order to allocate 35% of EFB as biomass fuel, an optimization on the existing consumption of EFB is proposed, whereby 62% for mulching is reduced to 55%, 6% for composting is adjusted to 5%, and 5% is retained for commercial trade, while 16% of discarded waste and 11% openly incinerated EFB will be converted into biomass fuel. Power generation derived from EFB is estimated at 809 MW with an annual electricity output of 4,958 GWh. After considering realistic sustainable expansion of the palm oil plantation in Malaysia, by 2050 a total of 1,181 MW power generation capacity can be achieved with electricity output totaling 7,242 GWh per annum;
- The estimated generated power from biogas is 755 MW and the annual electricity yield is 4,629 GWh. The projections up to 2050 indicate that with the increase of POME volume due to the increase in FFB production, generated power will increase up to 1,103 MW with annual electricity output of 6,761 GWh;
- Wave power per metre crest in Malaysian seas are estimated to fall in the lower range of 8.57 kWm^{-1} which is not viable for exploitation. Thus, wave power will not be envisaged in MYTEM;
- Malaysia's hydropower potential comprises of 490 MW mini hydro and 23,844.6 MW large hydro. To date, 29.6 MW (6%) mini hydro and 5,656 MW (23.7%) large hydro has been exploited. Therefore, the unexploited share for mini hydro is 94%, while large hydro has a balance of 76.3% of untapped potential;
- Geothermal power potential is approximated at 69 MW with annual electricity output of 574.22 GWh; and,
- Malaysia has been blessed with an abundance of renewable resources, therefore Malaysia should strive in ensuring the nation's energy security becomes less dependent on foreign fuel imports. Instead Malaysia should tap on the available indigenous renewable resources to transform into a sustainable electrical power sector.

Chapter 7. Malaysia TIMES Electricity Modelling Scenarios and Results

7.1 Introduction

The Malaysian Government has been introducing fuel diversification policies for the power sector over the past decade by considering other sources of energy such as nuclear and renewable energy. The purpose of these policies are primarily to lengthen the economy's oil and gas reserves against premature depletion, apart from that is to diversify the electricity generation mix from its current heavy reliance on fossil fuels, as well as to reduce the nation's CO_2 emission levels.

In this chapter, an insight into Malaysia's future power generation possible pathways from 2015 up to 2050 will be explored through a modeling approach known as the Malaysia TIMES Electricity Model (MYTEM). MYTEM is designed to find possible solutions to the following challenges:

i) To provide options for an optimized power capacity configuration, with the primary goal to gradually substitute fossil-fuelled power plants with other technologies that are more sustainable and environmentally friendly by 2050;

ii) To identify possible pathways based on fuel diversification policy approach to achieve an optimized electricity generation portfolio in order to meet the rising electricity demand by 2050;

iii) To determine the fuel mix trajectories based on the developed scenarios under MYTEM;

iv) To explore options to transform the power sector into a low carbon system which is imperative for climate change mitigation and to ensure that by 2030, the power sector contributes at least an equal share to the CO_2 reduction targets from the other sectors as pledged by Malaysia in the Paris Agreement.

7.2 General assumptions

MYTEM was established with following parameters and assumptions:

i) Base year: 2015 was designated as the base year in this study as the latest technology stock was compiled from 2015's energy balance [6];

ii) Study duration: This study commences from 2015 until 2050, covering a total period of 35 years;

iii) Milestone reporting period: The 35 years is divided into 8 periods which allows the model to report the results based on 5-year intervals;

iv) The chosen currency was specified in United State Dollar (USD);

v) Discount rate: the discount rate was fixed at 3% following the Malaysian Central Bank's discount rate over the entire simulation period. This rate is also the suggested rate for energy investment by the National Renewable Energy Laboratory [224];

vi) All power plants or conversion technologies connected to the grid were covered mainly to emulate the centralized National Grid;

vii) As an emerging economy, Malaysia's GDP is assumed to have a moderate positive annual growth rate of 5.5% throughout the projection period;

viii) The electricity demand will continue to increase in tandem with the electricity generation levels with a 25% reserve margin, thus the electricity demand shall never exceed the generation levels;

ix) The end user demand sectors have been merged to represent the gross demand of each sector;

x) Despite the addition of cogeneration plants such as the combined heat power into the RES, only the electricity load was measured, heating load from heat rejected in the energy conversion process was not considered;

xi) Seasonal and daily load fluctuations were not considered in the optimization model;

xii) Cost for conversion technologies which include investment cost (INVCOST), fixed maintenance and operation cost (FIXOM) and variable maintenance and operation cost (VAROM) were taken from European Union Energy Technology Reference Indicator projections until 2050 [104] as Malaysia usually acquires foreign technology;

xiii) New technology installations considered the decline in technology cost as well as the improved technology efficiency over time;

xiv) Primary and secondary fuel cost was obtained from the United States Energy Information Agency annual outlook [222];

xv) The electricity averaged transmission and distribution losses for Malaysia was set at 5.79% [225];

xvi) Transmission and distribution network cost was not accounted in the model;

xvii) Electricity from Sarawak is assumed accessible to the Peninsular via a subsea High Voltage Direct Current (HVDC) interconnector transmission system which is installed in 2025;

xviii) The CO_2 gas is the considered greenhouse gas (GHG) in the model, and IPCC's emission factors for stationary combustion by fuel type was adopted [230];

xix) No financial constraints were imposed in the model due to active private sector investments in the power sector.

7.3 Base year 2015 (BY 2015)

7.3.1 Available capacity (GW)

The available power capacity stock levels identified by technology in the base year 2015 (BY 2015)[6] are presented in Figure 62. The largest share is contributed by the gas-fired power plants with a total cumulative capacity of 11.83 GW (47.18%), which includes Combined Cycle Gas Turbine (36.65%), Open Cycle Gas Turbines (8.29%) and the Conventional Thermal Gas Turbines (2.24%). Coal-fired power plants encompass 8.49 GW (33.89%), while 4.30 GW (17.17%) is allotted to large hydropower plants. Fuel oil and diesel engine generators still account for 1.39% of the generation capacity. Renewable penetration is still very low in which only 0.06 GW (0.25%) is connected to the grid. Hence, it is apparent that Malaysia's power generation is strongly dependent on fossil-fuelled power plants maintaining a total capacity share of 82.46%.

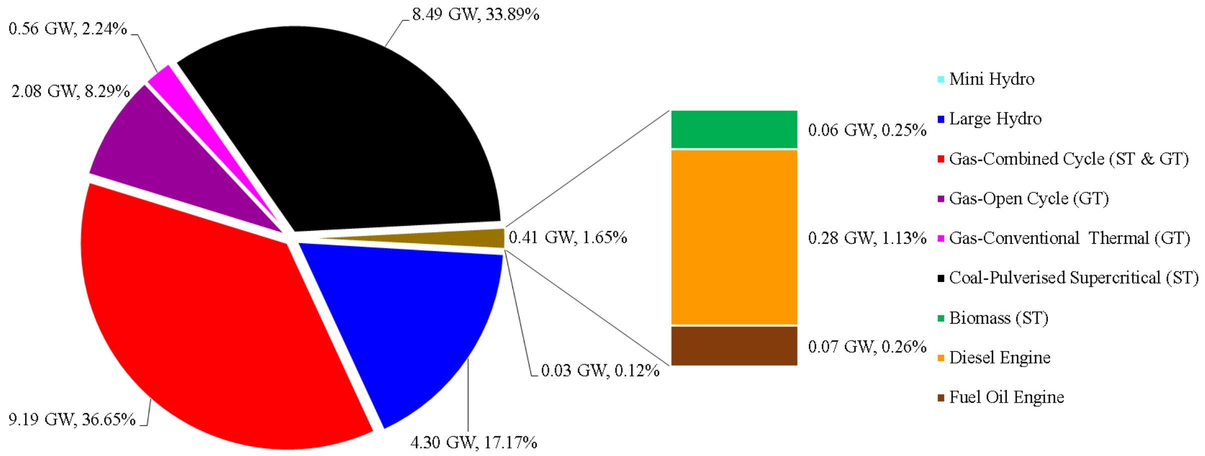


Figure 62. Base year available capacity stock by technology

7.3.2 Electricity output (PJ)

The pie chart in Figure 63 indicates the electricity output share itemized by technology for BY 2015 [228]. About 88.4% of Malaysia's electricity output was generated by fossil fuel which specifically comprised of 46.3% natural gas, 41% coal, 1.07% diesel and 0.03% heavy fuel oil. Large and mini-hydro generated a total of 10.7% of the electricity supply, while biomass only has a minor generation share of 0.9%. The 46.3% generated electricity from natural gas-fired plants component can be further substantiated into 35.97% combined cycle plants, 8.13% are from open cycle plants and 2.20% is supplied by conventional thermal plants.

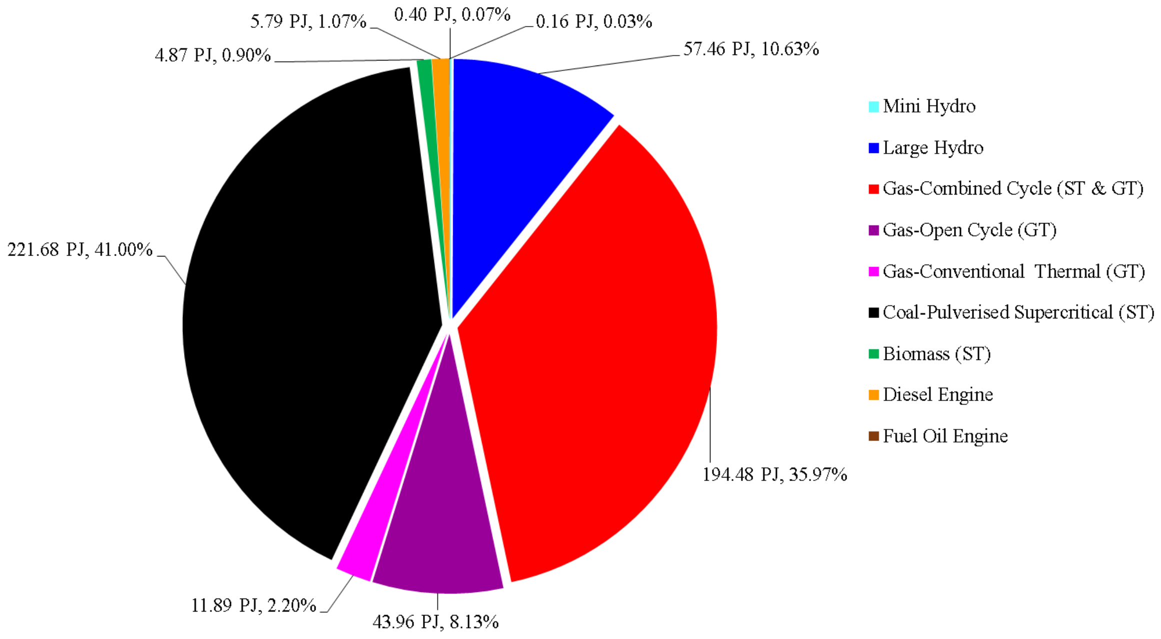


Figure 63. Base year electricity output by technology

7.4 Electricity generation and demand levels 2015-2050 (PJ)

The electricity generation levels were set to be 25% higher compared to the demand levels (refer Figure 64), this is to cater for peak demand as well as to stabilize the grid from technical and non-technical losses. Technical losses naturally transpire during transmission of electricity passing through converters, substations, transformers, transmission, and distribution line predominantly due to the corona effect in high voltage power systems. The corona effect happens when the fluid medium (air) surrounding the conductor gets ionized and the electrons from the conductor are discharged to the air during high voltage transmissions at 30 kV. Usually, this phenomenon is accompanied by the formation of ozone gas, a hissing sound, and a violet glimmer can be observed around the transmission lines. Whereas non-technical or commercial losses refers to occurrences such as theft of electricity and faulty apparatus for meter readings.

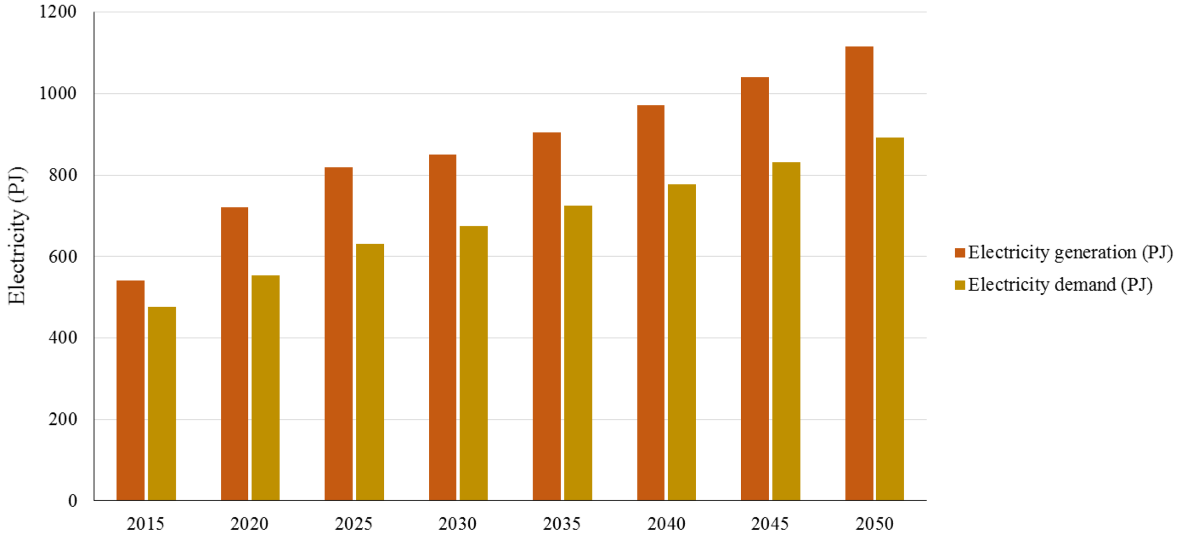


Figure 64. Electricity generation and demand 2015-2050

7.5 Electricity demand by end-user sectors 2015-2050 (PJ)

The final demand by end-user sectors as presented in Figure 65 was projected by the model on the basis that the base year sector-wise share was kept constant throughout the study period until 2050.

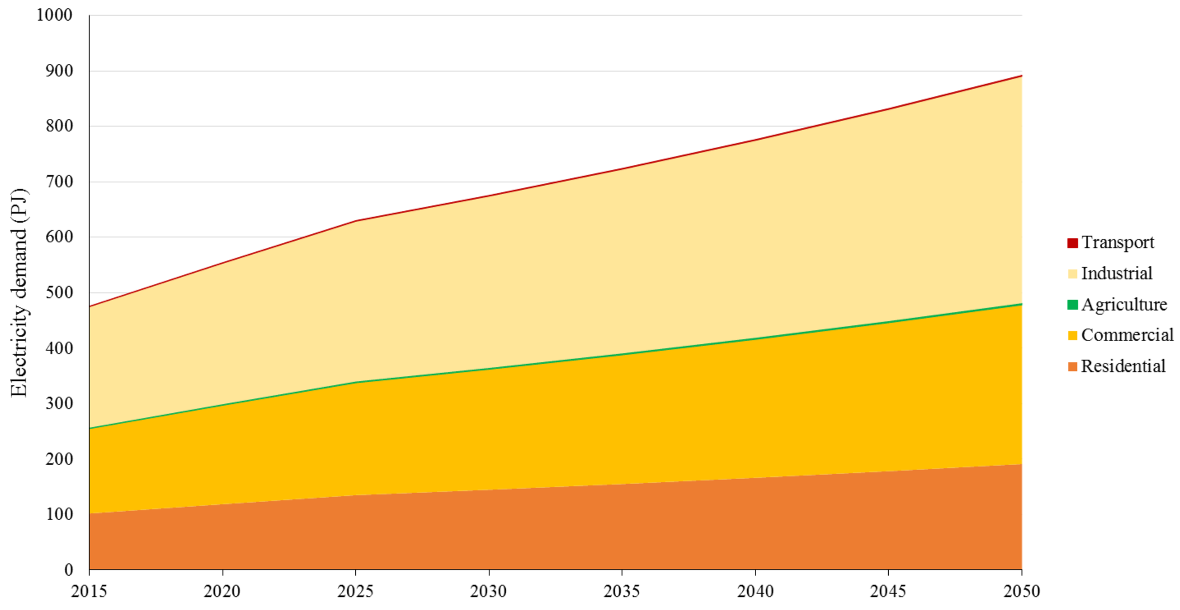


Figure 65. Electricity demand by end-user sectors 2015-2050

Nevertheless, this sector wise proportions can be altered based on certain policy interventions without affecting the overall demand levels, for instance, if the Malaysian government were serious in pursuing emission-free vehicles and encouraged the usage of hybrid or electric vehicles in both the transport and agriculture sectors, then the percentage in these categories will definitely increase according to the targets set by the national automotive policy. Apart from that with the implementation of energy efficiency policy such as switching to light emitting diode (LED) lighting systems and application of innovative energy savings electrical devices would lead to lower consumption of electricity in the industrial, commercial and residential sectors. Since the MAPE for the growth model projection is within ± 4.68%, thus the sector wise demand levels can be attuned to produce a lower and upper demand boundary as tabulated in Table 85 and 86.

Table 85. Lower boundary of electricity demand by end user sectors (2015-2050)

Demand (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
RSD	101.89	113.14	128.64	137.90	147.82	158.46	169.87	182.10
COM	153.10	170.00	193.28	207.20	222.11	238.10	255.24	273.62
IND	218.30	242.40	275.60	295.44	316.70	339.50	363.94	390.14
AGR	1.67	1.85	2.10	2.25	2.42	2.59	2.78	2.98
TRA	0.95	1.06	1.20	1.29	1.38	1.48	1.59	1.70
Total	475.92	528.46	600.82	644.07	690.44	740.14	793.42	850.54

Table 86. Upper boundary of electricity demand by end user sectors (2015-2050)

Demand (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
RSD	101.89	124.25	141.27	151.44	162.34	174.02	186.55	199.98
COM	153.10	186.70	212.26	227.54	243.92	261.48	280.31	300.49
IND	218.30	266.21	302.66	324.45	347.80	372.84	399.68	428.45
AGR	1.67	2.03	2.31	2.48	2.65	2.84	3.05	3.27
TRA	0.95	1.16	1.32	1.41	1.52	1.63	1.74	1.87
Total	475.92	580.35	659.82	707.32	758.24	812.82	871.33	934.06

7.6 Business as usual (BAU) scenario

7.6.1 Capacity levels (GW)

The power capacity in the BAU scenario increased by 57.50% from 25.06 GW in the base year to 39.47 GW in 2050 (refer Figure 66). It is interesting to note that the capacity expansion by

2050, is led by coal-fired power with 23.48 GW (59.49%) followed by 10.02 GW (25.39%) of hydropower, and 4.88 GW (12.36%) from gas-fired plants. Whereas renewable technology such as solar PV, geothermal, biomass and biogas only held a marginal capacity share of 1.09 GW (2.76%). It is observed that the capacity levels increase significantly in 2020 and 2025, this is due to the planned capacity addition on selected existing technologies such as the combined cycle plants, coal pulverized supercritical plants and large hydropower (refer Table 87). Apart from that, with the addition of new technologies into the RES such as solar PV, combined heat power, geothermal, lignite fuelled supercritical fluidized bed and biogas anaerobic digestion plants also instigated the capacity rise. This is as a countermeasure for the retirement of old generators fired by fuel oil and diesel by 2020. Besides that the retirement of gas-fired power plants such as the open cycle plants is expected to terminate the RES by 2025, followed by the exit of conventional thermal gas plants which takes effect in 2030.

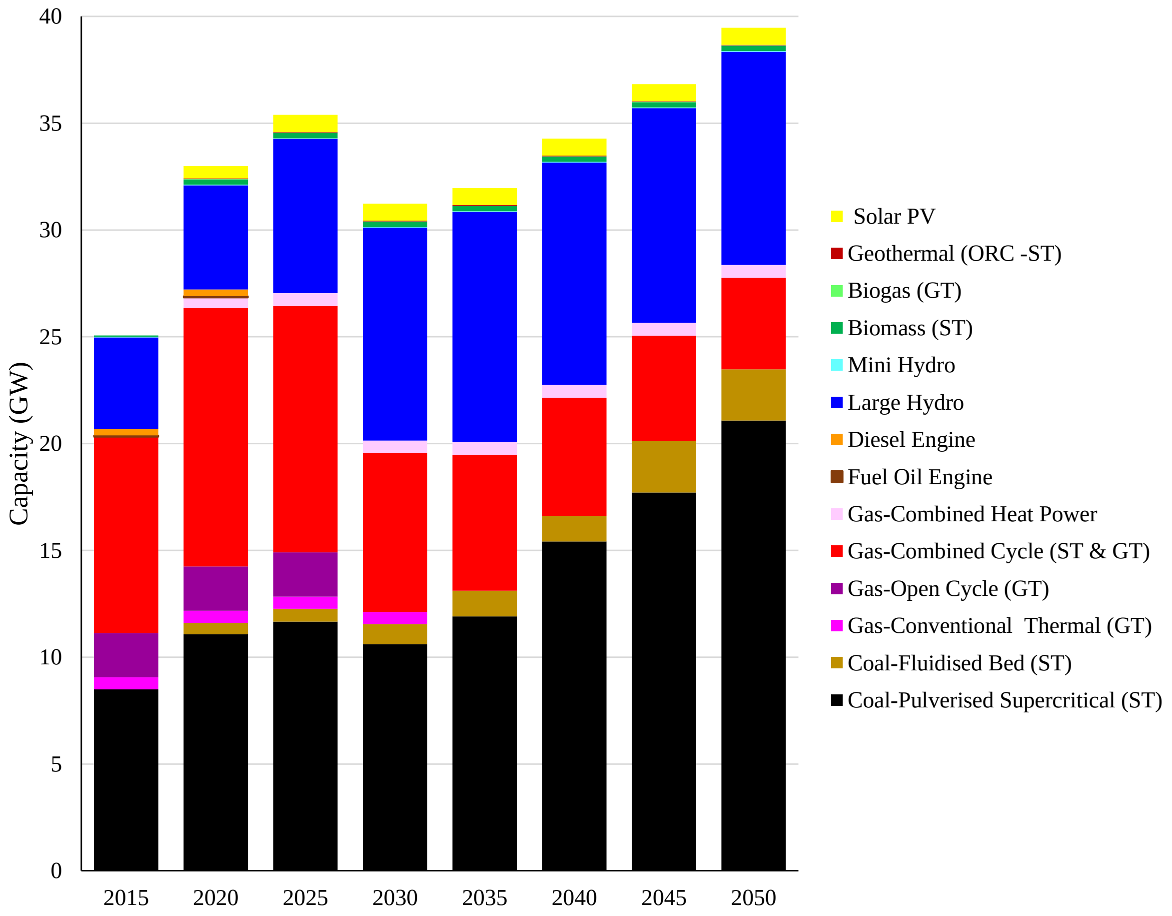


Figure 66. BAU capacity level by technology

It is apparent that under this scenario, by 2050, more than two thirds (71.85%) of the power capacity will still be based on fossil-fired power plants. In order to prolong the domestic gas reserve, the Malaysian government implemented a policy to utilize more coal to narrow down the natural gas consumption in the fuel mix. Therefore combined cycle generation capacity seems to show a declining pattern over the years as a direct implication of the aforementioned policy. Nevertheless, with the gradual shift to coal-fired power, will cause Malaysia to continuously import coal as it is cheaper than the local production of coal which require infrastructure development cost as most of the Malaysian coal reserve is remotely located. This situation does not improve the energy security of Malaysia, because Malaysia will be dependent on foreign energy commodities and will be susceptible to volatile fuel prices determined by market forces. Furthermore, this scenario does not solve the depletion issue of indigenous natural gas which is foreseen to happen in the next 40 years [6]. The gas depletion year was deduced based on the reserve to production ratio, on condition that the annual production rate remains constant.

Table 87. BAU scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	2.58	0.59	-1.06	1.30	3.51	2.30	3.37
Coal-Fluidised Bed	0.00	0.53	0.07	0.34	0.26	0.00	1.20	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	2.91	-0.57	-4.10	-1.07	-0.83	-0.59	-0.66
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	0.58	2.34	2.74	0.81	-0.36	-0.36	-0.07
Mini Hydro	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.06	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Biogas	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Geothermal	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	0.00	0.00	0.00	-0.01	0.00

7.6.2 Electricity output (PJ)

The electricity generation in the BAU scenario as shown in Figure 67 indicates a rise from 540.68 PJ in the base year up to 1115.36 PJ by 2050, which is an overall growth of 106.29%. It is observed that electricity output from diesel and fuel oil generators begins to cease by 2020. While gas-fired plants such as open cycle and conventional thermal terminate production by 2025 and 2030 due to scheduled retirement of the plant. This pattern will be visible in all other scenarios in compliance to the plant expiry term and to give way to other technologies with higher efficiency in converting primary fuels to electrical energy. It is noted that electricity generation from new technologies such as solar PV, geothermal, supercritical fluidized bed, biogas and combined heat power commence from 2020 onwards. It is also apparent that electricity generated from coal-fired plants keeps increasing as a direct result of the Malaysian government's policy to divert to coal instead of gas. It was noted that in order to satisfy the demand, the optimization doubled the generation output of lignite fuelled fluidized bed technology from 32.17 to 64.33 PJ beginning 2045.

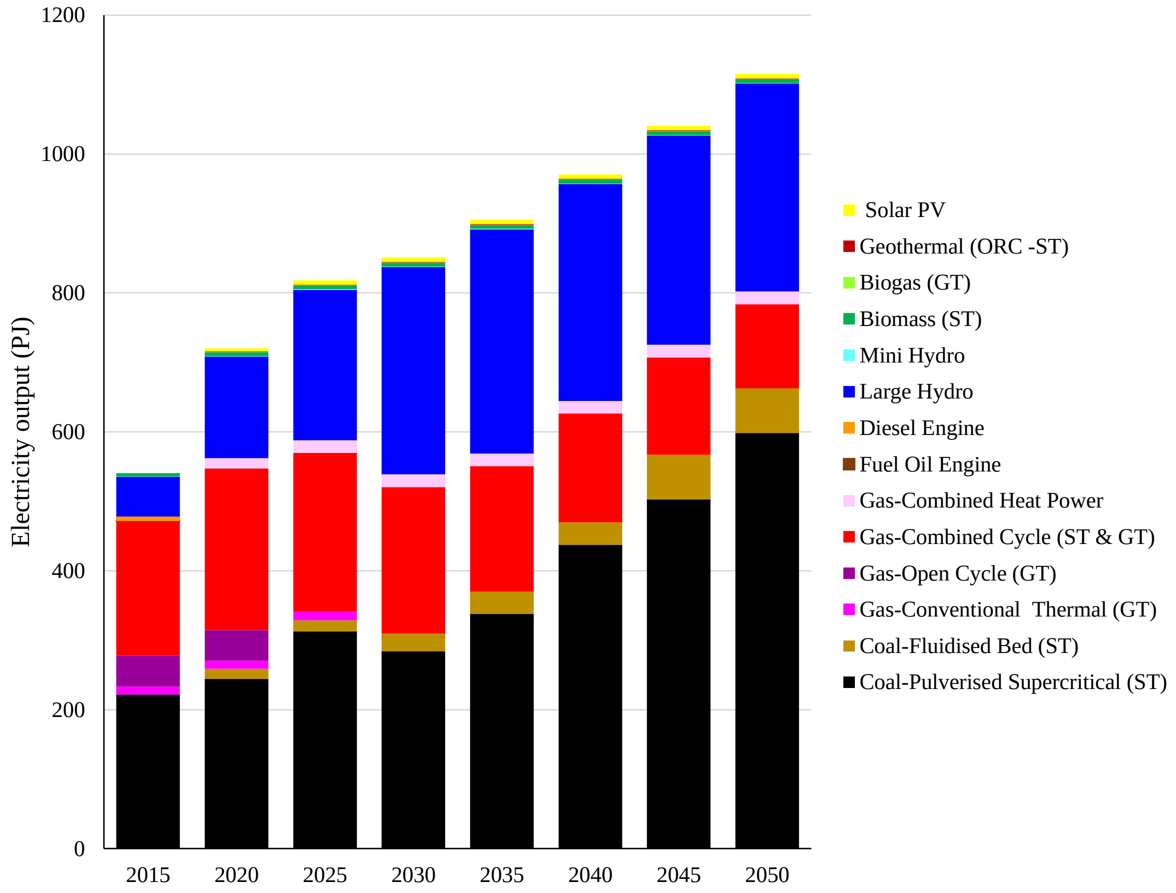


Figure 67. BAU electricity output by technology

The electricity generation mix based on technology type as per Figure 68 anticipated that by 2050, the dominant electricity generator by technology share will be pulverized supercritical bituminous coal with 53.64%, followed by large hydro providing 26.84% and combined cycle gas plants with 10.88%. Fluidised bed supercritical lignite plants in Sarawak is expected to generate 5.77%, while electricity from cogeneration plant (combined heat power) will provide 1.63% of the portfolio. Other technologies with minor share are the renewable based technologies such as solar PV (0.57%), biomass (0.49%), mini hydro and geothermal have a mutual share of 0.08%, while biogas holds 0.03%. In contrast to the base year portfolio, all the gas-fired plants such as the combined cycle, open cycle and the conventional thermal championed the mix with a cumulative share of 46.3%, pulverized supercritical coal held 41.00%, while large hydro stood at 10.63%.

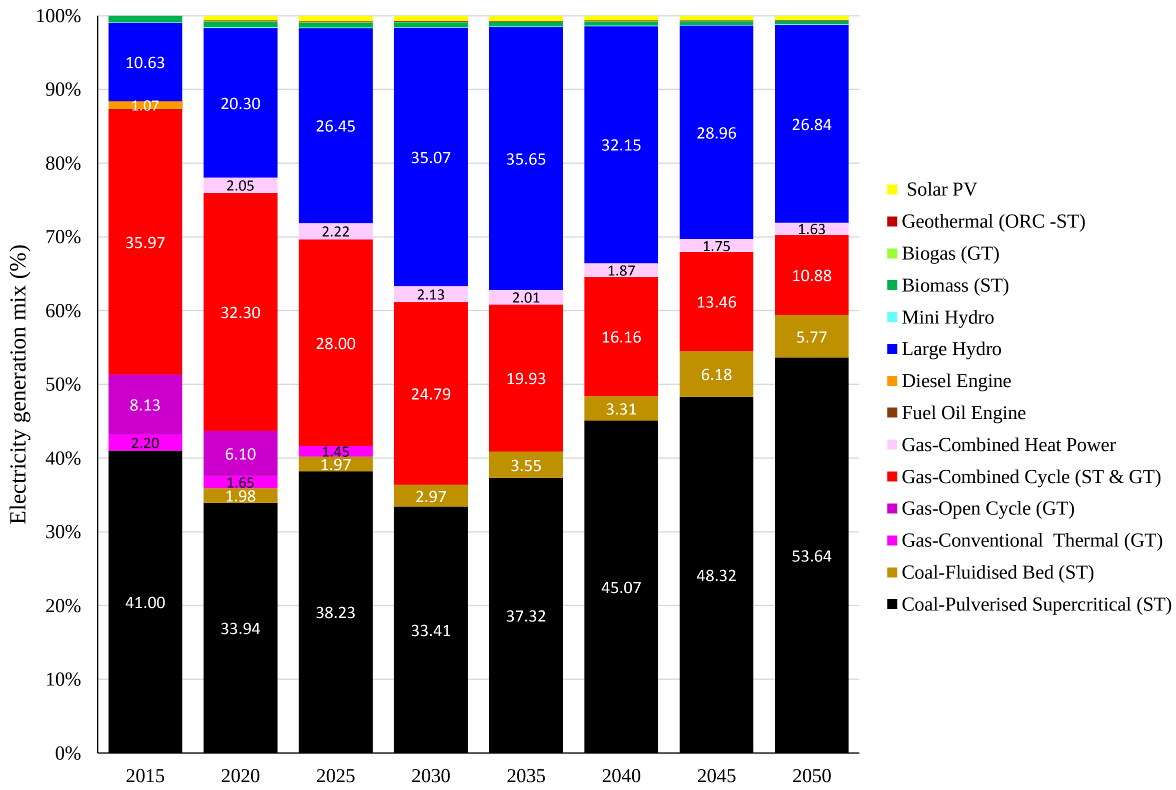


Figure 68. BAU electricity generation mix by technology

7.6.3 Fuel input (PJ)

Figure 69 represents the primary and secondary fuel energy levels consumed by the power plants and Figure 70 presents the fuel mix for the BAU scenario, it is apparent that coal remained as the major fuel throughout the study horizon, whereby coal had a 45.26% energy share in 2015 and it rose to 63.39% by 2050. Apart from that, lignite which is a lower grade coal also commonly known as brown coal enters the fuel mix from 2020 onwards with a 2.55% share and grew to 6.97% by 2050. Within the same period, hydro expanded from 4.85% to 15.40%. Nevertheless, in between 2015 to 2050, the reliance on natural gas in the fuel mix managed to be contracted from 47.36% to 11.31%. In hindsight, by 2050 renewable energy aside from large hydro, such as solar, biomass, biogas, geothermal and mini-hydro only constituted 2.92% out of the total fuel mix. This scenario is evidently unsustainable as it will require continuous import of coal and it wouldn't solve the depletion of the domestic natural gas reserve in the near future due to the high preservation of fossil fuel in the fuel mix quantified at 81.67% by 2050.

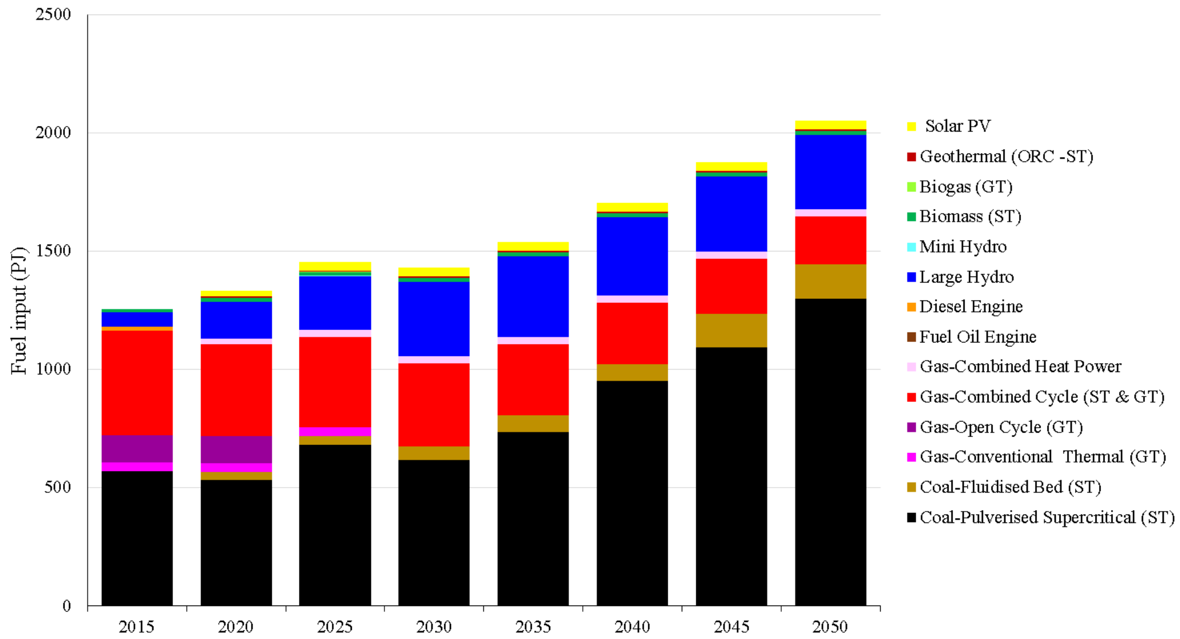


Figure 69. BAU fuel level by technology

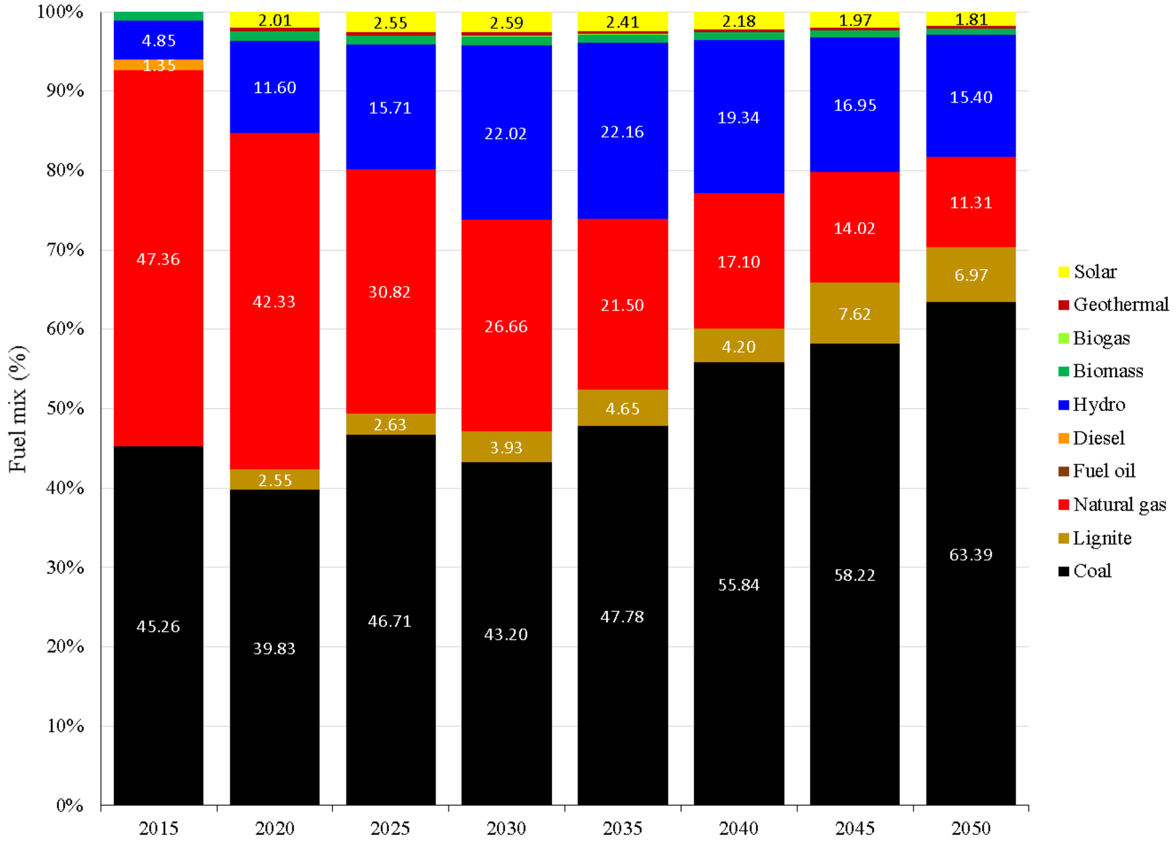


Figure 70. BAU fuel mix profile

7.6.4 CO_2 emission (kt)

The BAU scenario marked an increase in CO_2 emission levels by 69.31% over the 35 years span, from 89,873.44 kt to 152,162.24 kt as indicated in Figure 71. This is largely contributed by the combustion of fossil fuels such as bituminous coal (black coal), lignite (brown coal) and natural gas. Combustion of renewable resources such as biomass and biogas also adds to the carbon footprint, based on the Intergovernmental Panel on Climate Change (IPCC) guideline the default CO_2 emission factor for combustion of biomass and biogas is 100 $ktPJ^{-1}$ and 54.6 $ktPJ^{-1}$ respectively [230]. It is observed that the CO_2 levels are expected to experience a small peak in 2025 due to the capacity addition of combined cycle power plants, lignite fuelled fluidized bed plants, pulverized coal supercritical plants, and combined heat power plants. Conversely, the CO_2 emission levels will noticeably drop in 2030 due to the retirement of old gas-fired plants which include the open cycle, conventional thermal and combined cycle technology. Percentage wise by 2050, 80.86% of the emitted CO_2 is released from the combustion of black bituminous coal, 9.49% is derived from burning lignite, while natural gas combustion accounted for 8.56%. Besides the incineration of biomass and biogas is answerable for the corresponding release of 1.06% and 0.03% carbon emission. The emission levels will continue to rise until 2050 in tandem with the increase in electricity generation in the BAU case.

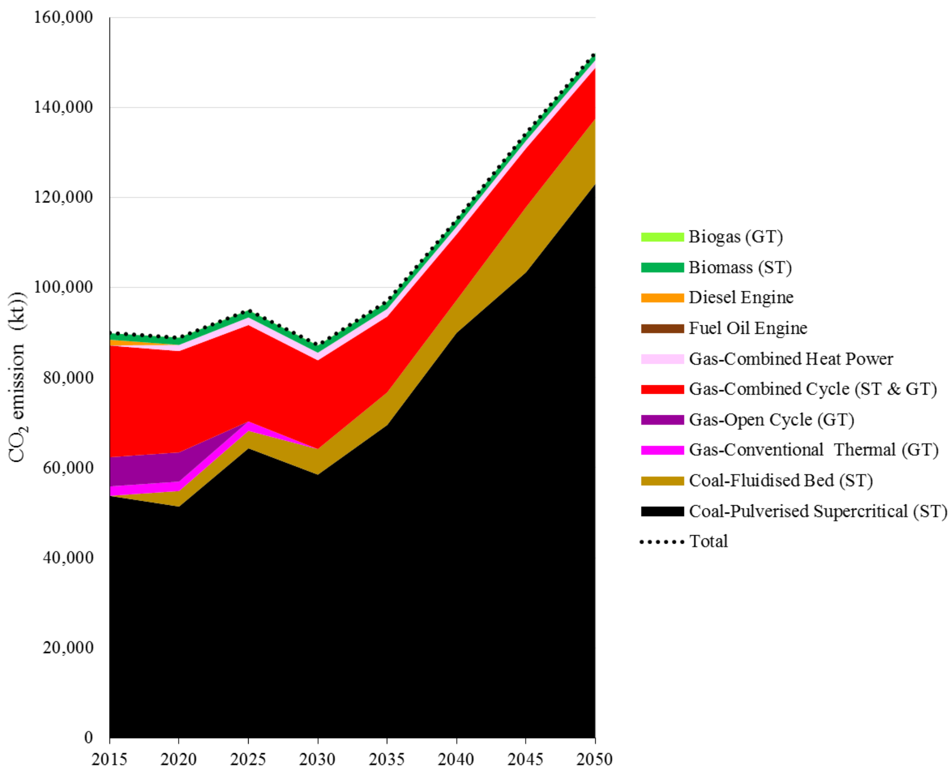


Figure 71. BAU CO_2 emission level

7.7 Nuclear scenario

7.7.1 *Capacity levels (GW)*

The capacity levels for the NUC2 scenario as presented in Figure 72 simulates the addition of the 2 GW nuclear power into the RES by 2030. As a consequence, to this newly added technology, it is observed that the capacity levels of combined cycle power in the NUC2 scenario starts to decline from 2030 onwards, from 6.30 GW to 2.28 GW in 2050. In contrast to the BAU scenario, by 2050 the combined cycle power in the NUC2 scenario experienced a capacity drop by 46.73%. This continuous drop in generation capacity from gas-fueled combined cycle power is further enhanced in the NUC4 scenario, when an additional 2 GW nuclear power gains entry into the RES by 2040 making the total cumulative nuclear power to 4 GW as represented in Figure 73, in which the final stock of combined cycle power by 2050 in contrast to BAU drops by 93.46% to 0.28 GW. This bodes well with the fuel substitution policy of natural gas with other resources in which nuclear power is filling the capacity gap that was originally sustained by gas-fired combined cycle plants. The capacity addition and retirement figures for NUC2 and NUC4 scenarios as are respectively reported in Table 88 and 89.

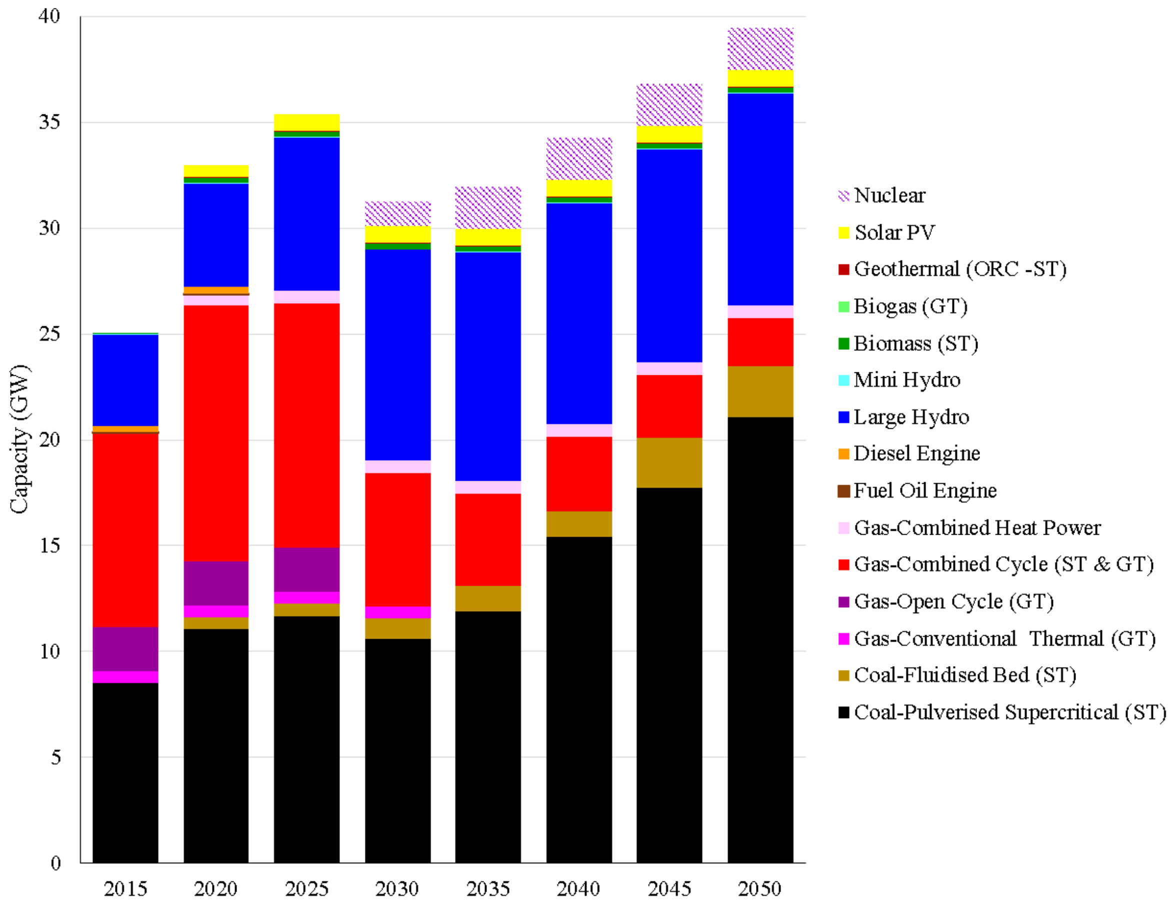


Figure 72. NUC2 capacity level by technology

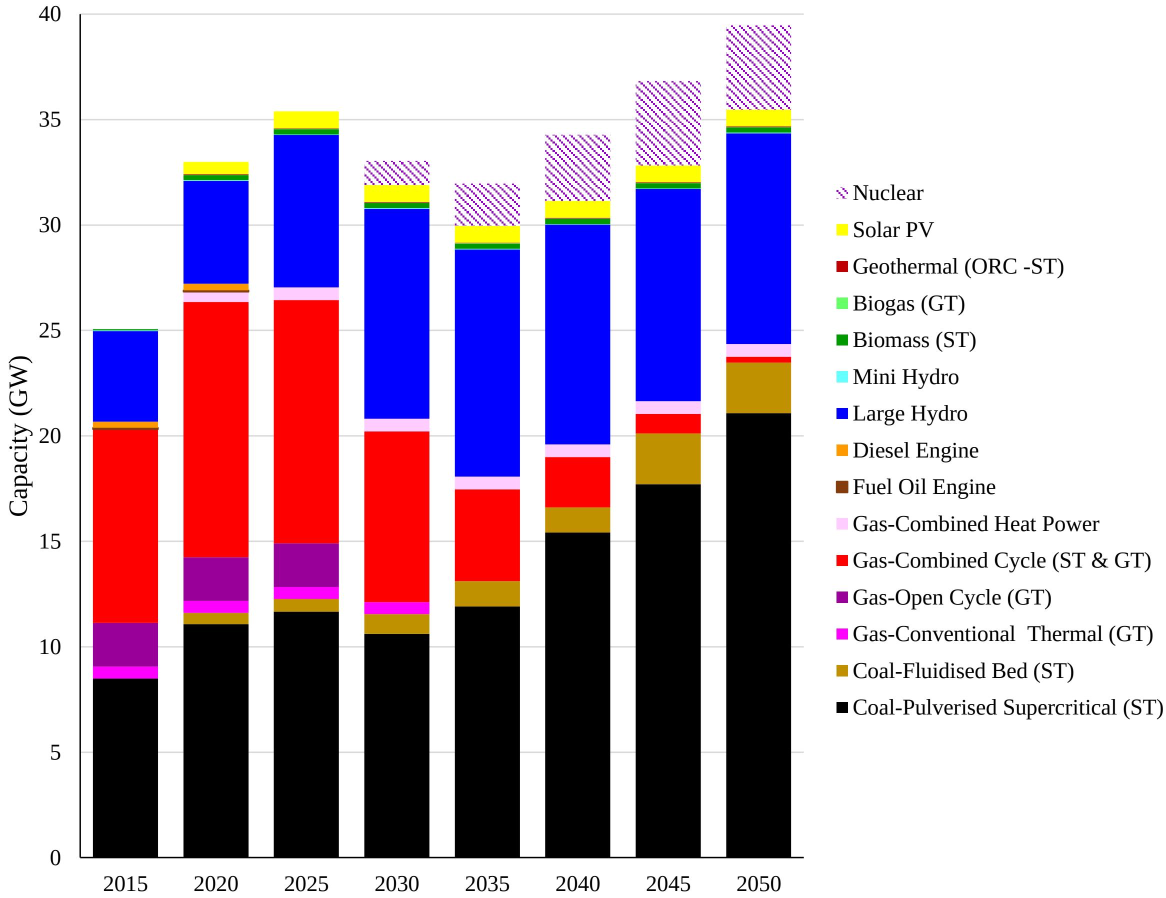


Figure 73. NUC4 capacity level by technology

Table 88. NUC2 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	2.58	0.59	-1.06	1.30	3.51	2.30	3.37
Coal-Fluidised Bed	0.00	0.53	0.07	0.34	0.26	0.00	1.20	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	2.91	-0.57	-5.23	-1.94	-0.83	-0.59	-0.66
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	0.58	2.34	2.74	0.81	-0.36	-0.36	-0.07
Mini Hydro	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.06	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Biogas	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Geothermal	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	0.00	0.00	0.00	-0.01	0.00
Nuclear	0.00	0.00	0.00	1.14	0.86	0.00	0.00	0.00

Table 89. NUC4 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	2.58	0.59	-1.06	1.30	3.51	2.30	3.37
Coal-Fluidised Bed	0.00	0.53	0.07	0.34	0.26	0.00	1.20	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	2.91	-0.57	-3.43	-3.74	-1.97	-1.45	-0.66
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	0.58	2.34	2.74	0.81	-0.36	-0.36	-0.07
Mini Hydro	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.06	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Biogas	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Geothermal	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	0.00	0.00	0.00	-0.01	0.00
Nuclear	0.00	0.00	0.00	1.14	0.86	1.14	0.86	0.00

7.7.2 Electricity output (PJ)

According to the NUC2 and NUC4 electricity generation profile as per Figure 74 and 75, showed a dominance from pulverized supercritical coal plants with 598.30 PJ followed by large hydro supplying 299.31 PJ by 2050. These two scenarios maintained similar electricity production levels for most conversion technologies as the BAU scenario, except for variations in the production levels of the combined cycle power plants, whereby in 2050 the levels significantly drop from base year levels of 194.48 PJ to 64.59 PJ in the NUC2 scenario and narrows down further in the NUC4 scenario to 7.81 PJ. In contrast to the BAU scenario, combined cycle electricity output by 2050 is reduced by 46.77% in the NUC2 and 93.56% in the NUC4 scenario. As for nuclear fission technology, by 2050 the electricity output reached 56.76 PJ and 113.53 PJ respectively for the NUC2 and NUC4 scenarios.

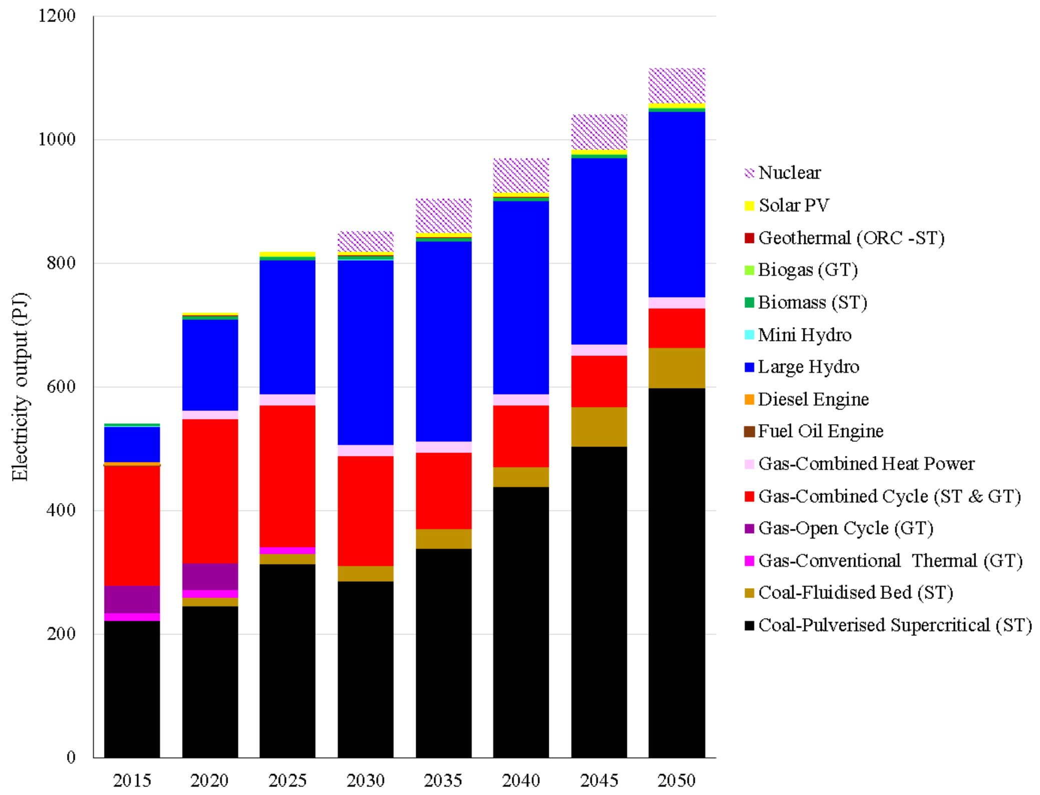


Figure 74. NUC2 electricity output by technology

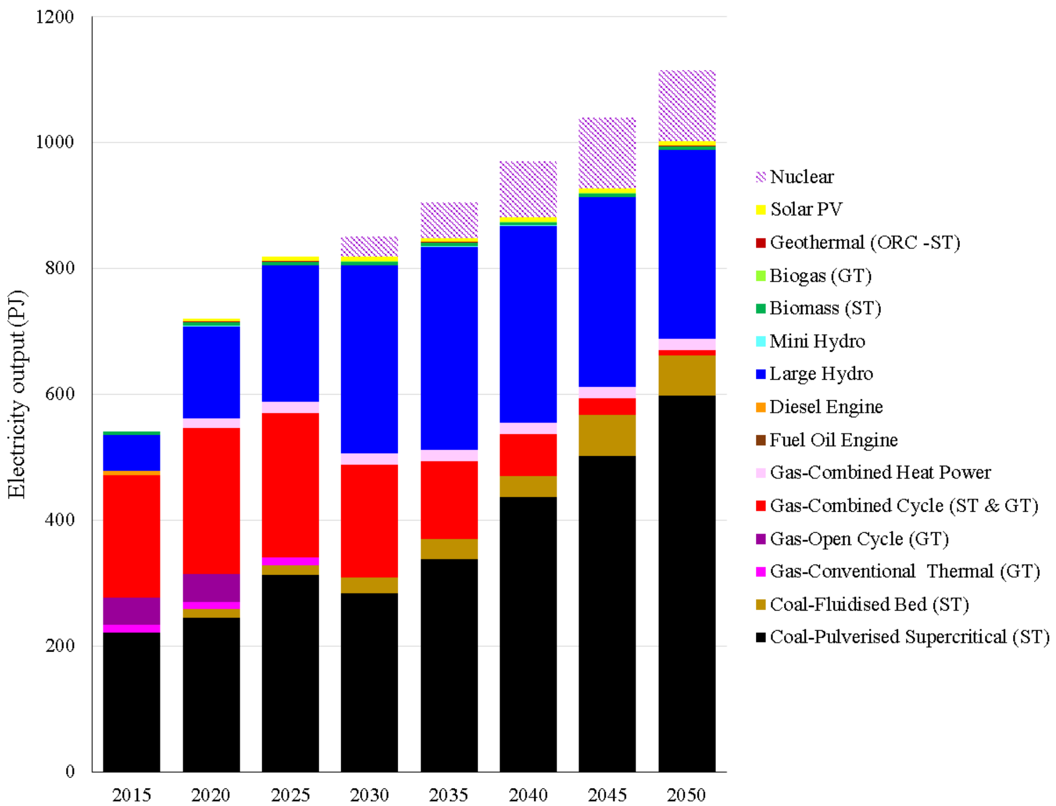


Figure 75. NUC4 electricity output by technology

It is observed that by 2050, the generation mix portfolio for the NUC2 model as shown in Figure 76 comprised of 53.64% coal pulverized supercritical, 26.84% large hydro, 5.79% combined cycle, 5.77% lignite fluidized bed, 5.09% nuclear, 1.63% cogeneration and only 1.25% is derived from renewable technologies. In the NUC4 case as depicted in Figure 77 showed that by 2050, the generation mix retains the same proportions as the NUC2 model, except for nuclear and combined cycle technology whereby an increase of 10.18% is noted for nuclear and a decrease in generation levels from combined cycle plants to 0.70%.

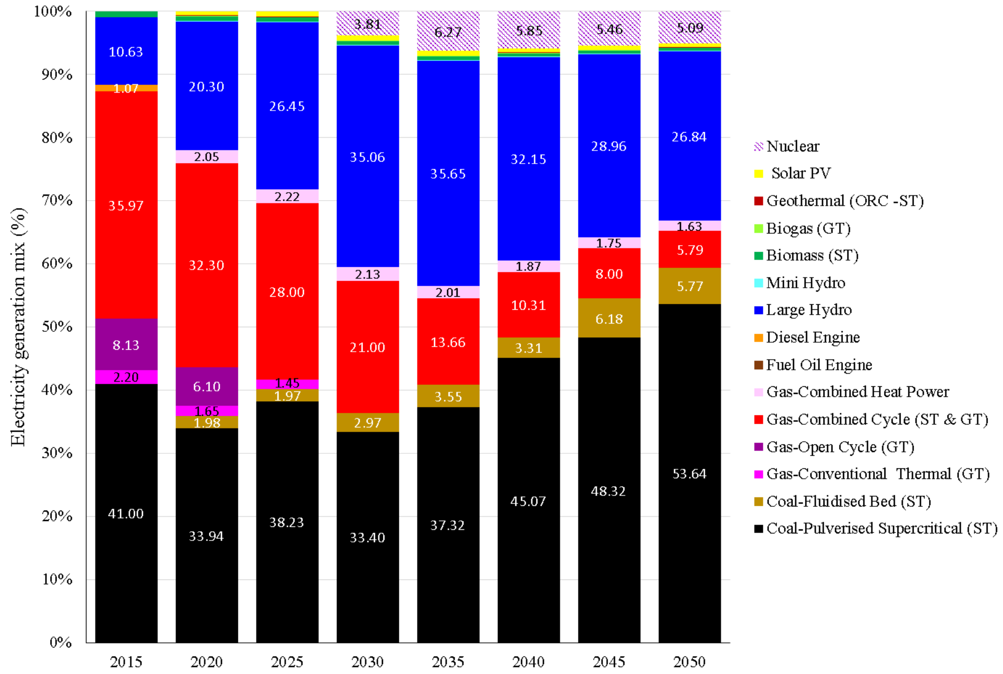


Figure 76. NUC2 electricity generation mix by technology

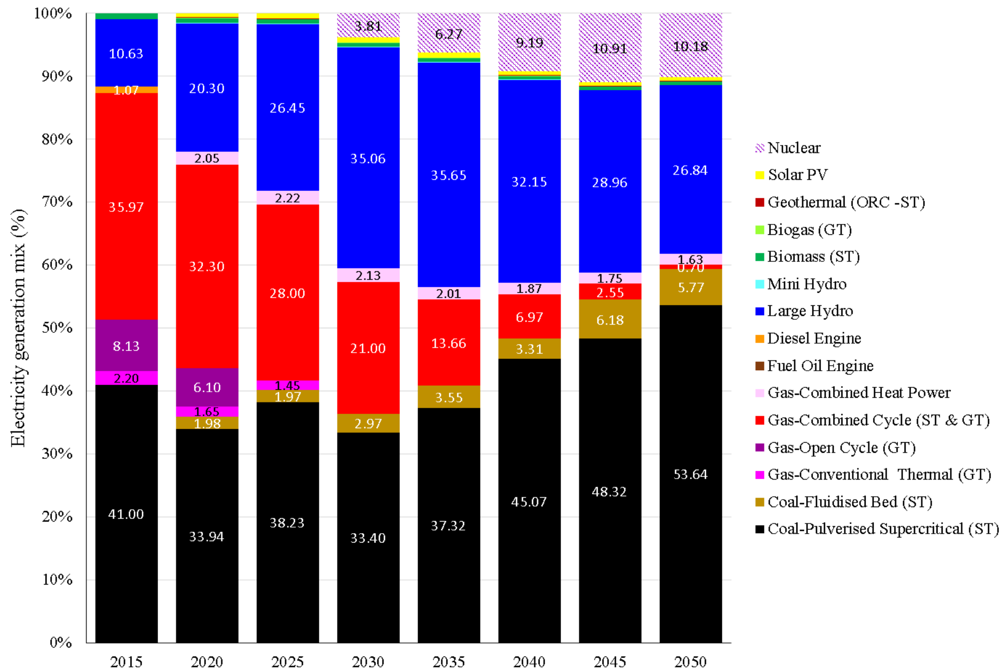


Figure 77. NUC4 electricity generation mix by technology

7.7.3 Fuel input (PJ)

The NUC2 and NUC4 fuel levels as exhibited in Figure 78 and 79 demonstrated a reduction in natural gas consumption by the combined cycle power plants. This gradual decline commences from 2030, upon entry of nuclear energy in the fuel mix. When collated against the BAU, the model depicts that by 2050 natural gas in the NUC2 case will drop by 46.77% and continues to decline up to 93.56% in the NUC4 case. The energy levels exhibited by the fuels in the NUC2 and NUC4 case generally are similar to the BAU levels, except for the obvious decrease in natural gas consumption and the change in nuclear energy from 149.38 PJ to 298.76 PJ in both scenarios.

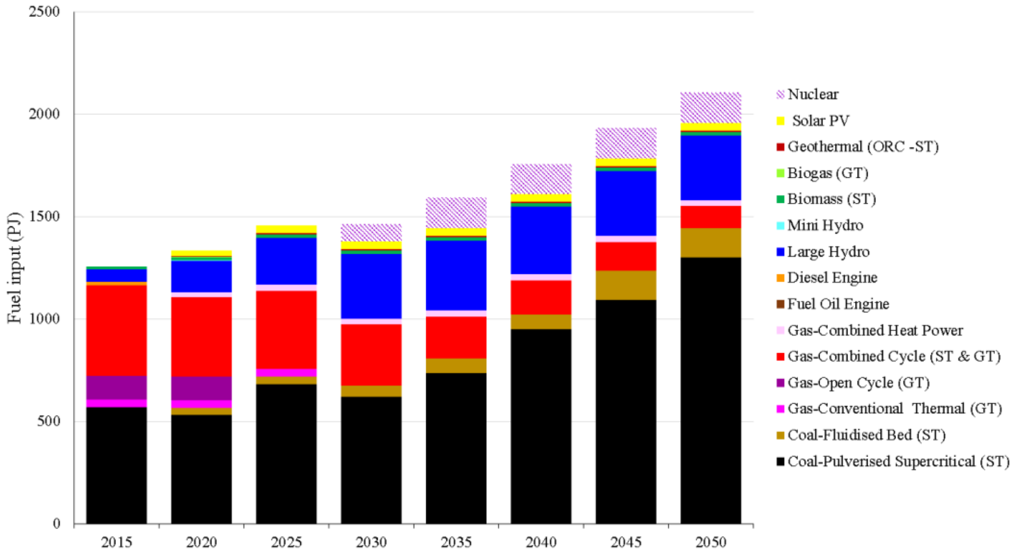


Figure 78. NUC2 fuel level by technology

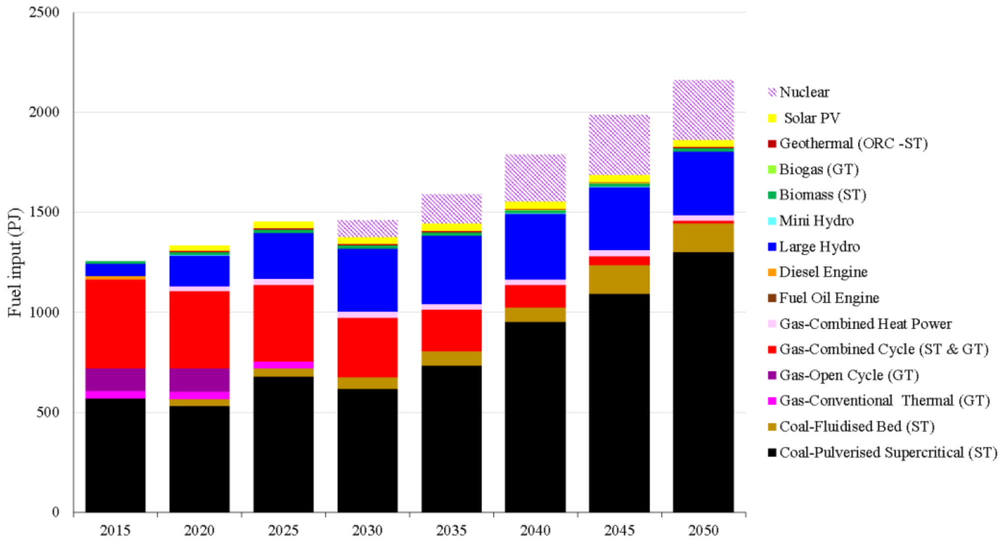


Figure 79. NUC4 fuel level by technology

The NUC2 fuel mix accomplished in 2050 (refer Figure 80) is led by 61.74% coal, 15.00% hydro, 7.09% nuclear, followed by 6.79% lignite, 6.53% natural gas and the balance of 2.84% is fuelled by renewable energy other than hydro. Similarly, the NUC4 fuel mix as in Figure 81 depicts a transformed fuel mix by 2050 which comprised of 60.18% coal, 14.62% hydro, nuclear was stretched to 13.82%, lignite keeps a 6.61% share, while natural gas plunged to a sheer 1.99%, and renewables just have a 2.79% share out of the total mix.

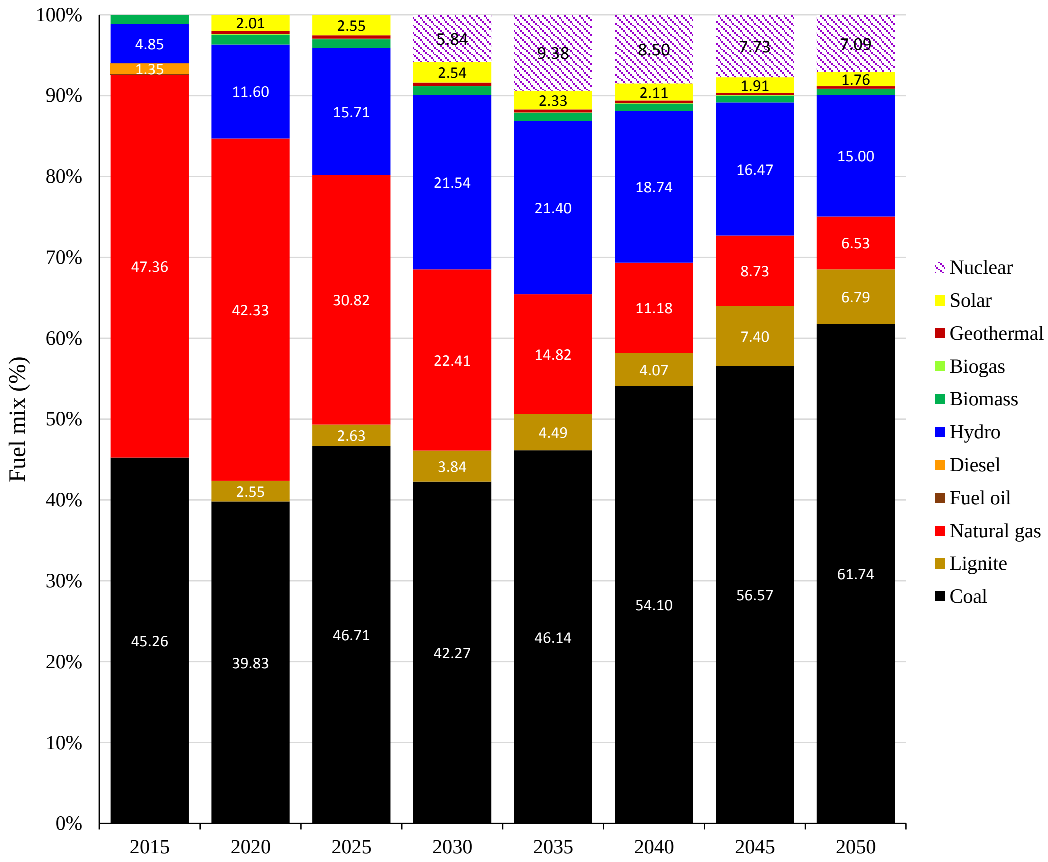


Figure 80. NUC2 fuel mix profile

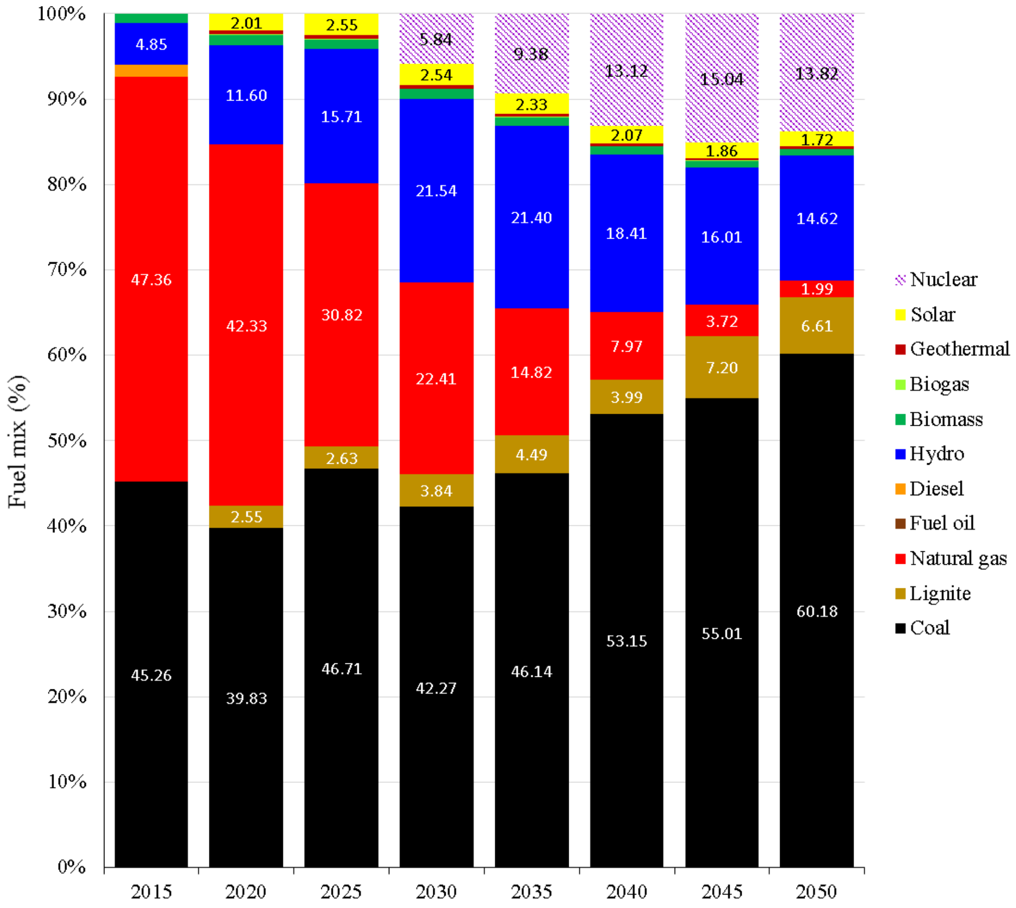


Figure 81. NUC4 fuel mix profile

7.7.4 CO_2 emission levels (kt)

The CO_2 emission levels for the NUC2 and NUC4 models as per Figure 82 and 83 shows a significant decline in emission levels starting from 2030 onwards. The emission drop is stemming from the reduced combined cycle electricity output, which has been switched to nuclear power, an emission-free technology. The CO_2 reduction levels in the NUC2 model, when paralleled to the BAU model, indicates a 15.27% drop from 19,726.48 kt to 16,713.35 kt in 2030, and by 2050 the drop is intensified to 46.77% from 11,346.09 kt to 6,039.19 kt. However, by 2050 under the NUC4 scenario, the CO_2 emission from combined cycle plants is mitigated by 93.56% in contrast to the BAU levels which is a drop from 11,346.09 kt to 730.66 kt.

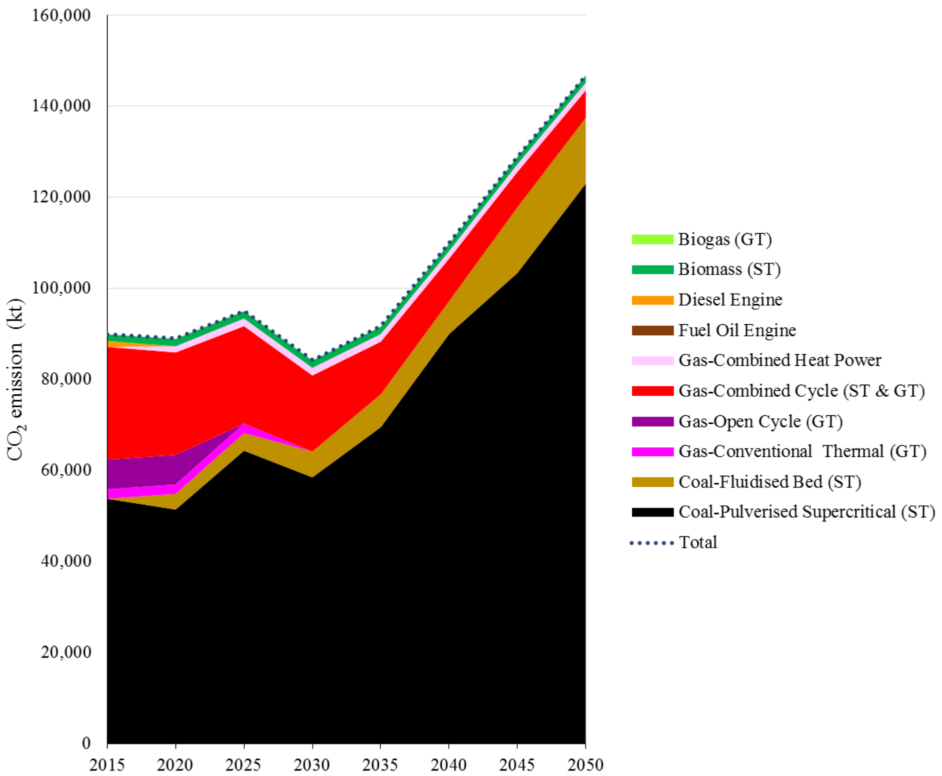


Figure 82. NUC2 CO_2 emission level

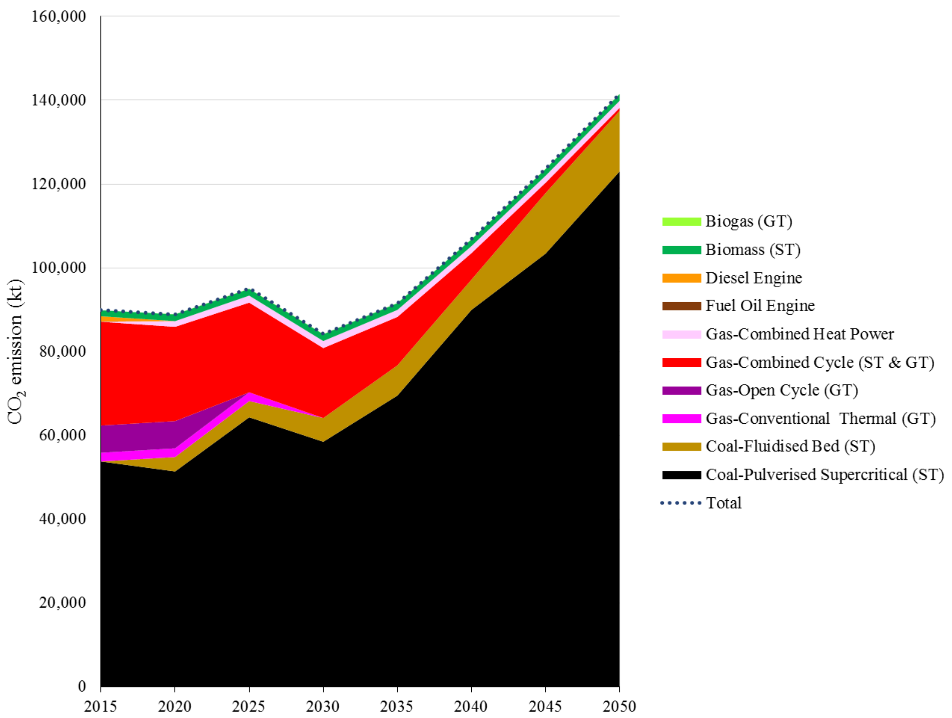


Figure 83. NUC4 CO_2 emission level

7.8 Renewable scenario

7.8.1 Capacity levels (GW)

The RNW6S7 scenario is augmented with 6 different renewable technologies which include solar PV mounted on existing rooftops, geothermal, biomass, biogas, mini and large hydro along with pump hydro storage capacity sufficient to store 7 days generation output, hence the optimized capacity levels suggested by the model is revealed in Figure 84. While the RNW6S14 scenario is similar to RNW6S7 whereby this scenario still relies on the same types of renewable technologies, nevertheless the pump hydro capacity has been increased to enable 14 days of electricity storage (refer Figure 85). When offshore wind technology starts to penetrate the RES on top of the six renewable technologies along with the 7 and 14 days equivalent storage system, the capacity configurations for the RNW7S7 and RNW7S14 scenarios considerably changes as indicated in Figure 86 and 87.

With the introduction of solar PV, biomass, biogas, mini hydro and geothermal tuned to reach their upper bound capacity as assessed in Chapter 6 has impacted the capacity levels in 2050 to increase by 65.54% to 68.08% in all the renewable scenarios compared to the BAU levels for the same period. This is mainly instigated by the addition of the solar PV technology, due to the lower efficiency capability of PV technology to convert solar energy into electrical energy hence more panels need to be installed to achieve the expected generation levels.

It is prominent in all four renewable scenarios that with the increase in renewable power, the combined cycle capacity levels significantly reduce to 1.16 GW by 2030 which is an 84.39% drop compared to the BAU record and fully withdraws from the RES by 2035. Across all the renewable scenarios, the model also recommended that fluidized bed lignite-fueled power exits the system from 2030 onwards. A similar downward trend is imminent on the coal pulverized supercritical capacity levels through all the renewable scenarios, this technology is suggested to retire from the RES by 2050 in both RNW6S7 and RNW6S14 scenarios, and the retirement period is brought forward to 2040 in the RNW7S7 and RNW7S14 scenarios. The model allocated a huge increase in large hydro capacity by 2050 in contrast to the BAU levels, for RNW6S7 and RNW6S14 the rise was substantiated at 138.64% and 131.43% respectively. Whereas for the RNW7S7 and RNW7S14 scenarios, a corresponding growth of 102.40 % and 95.20% for large hydro capacity were detected. The noted lessening in large hydro capacity between RNW6 and RNW7 scenarios is particularly to give way for offshore wind power, while the further descent between S7 and S14 scenarios is to accommodate the increase in storage capacity. The capacity addition and retirement progress for each of the developed renewable scenarios are listed in Table 90, 91, 92 and 94.

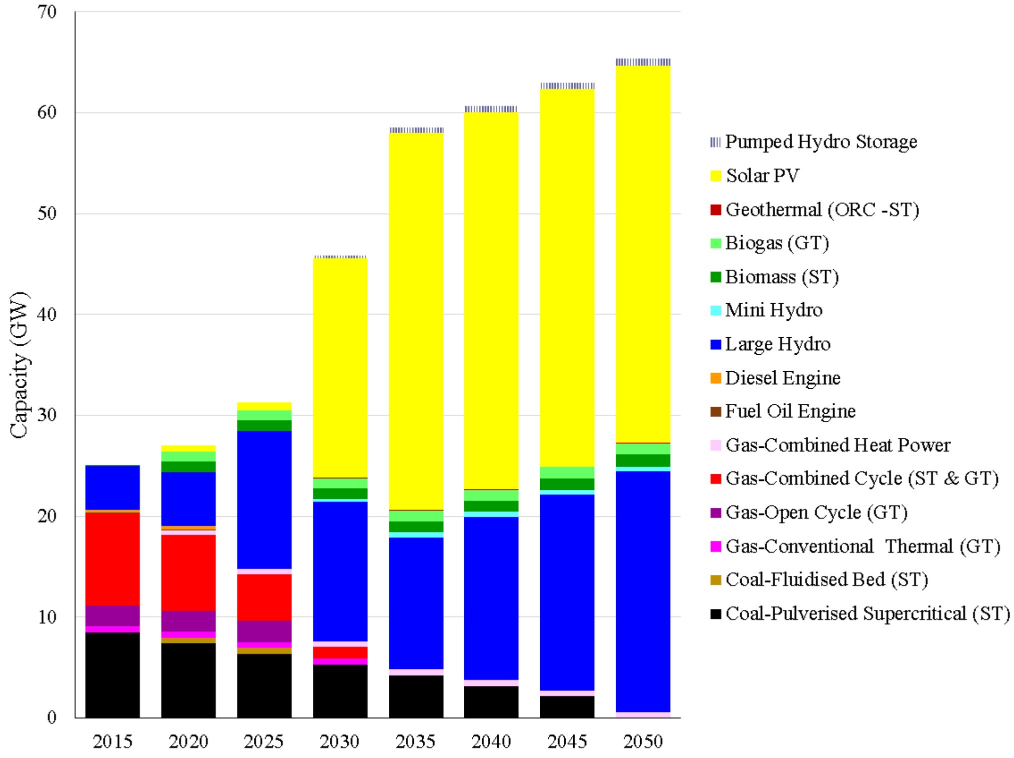


Figure 84. RNW6S7 capacity level by technology

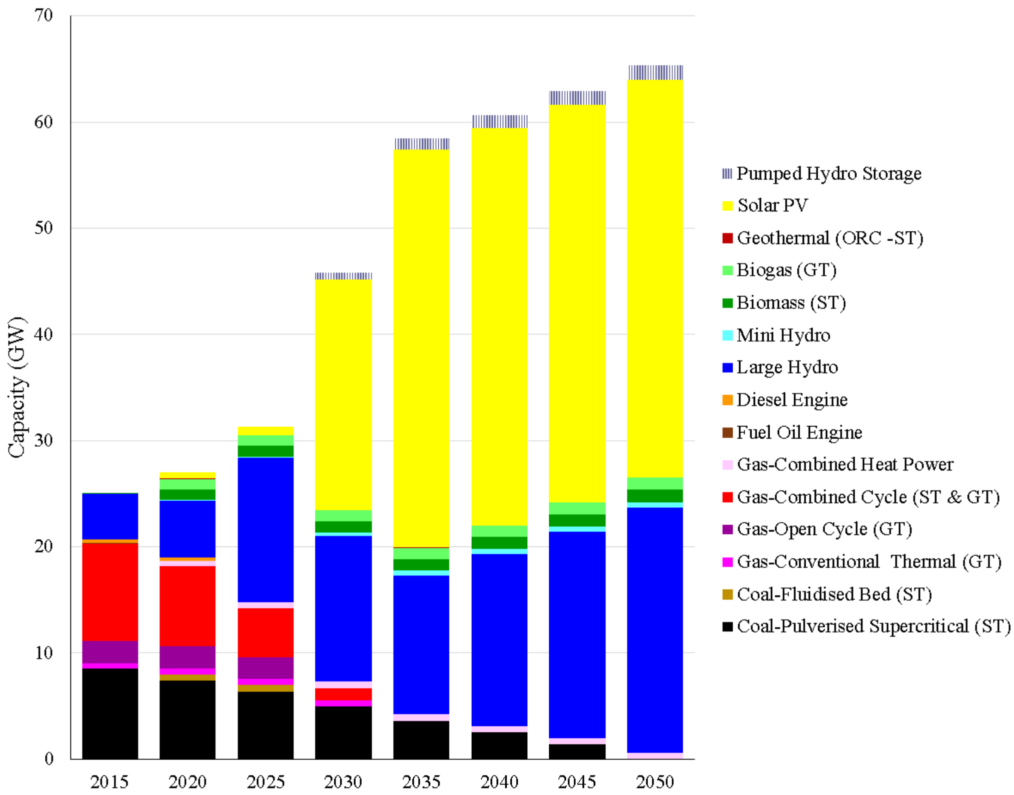


Figure 85. RNW6S14 capacity level by technology

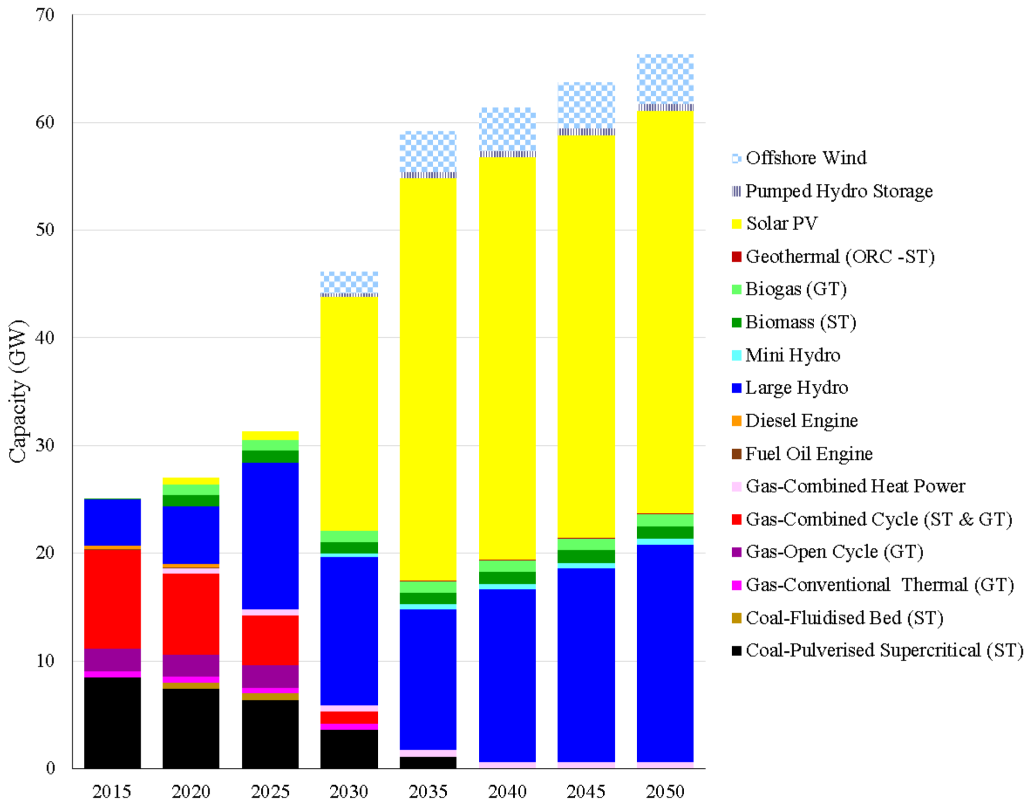


Figure 86. RNW7S7 capacity level by technology

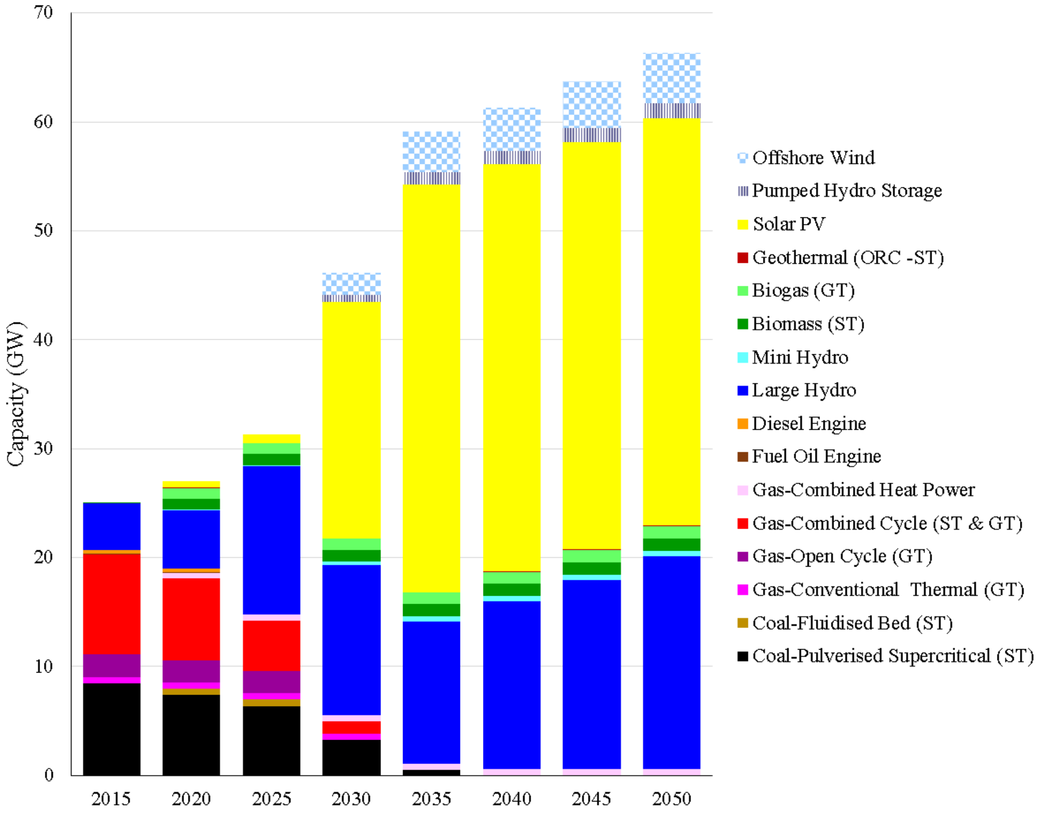


Figure 87. RNW7S14 capacity level by technology

Table 90. RNW6S7 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	-1.06	-1.06	-1.06	-1.06	-1.06	-1.06	-2.12
Coal-Fluidised Bed	0.00	0.53	0.07	-0.60	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	-1.65	-2.95	-3.43	-1.16	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	1.05	8.27	0.15	-0.72	3.11	3.25	4.43
Mini Hydro	0.03	0.00	0.00	0.26	0.20	0.00	0.00	0.00
Biomass	0.06	0.97	0.02	0.02	0.02	0.02	0.03	0.03
Biogas	0.00	0.97	0.02	0.02	0.02	0.02	0.02	0.02
Geothermal	0.00	0.03	0.00	0.02	0.02	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	20.92	15.69	0.00	-0.01	0.00
Pumped Hydro Storage	0.00	0.00	0.00	0.31	0.25	0.04	0.05	0.04

Table 91. RNW6S14 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	-1.06	-1.06	-1.40	-1.34	-1.10	-1.11	-1.41
Coal-Fluidised Bed	0.00	0.53	0.07	-0.60	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	-1.65	-2.95	-3.43	-1.16	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	1.05	8.27	0.15	-0.72	3.11	3.25	3.70
Mini Hydro	0.03	0.00	0.00	0.26	0.20	0.00	0.00	0.00
Biomass	0.06	0.97	0.02	0.02	0.02	0.02	0.03	0.03
Biogas	0.00	0.97	0.02	0.02	0.02	0.02	0.02	0.02
Geothermal	0.00	0.03	0.00	0.02	0.02	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	20.92	15.69	0.00	-0.01	0.00
Pumped Hydro Storage	0.00	0.00	0.00	0.62	0.51	0.07	0.09	0.08

Table 92. RNW7S7 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	-1.06	-1.06	-2.78	-2.47	-1.12	0.00	0.00
Coal-Fluidised Bed	0.00	0.53	0.07	-0.60	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	-1.65	-2.95	-3.43	-1.16	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	1.05	8.27	0.15	-0.72	2.98	2.00	2.20
Mini Hydro	0.03	0.00	0.00	0.26	0.20	0.00	0.00	0.00
Biomass	0.06	0.97	0.02	0.02	0.02	0.02	0.03	0.03
Biogas	0.00	0.97	0.02	0.02	0.02	0.02	0.02	0.02
Geothermal	0.00	0.03	0.00	0.02	0.02	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	20.92	15.69	0.00	-0.01	0.00
Offshore Wind	0.00	0.00	0.00	2.06	1.70	0.23	0.32	0.28
Pumped Hydro Storage	0.00	0.00	0.00	0.31	0.25	0.04	0.05	0.04

Table 93. RNW7S14 scenario capacity addition and retirement plan

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	-1.06	-1.06	-3.12	-2.76	-0.49	0.00	0.00
Coal-Fluidised Bed	0.00	0.53	0.07	-0.60	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.00	0.00	0.00	-0.56	0.00	0.00	0.00
Gas-Open Cycle	2.08	0.00	0.00	-2.08	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	-1.65	-2.95	-3.43	-1.16	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.11	0.00	0.00	0.00	0.00	0.00
Fuel Oil Engine	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.03	-0.31	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	1.05	8.27	0.15	-0.72	2.35	1.95	2.15
Mini Hydro	0.03	0.00	0.00	0.26	0.20	0.00	0.00	0.00
Biomass	0.06	0.97	0.02	0.02	0.02	0.02	0.03	0.03
Biogas	0.00	0.97	0.02	0.02	0.02	0.02	0.02	0.02
Geothermal	0.00	0.03	0.00	0.02	0.02	0.00	0.00	0.00
Solar PV	0.00	0.58	0.22	20.92	15.69	0.00	-0.01	0.00
Offshore Wind	0.00	0.00	0.00	2.06	1.70	0.23	0.32	0.28
Pumped Hydro Storage	0.00	0.00	0.00	0.62	0.51	0.07	0.09	0.08

7.8.2 *Electricity output (PJ)*

The optimized electricity generation portfolio for RNW6S7 and RNW6S14 scenarios as reflected in Figure 88 and 89 clearly shows that electricity output from combined cycle plants and pulverized supercritical coal plants are expected to cease by 2035 and 2050. It is observed that by 2050, both scenarios projected a dominance of generation from large hydropower. By 2050, the generation mix for RNW6S7 mainly comprises of 64.03% large hydro and 26.44% solar PV. While the minor generators consist of 2.34% biomass, 2.18% biogas, 1.25% mini-hydro, and 0.19% of geothermal energy. In terms of storage, the pump hydro storage holds a 1.94% share out of the total generation mix which equals to 7 days of stored electricity (refer Figure 90). This is close to the storage model applied in the United States which maintains storage at nearly 2% out of the total output levels [279]. Whereas in the RNW6S14 scenario, the model allocated 62.09% to large hydro, followed by 26.44% of solar PV, other renewables technologies collectively accounted for 5.96% of the production levels and the electricity storage has been doubled to 3.88% which is enough to supply electricity for 14 days (refer Figure 91). The storage levels in Europe are close to 5% of the generation mix [279].

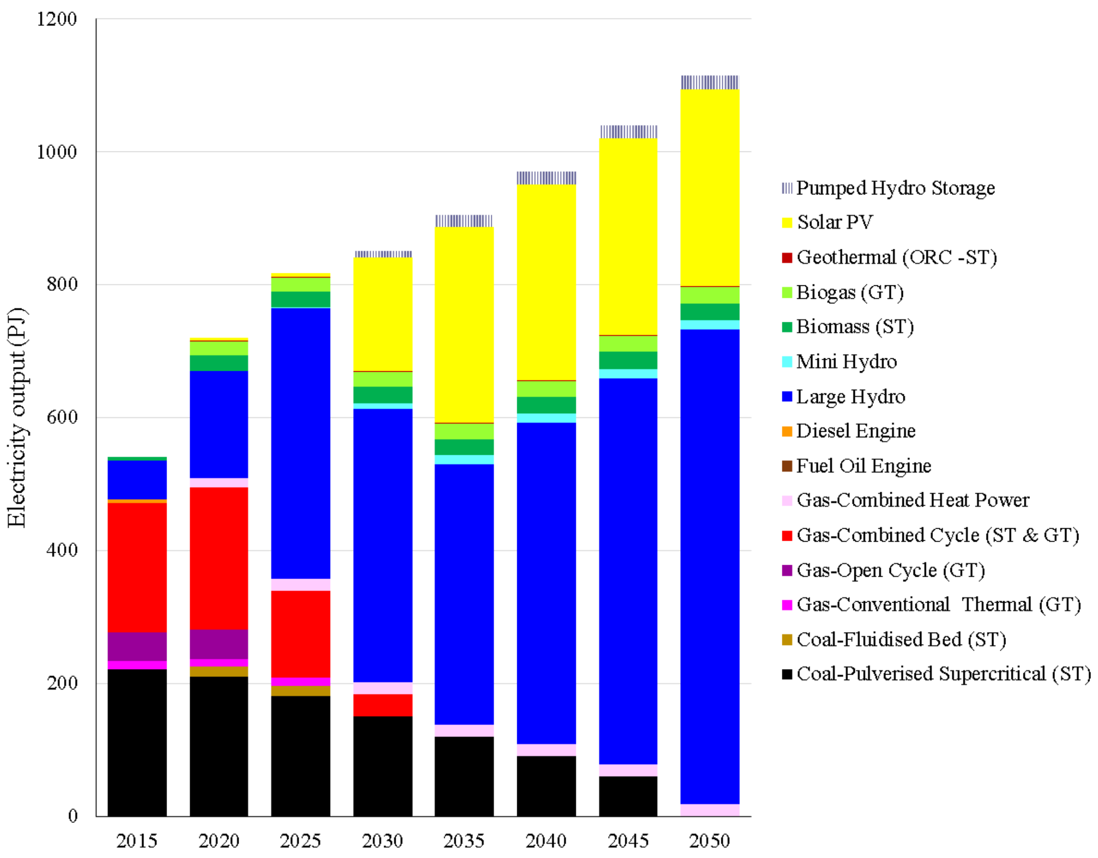


Figure 88. RNW6S7 electricity output by technology

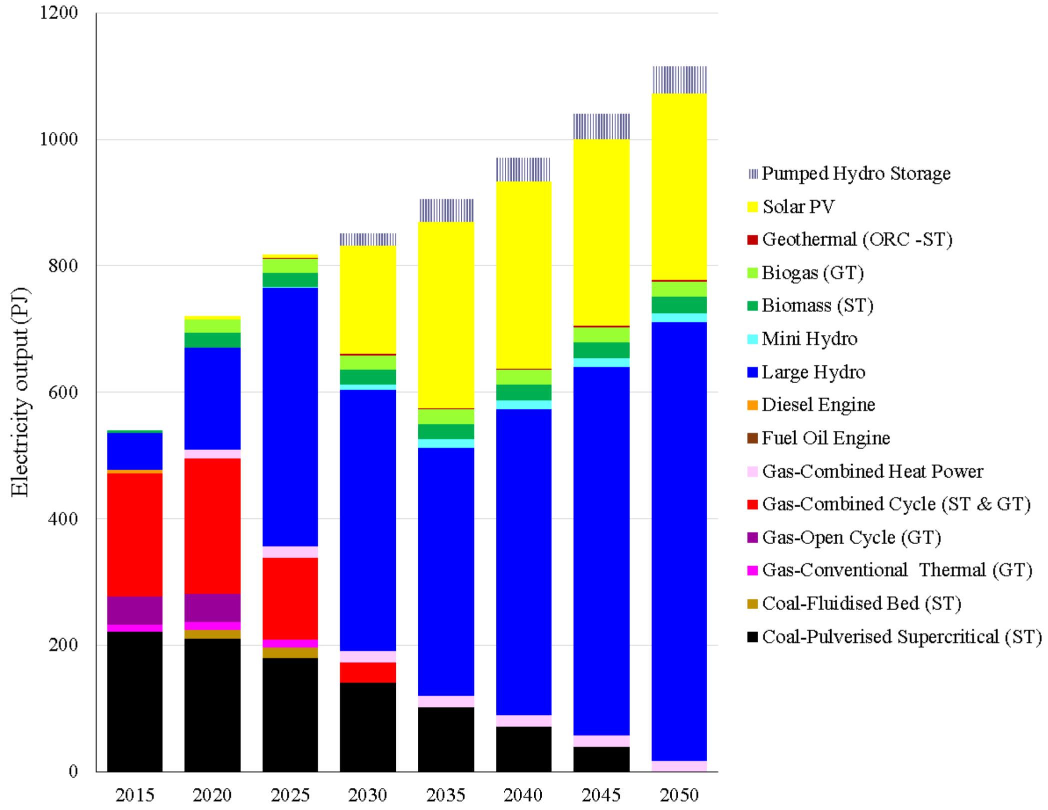


Figure 89. RNW6S14 electricity output by technology

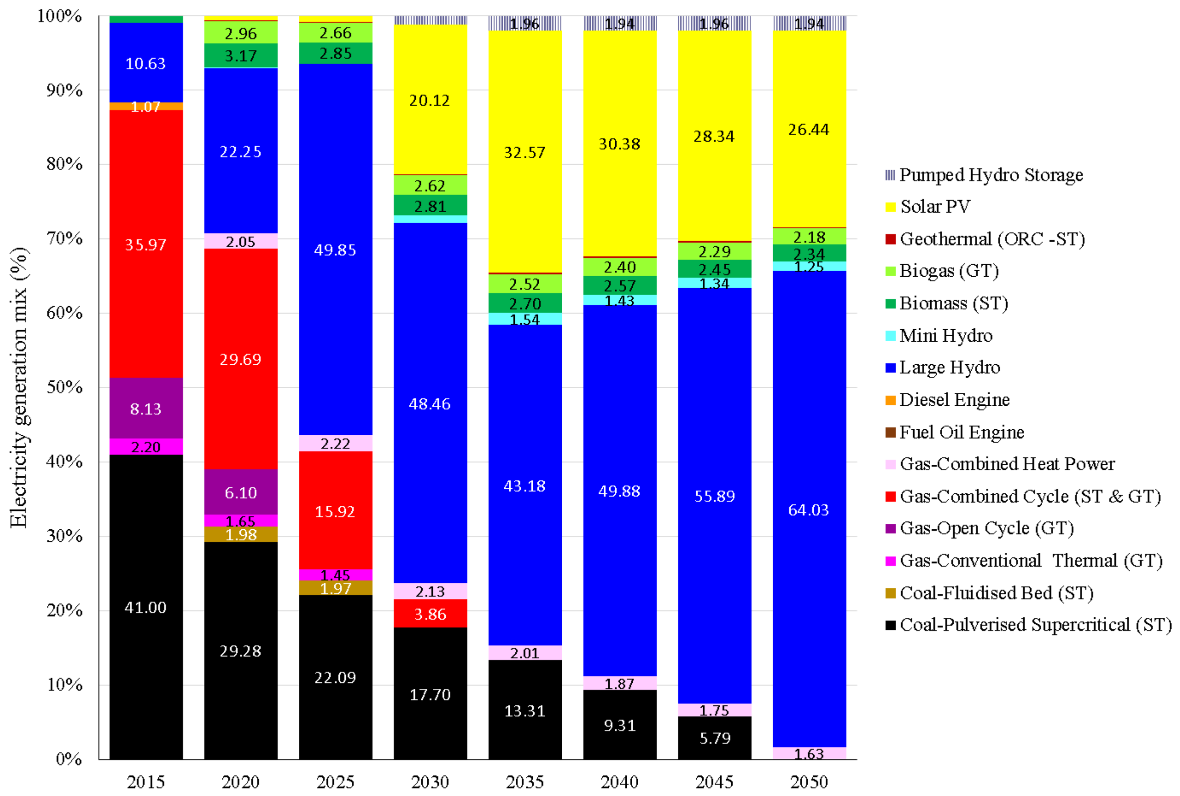


Figure 90. RNW6S7 electricity generation mix by technology

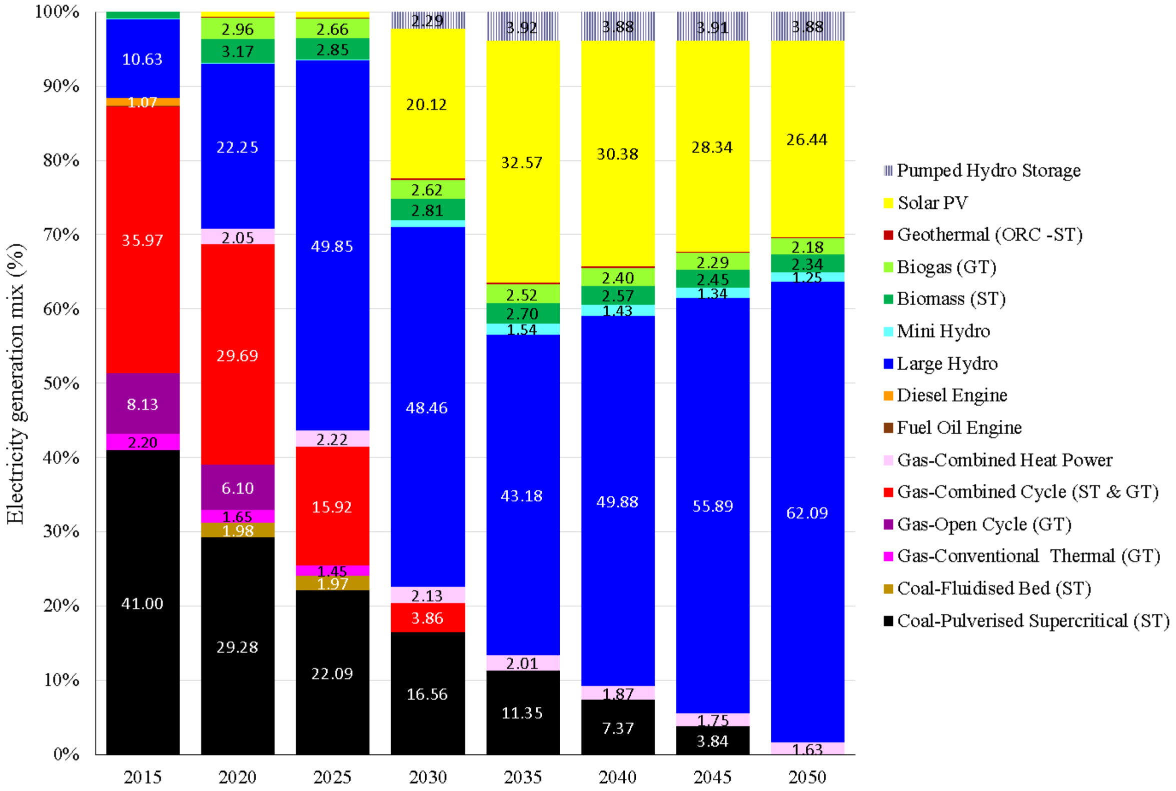


Figure 91. RNW6S14 electricity generation mix by technology

With the integration of offshore wind technology by 2030, has directed the generation outlook for RNW7S7 and RNW7S14 scenarios to appear as Figure 92 and 93. The generation levels from offshore wind by 2050 reach 108.33 PJ (9.71%) in both scenarios and pulverized supercritical coal-fired plants will completely withdraw from the mix by 2040. Furthermore, all natural gas-fired plants except for combined heat power is expected to exit the system by 2035. The model also recommended that lignite fuelled fluidized bed plant to be discontinued by 2030. It is also observed that by 2050 the generation levels from large hydro is reduced in comparison to the RNW6S7 and RNW6S14 scenarios. Thus, the generation mix profile by 2050 for RNW7S7 (refer Figure 94) entails 54.32% large hydro, 26.44% solar PV, followed by offshore wind with 9.71%, and the cumulative generation from biomass, biogas, mini hydro and geothermal sum up to 5.96%, 1.94% is being allotted for stored electricity and the balance of 1.63% are produced from the cogeneration plants. The generation mix by 2050 for RNW7S14 scenario (refer Figure 95) maintains similar levels as in the RNW7S7 scenario with the exception that storage generation levels have been intensified to 3.88% and this has decreased the generation levels from large hydro to 52.38% in the mix.

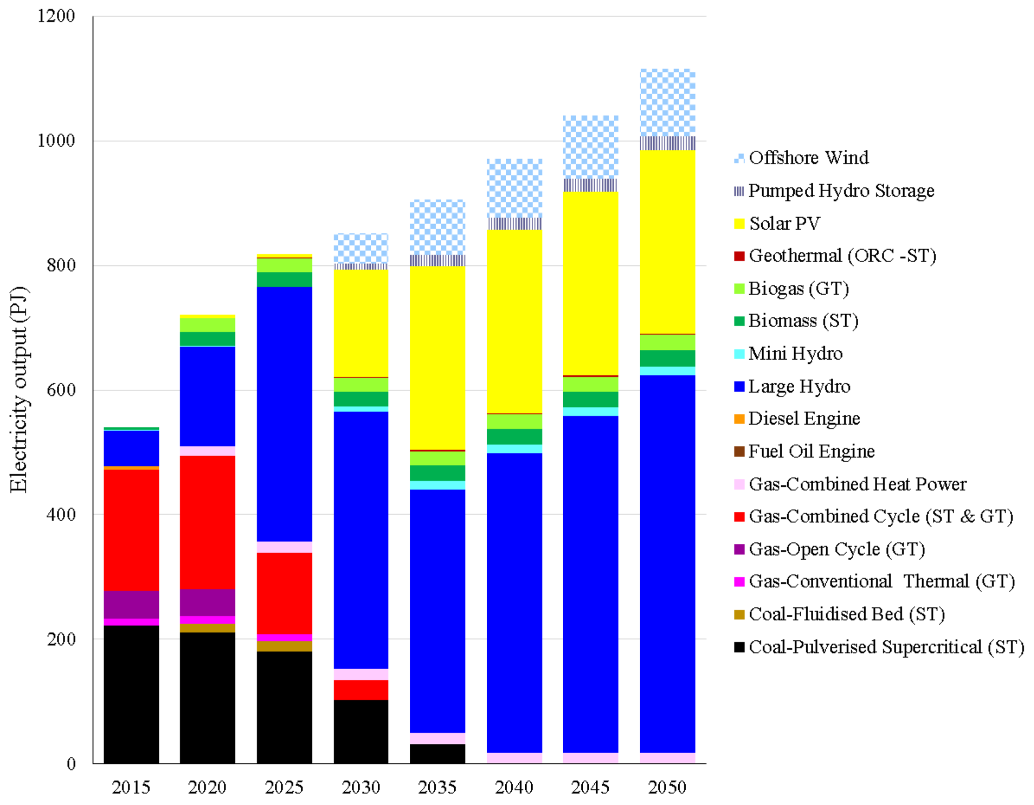


Figure 92. RNW7S7 electricity output by technology

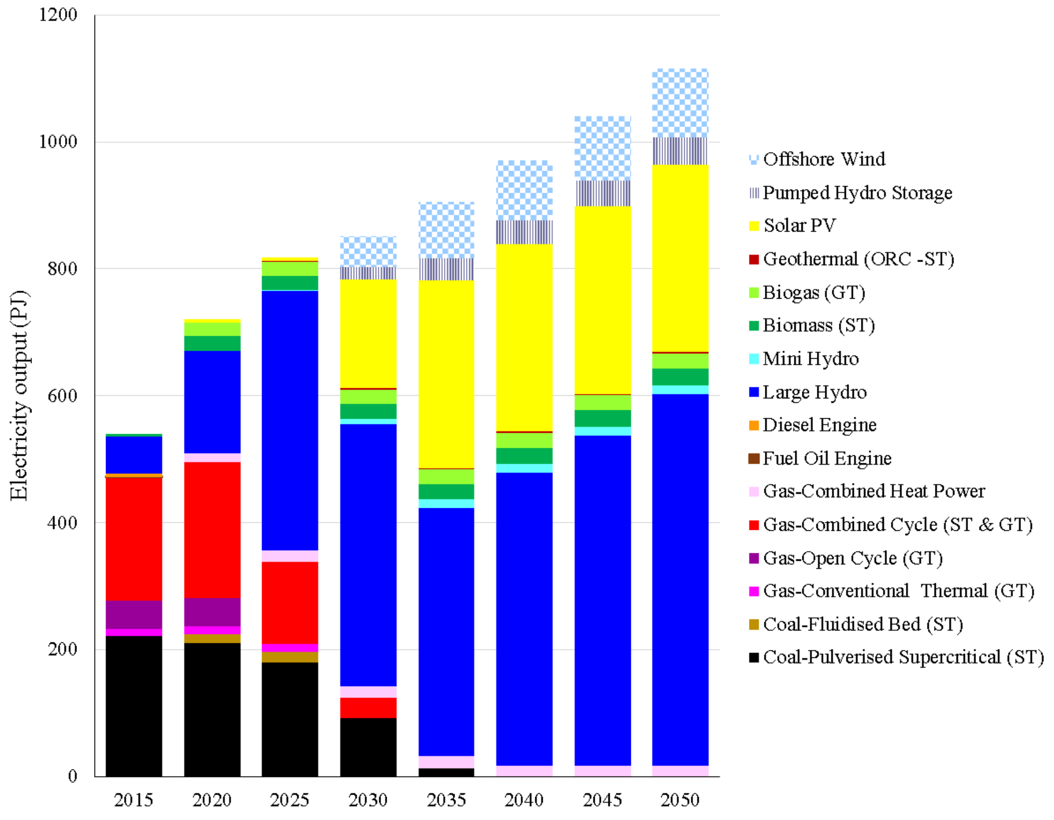


Figure 93. RNW7S14 electricity output by technology

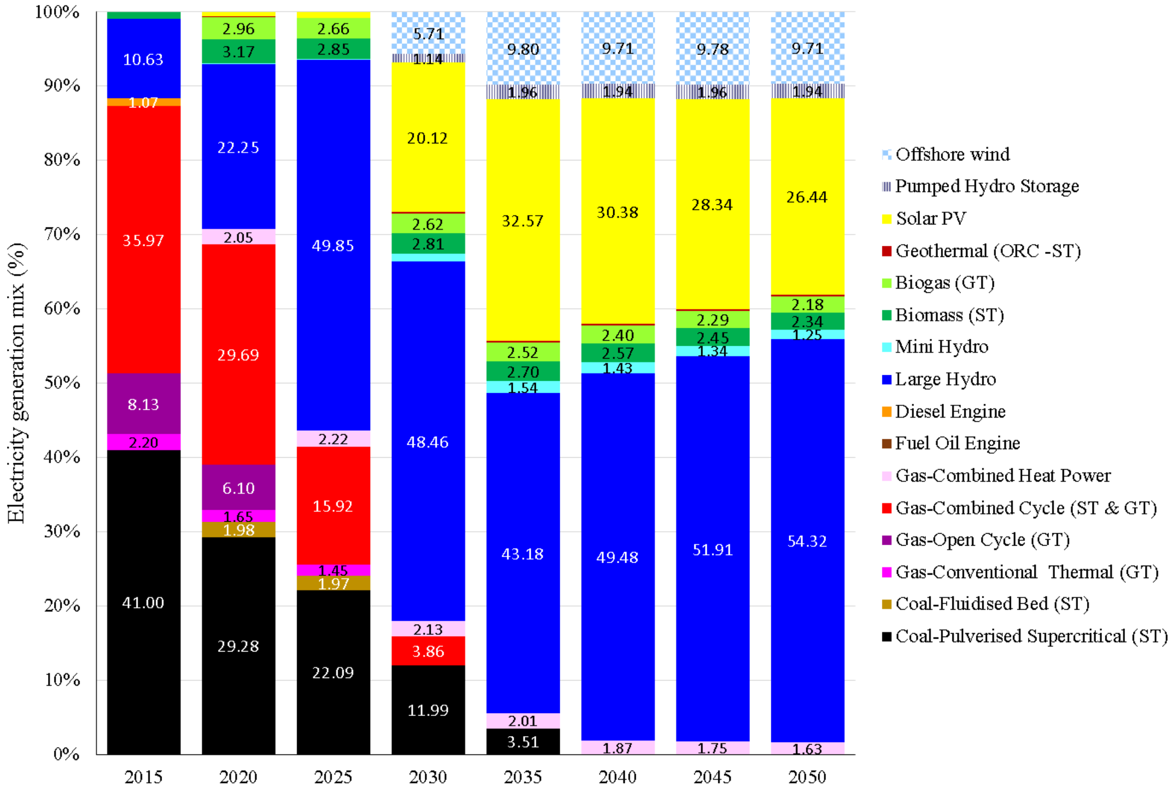


Figure 94. RNW7S7 electricity generation mix by technology

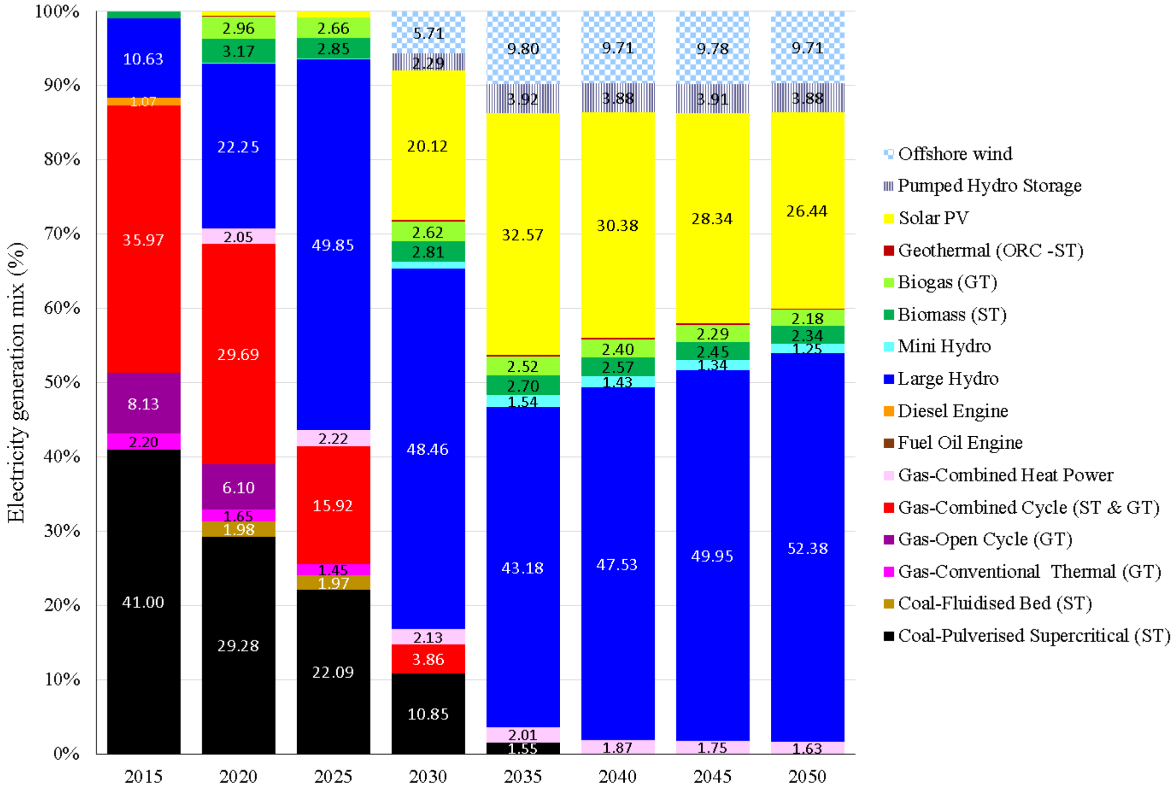


Figure 95. RNW7S14 electricity generation mix by technology

In contrast to the BAU, the generation mix by 2050 for all the renewable scenarios has been significantly transformed whereby fossil-fired plants has been totally rejected by the RES except for combined heat power which is allocated 1.63% as heat generation is still required by certain industries especially in the oil and gas sector, nevertheless the balance of the mix is all renewable-based generation.

7.8.3 Fuel input (PJ)

The energy required by the conversion technologies in the RNW6S7 and the RNW6S14 are represented in Figure 96 and 97. By 2050, solar energy clearly dominated the fuel mix reaching 1,474.39 PJ in both scenarios, this is indeed a big leap in solar energy uptake since the BAU scenario only utilized 37.10 PJ of solar energy. Large hydro energy decreased a little by 3.03% when pumped hydro energy levels are doubled from 25.49 PJ to 50.98 PJ. It is obvious that by 2050, the energy levels for all the renewable technologies showed a considerable increase, mini-hydro increased from 0.94 PJ to 15.45 PJ, geothermal energy also increased from 5.99 PJ to 13.78 PJ, biomass, and biogas rose up to a respective 68.61 PJ and 54.09 PJ. The fuel mix for RNW6S7 and RNW6S14 are envisaged in Figure 98 and 99, an eminent fuel mix transformation occurred in 2050 in both scenarios, whereby 98.77% is fuelled by renewable resources, and only 1.23% is fuelled by natural gas.

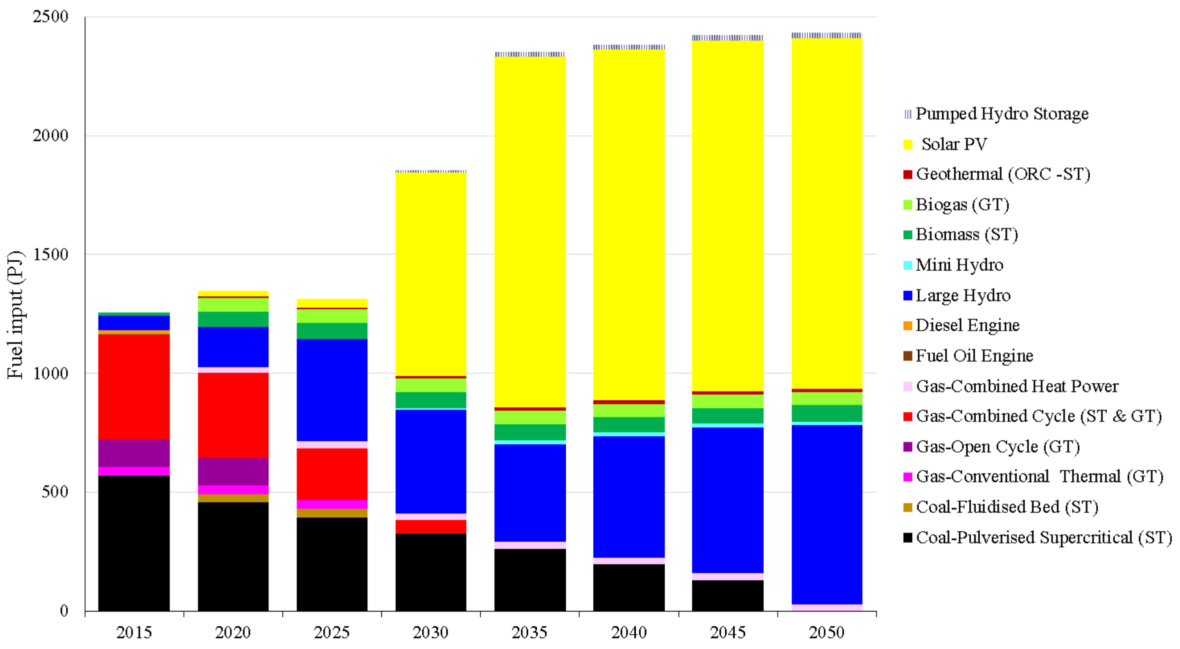


Figure 96. RNW6S7 fuel level by technology

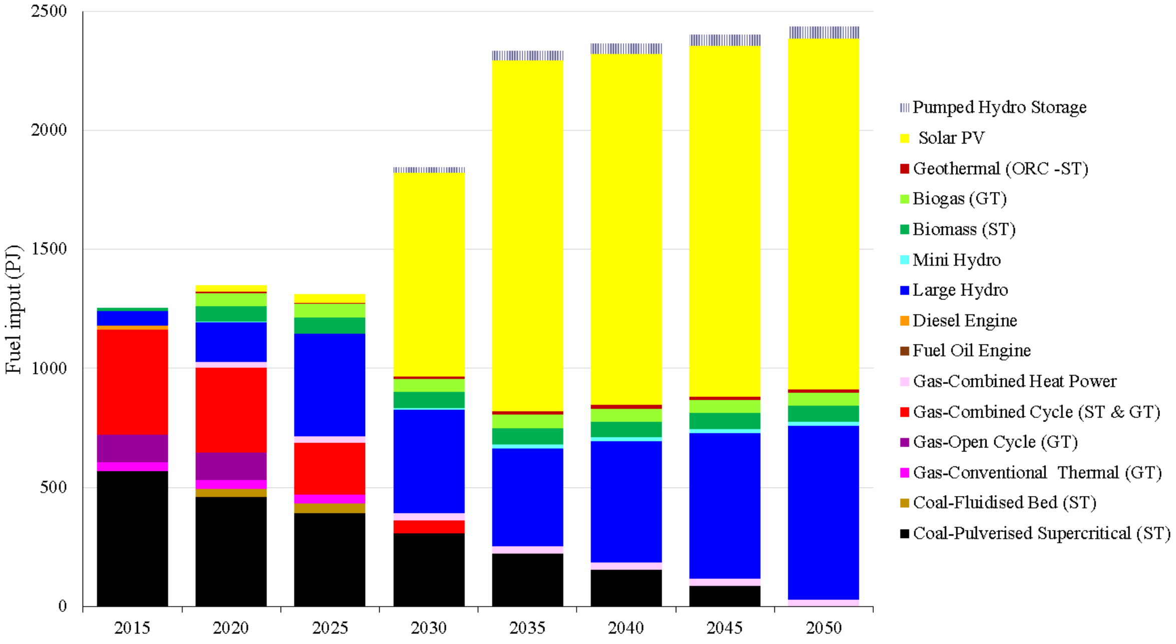


Figure 97. RNW6S14 fuel level by technology

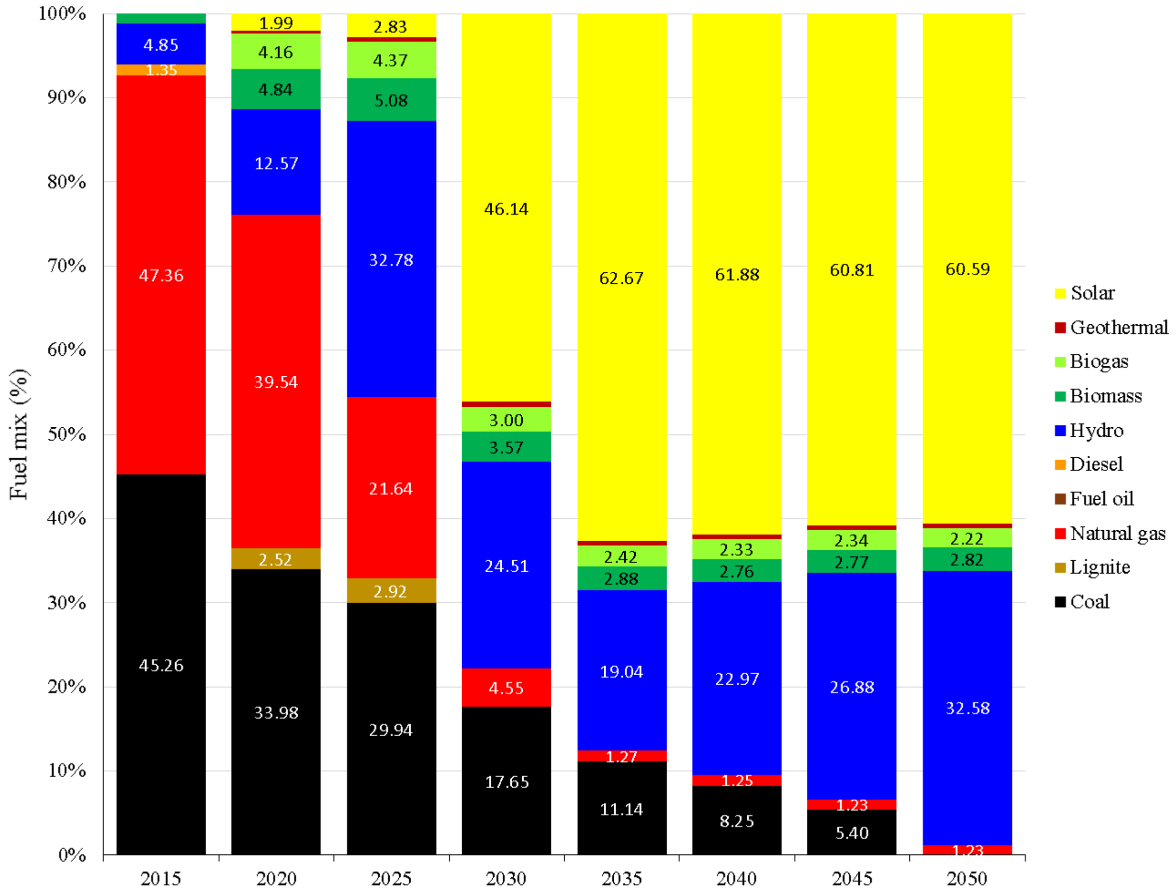


Figure 98. RNW6S7 fuel mix profile

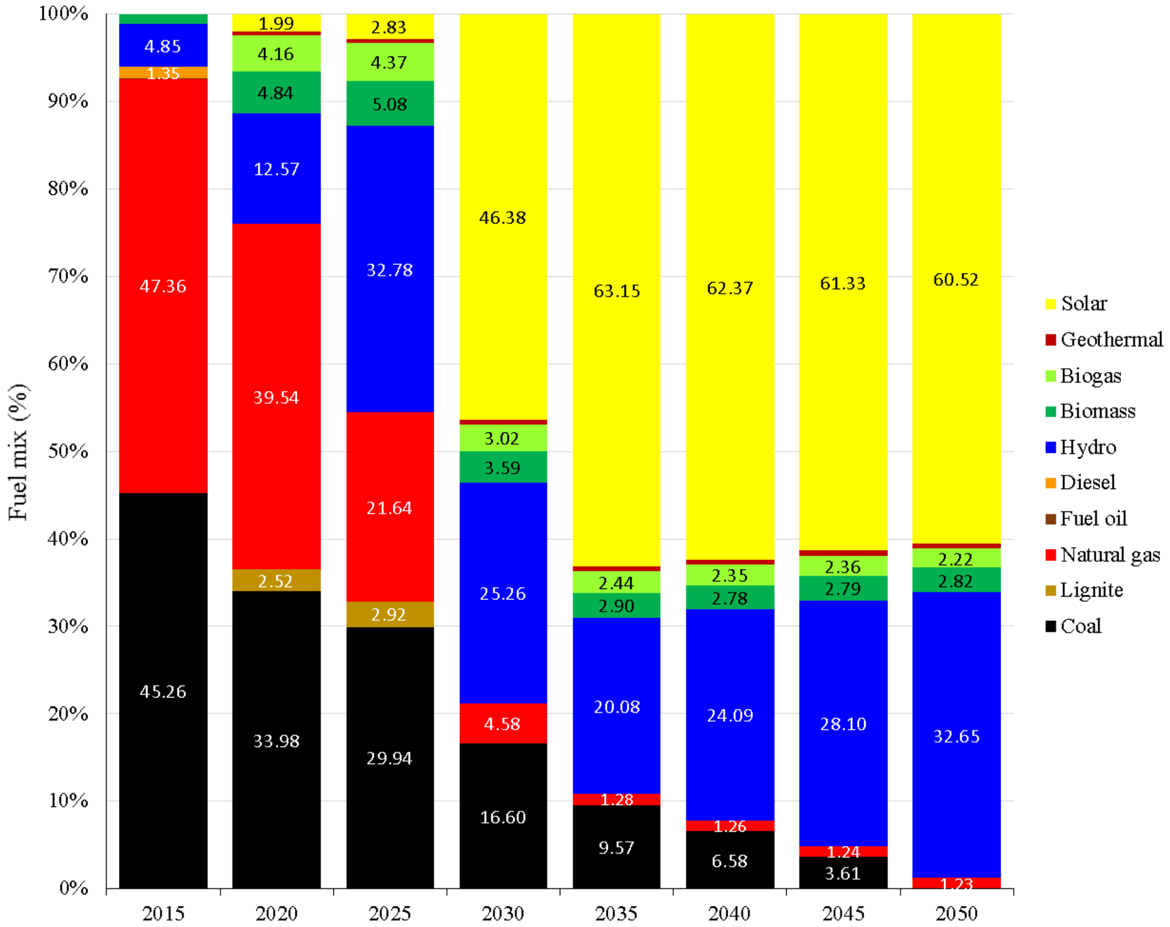


Figure 99. RNW6S14 fuel mix profile

The primary and secondary fuel energy levels inputted into the power plants or conversion technologies for the RNW7S7 and RNW7S14 scenarios are reflected in Figure 100 and 101. The noticeable difference upon addition of offshore wind energy in both cases is that by 2050, hydro energy is further reduced by a range of 15.17% to 18.20% in contrast to the RNW6S7 level. Upon the expansion of the pumped hydro storage system to accommodate 14 days of generation level, has also slightly decreased the large hydro energy levels by 3.58% from 637.78 PJ to 614.97 PJ between the two denoted scenarios. Ultimately the fuel mix profile for these two scenarios as presented in Figure 102 and 103 respectively, indicated that 98.83% will be fuelled by renewable sources of energy, except for the 1.17% of natural gas being maintained for combined heat power.

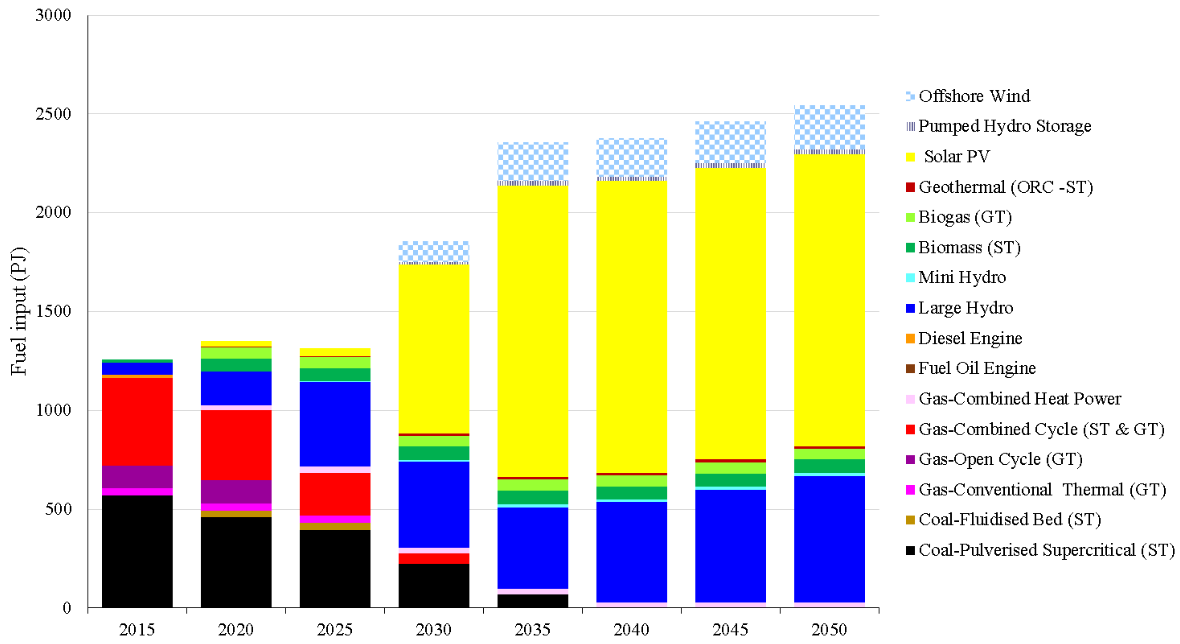


Figure 100. RNW7S7 fuel level by technology

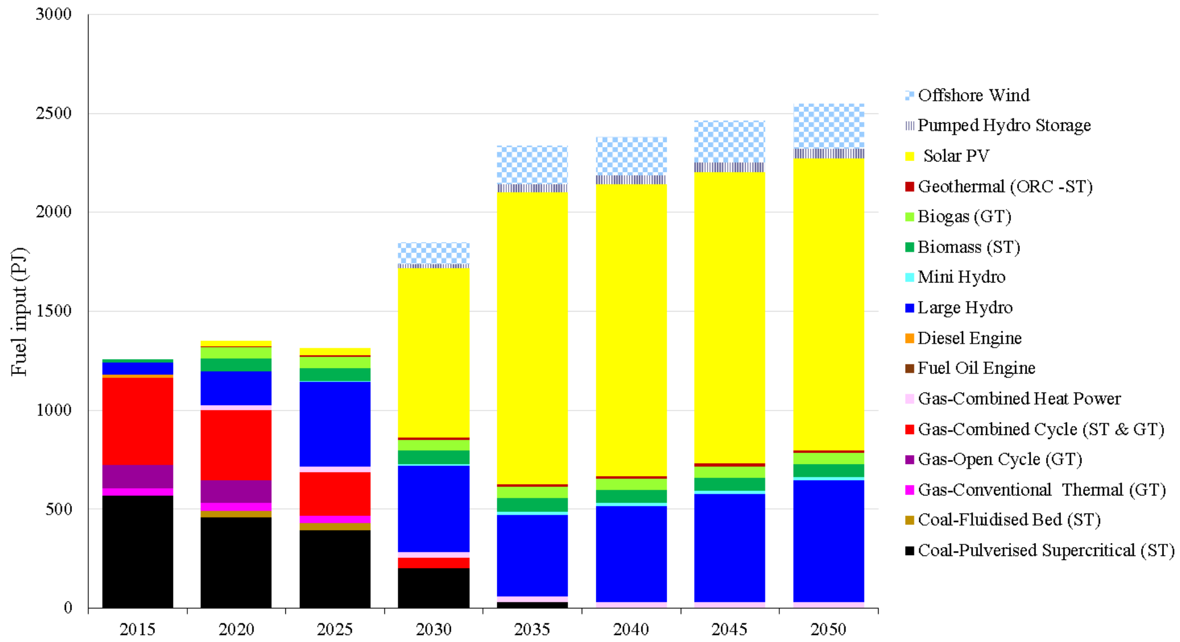


Figure 101. RNW7S14 fuel level by technology

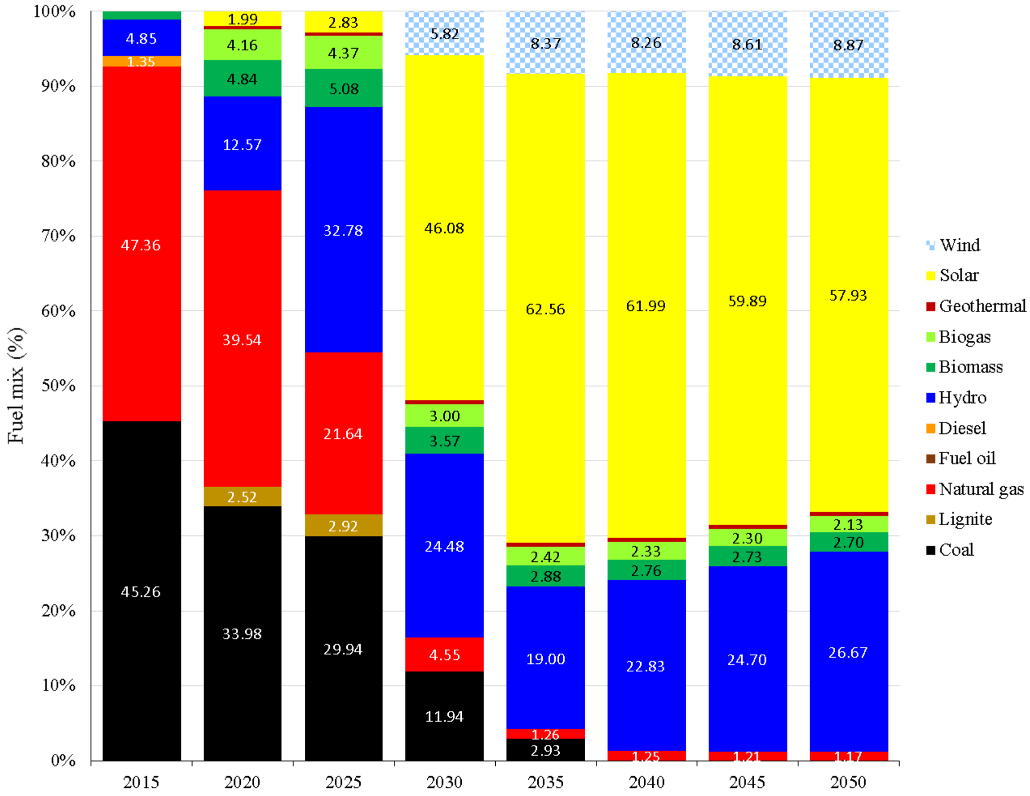


Figure 102. RNW7S7 fuel mix profile

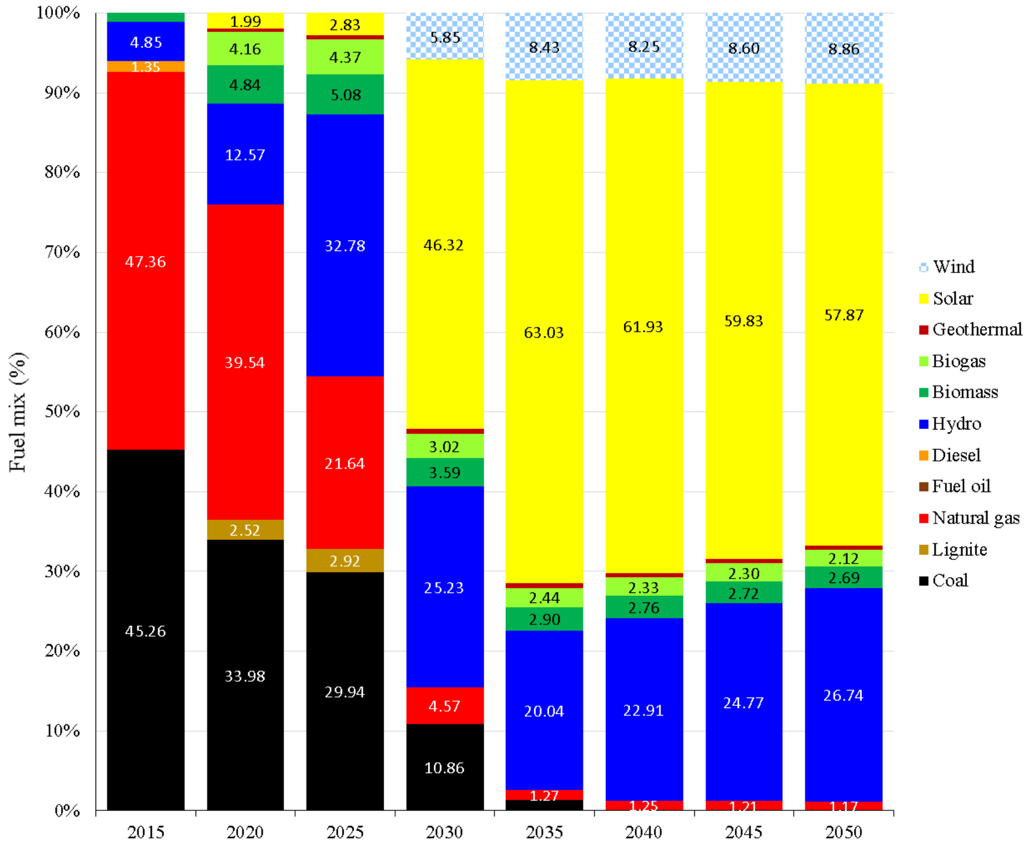


Figure 103. RNW7S14 fuel mix profile

7.8.4 CO_2 emission levels (kt)

The CO_2 emission levels showed a descending development in all the renewable scenarios (refer Figure 104, 105, 106 and 107). Malaysia agreed in the Paris Agreement to mitigate climate change by ensuring 35% to 45% of emission cuts based on the 2005 base year levels, thus in order to achieve the specified targets, the power sector needs to ensure that at least the same fractions of emissions are mitigated from the power sector by 2030.

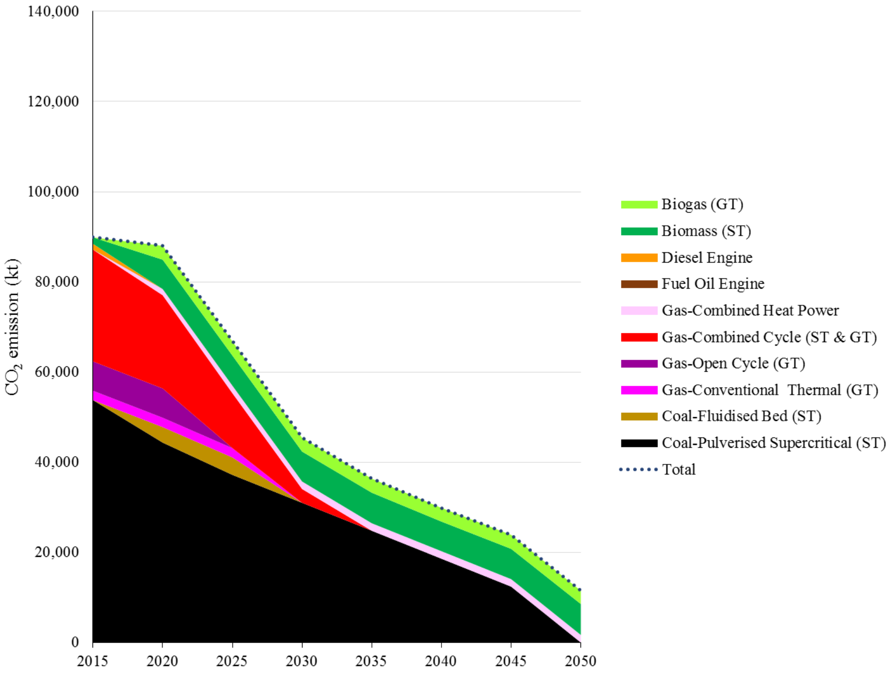


Figure 104. RNW6S7 CO_2 emission level

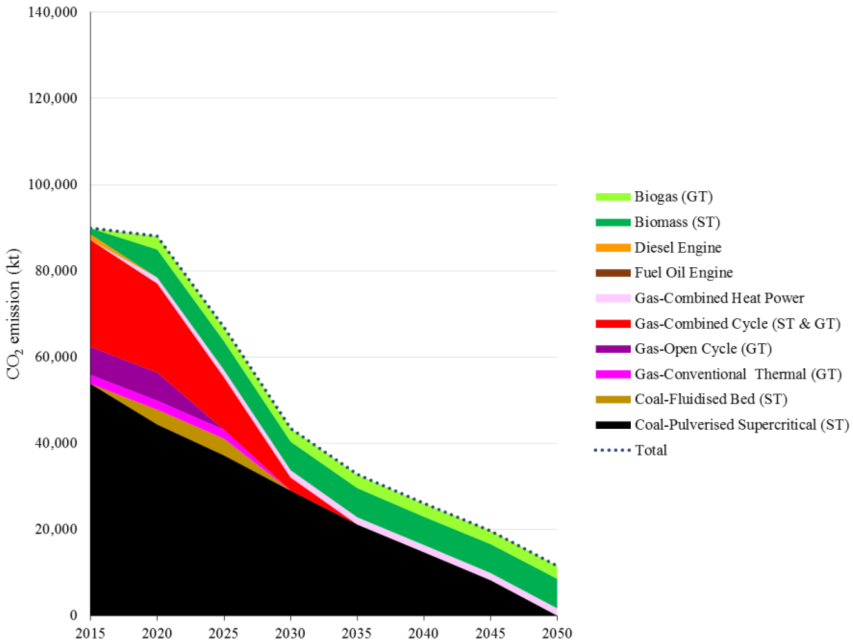


Figure 105. RNW6S14 CO_2 emission level

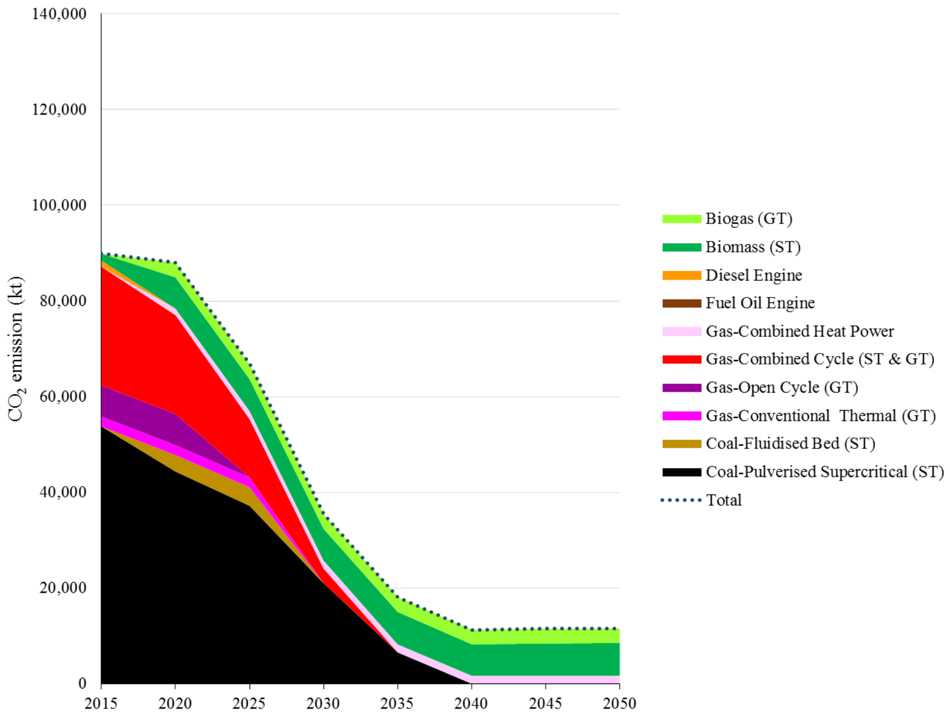


Figure 106. RNW7S7 CO_2 emission level

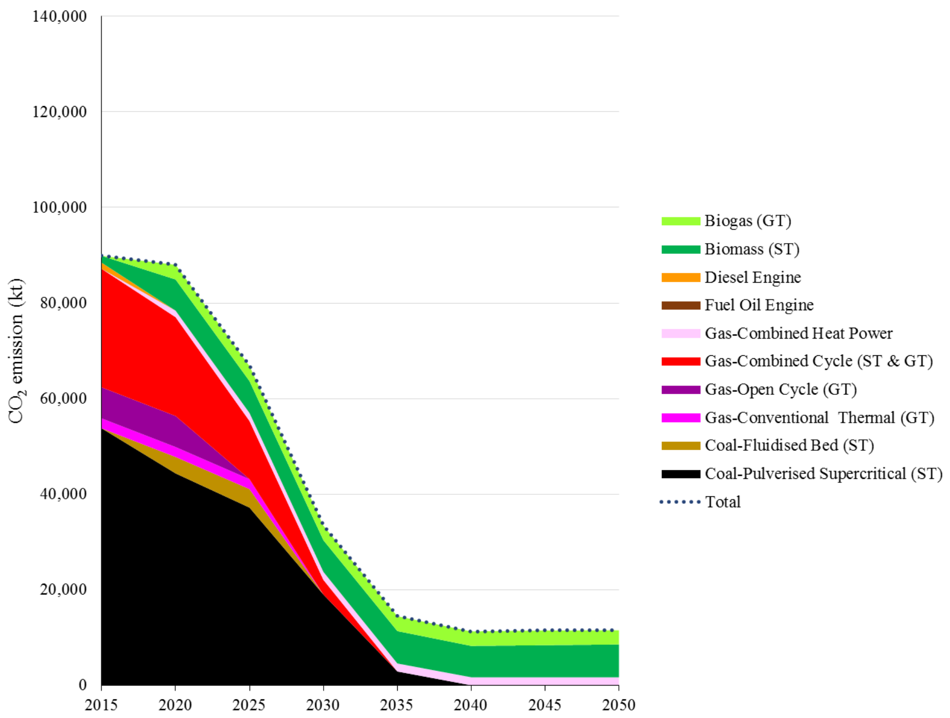


Figure 107. RNW7S14 CO_2 emission level

Since the power sector is accountable for 48.38% (84,415.76 kt) of CO_2 flux out of Malaysia's total CO_2 emission across all sectors in 2005 which equals to 174,486.86 kt [7]. Hence, the estimated 35% to 45% reduction in CO_2 from the power sector by 2030 would equate to 29,545.52 kt to 37,987.09 kt as described accordingly in Figure 108 and 109.

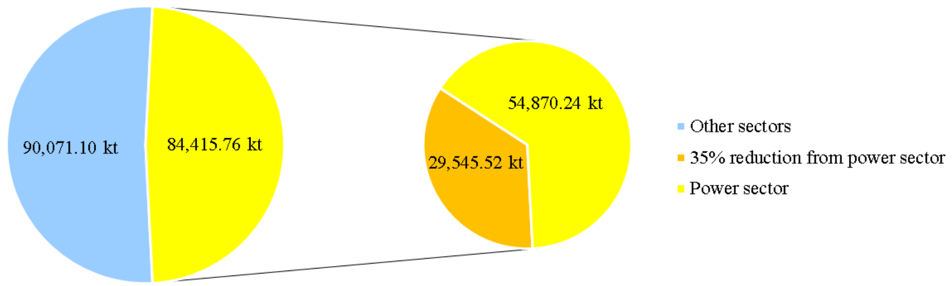


Figure 108. 35% CO_2 emission reduction target relative to 2005 levels

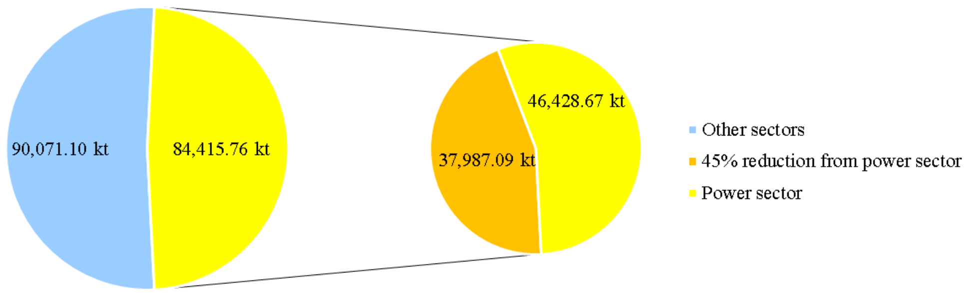


Figure 109. 45% CO_2 emission reduction target relative to 2005 levels

The simulation results confirmed that by 2030, all the renewable scenarios exhibited a decrease in CO_2 emission levels exceeding the 35% to 45% reduction targets as fixed in the Paris Agreement (refer Table 94). The highest decrease by 2030 was witnessed in the RNW7S14 with 60.44% reductions benchmarked against the 2005 power sector emission levels, while the lowest reductions are depicted in the RNW6S7 with a 46.22% decline. Whereas a drop by 48.59% and 58.07% were correspondingly detected in the RNW6S14 and RNW7S7 scenarios.

Table 94. The reduction of CO_2 emission levels in 2030

Scenario	ΔCO_2 (kt)	reduction $\%_{2005}$
RNW6S7	39,020.69	46.22
RNW6S14	41,020.44	48.59
RNW7S7	49,022.37	58.07
RNW7S14	51,021.31	60.44

Another interesting finding is the fact that all the renewable scenarios will eventually transform the power sector into a low carbon intensity RES by 2050. However, it is noted that the rate to achieve this decarbonised state can be expedited to 2040 by leveraging on 7 types of renewable technology in the generation mix as demonstrated by the RNW7S7 and RNW7S14 scenarios.

7.9 System objective cost (billion USD)

Comparison of the system objective cost or the net present value (NPV) for all scenarios at 3% reference discount rate are presented in Figure 110, the model assigned the lowest NPV to the BAU scenario which is valued at USD 88.95 billion. An increment of 3.41% was observed in the NUC2 scenario bringing up the NPV to USD 91.98 billion. While in the NUC4 scenario, the NPV increased to USD 93.23 billion, which is a boost of 4.81% in contrast to the BAU cost. This is due to the savings gained on using cheaper imported uranium fuel that requires refueling every 12 to 18 months [280, 281] as opposed to the steady flow of higher-priced natural gas for firing the combined cycle plants.

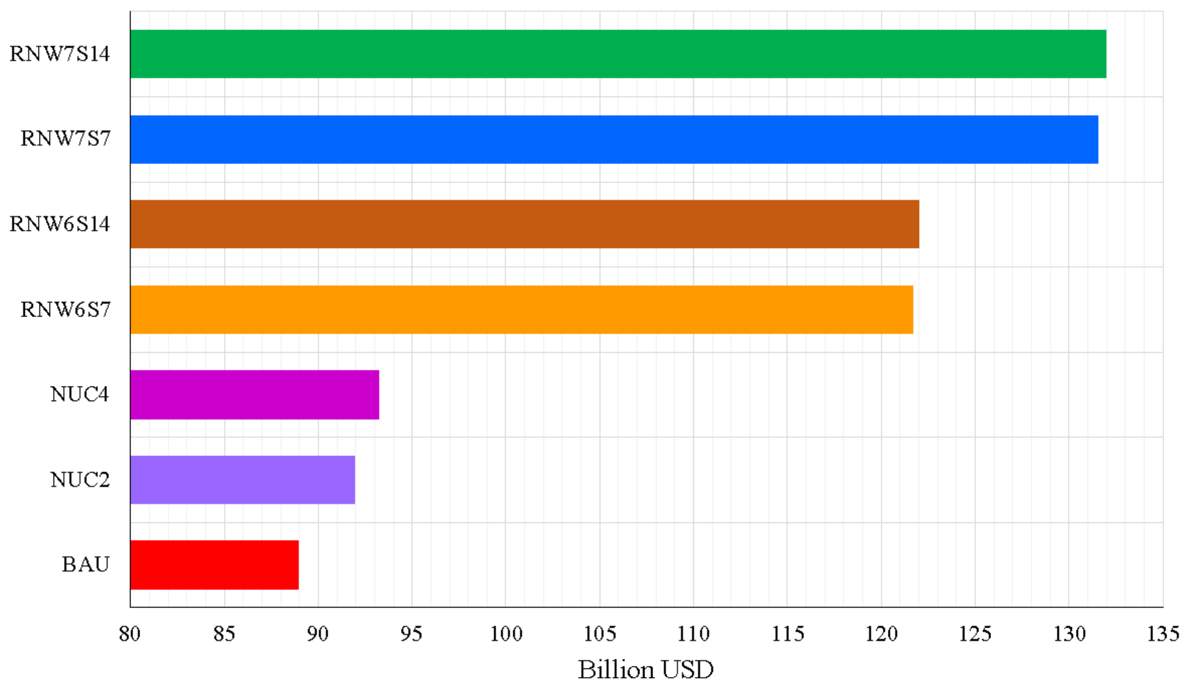


Figure 110. System objective cost at 3% discount rate for all scenarios

An exciting finding is the fact that all the renewable scenarios produced higher NPVs compared to the BAU and nuclear scenarios. The RNW7S14 scenario constituted the highest NPV worth USD 131.97 billion with a notable rise of 48.36%. While the RNW7S7 scenario was accorded with the second highest NPV valued at USD 131.57 billion. The NPV growth for RNW6S14 settled at 37.19% which equals to USD 122.03 billion, while for RNW6S7 the NPV indicated a 36.81% rise which is equivalent to USD 121.69 billion. The higher NPV in the renewable scenarios is mainly due to the savings on cost-free renewable resources such as solar, hydro, wind, geothermal, and biomass from empty fruit bunches. To comprehend the cost dynamics a step further, it is vital to grasp that cost of technology will depreciate over time, however, commodity cost such as fossil fuels or uranium ores will appreciate as resources become sparse or influenced by the conventional supply and demand principle.

7.10 Sensitivity analysis

The effect of the higher and lower discount rates of 7% and 2% on the system objective cost for all the involved scenarios are reflected in Figure 111. The higher discount rate of 7% is the rate usually offered by commercial banks when funding is high in demand and the economy generally is performing well. The lower discount rate of 2% is to simulate a market where the economy is facing a recession and funding provided by financial institutions becomes low in demand.

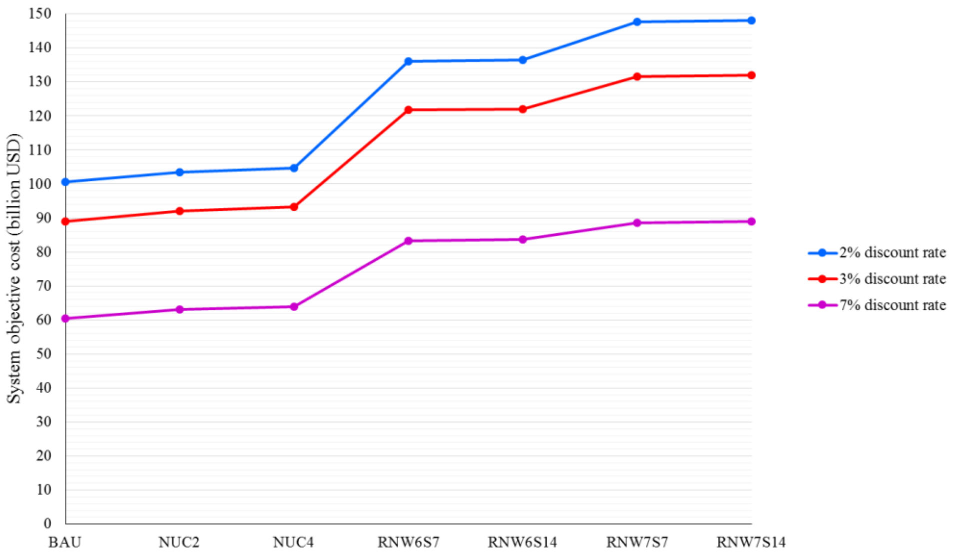


Figure 111. Sensitivity test on the system objective cost

When benchmarked against the system cost at 3% discount rate, it is observed that at the implementation of the lower 2% discount rate, the cost significantly increases by an average of

12.26% across all scenarios. However, upon introduction of a higher 7% discount, the system cost considerably reduced to an average 31.89% across all scenarios. The system objective cost for all the assessed scenarios at different discount rates is recorded in Table 95. It can be drawn that the discount rate has an inversely proportional effect to the system objective cost.

Table 95. The system objective cost at selected discount rates

System cost (billion USD)	2%	3%	7%
BAU	100.54	88.95	60.42
NUC2	103.40	91.98	63.06
NUC4	104.62	93.23	63.95
RNW6S7	136.07	121.69	83.34
RNW6S14	136.39	122.03	83.63
RNW7S7	147.75	131.57	88.59
RNW7S14	148.15	131.97	88.90

The results for the MYTEM scenarios are annexed in **Appendix H**.

7.11 Discussion

The benefit of modeling the long term projection of electricity reference systems through the MYTEM model scenario analysis allows policy makers to visualize the consequences of implementing certain policies ahead of time and therefore would create a more robust strategic planning which could direct the decision-making process related to energy investment in an evidence-based systematic approach.

Through the projected scenarios, the BAU scenario modeled a situation that is currently being practiced by the government and utility companies which incorporates the capacity succession planning up to 2030, thereafter this trend is then extrapolated by the model until 2050. This scenario highlights the government's strategy to gradually switch the fuel mix from natural gas to coal. Nevertheless, the BAU scenario is found to be unsustainable for the long term, as fossil fuel proportions reached a high of 81.67% in the fuel mix by 2050. Furthermore, this scenario would entail continuous import of black coal (bituminous) as domestic coal reserves primarily constitute of brown coal such as lignite or sub-bituminous coal [6]. Moreover by 2050 natural gas would still maintain a share of 11.31%, which would not address the depletion of the domestic natural gas reserves. The carbon emission is escalating upward in the BAU scenario as shown in Figure 112 which does not align with the carbon reduction goals agreed in the Paris Agreement.

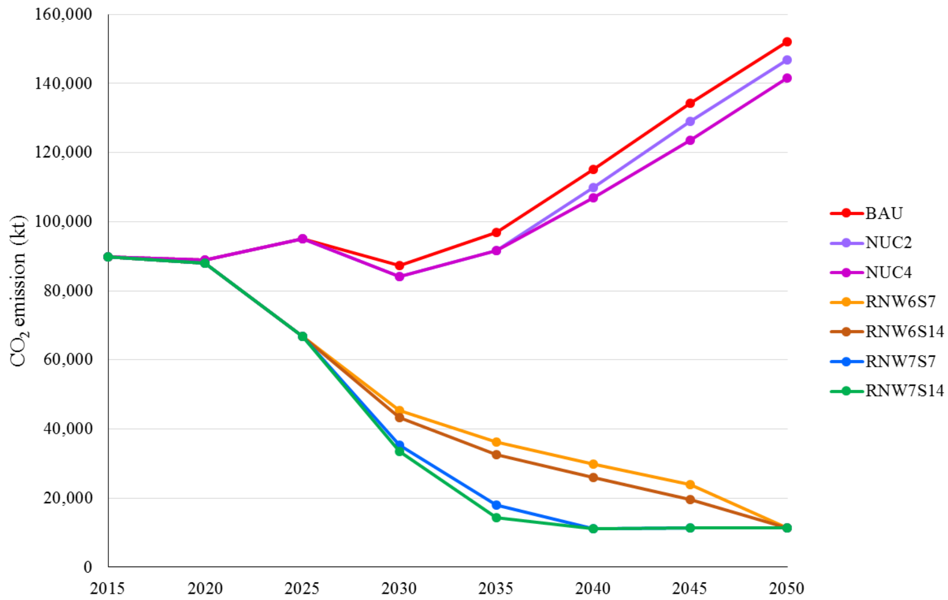


Figure 112. CO_2 emission levels for all scenarios

The Malaysian government had announced plans to source power from nuclear for post-2030 with the initial plan to commission two nuclear power plants with each unit having a capacity of 1,000 MW. This proposal was originally proposed by Nuclear Malaysia Agency in order to remain relevant and expand its current functions. However, the government established a new entity Malaysia Nuclear Power Corporation (MNPC) to realize this plan. MNPC is currently setting up the legal framework for a domestic nuclear power programme. This effort would include tabling a nuclear law in Parliament that would lay the foundation to implement this programme and signing various international treaties related to nuclear technology. Therefore, the NUC2 and NUC4 scenarios were developed to envision the implementation of the nuclear power policy. The results of the NUC2 and NUC4 scenarios were obviously unsustainable since both scenarios indicated a high dependence on fossil fuel up to 75.06% and 68.78% respectively. Despite the fact, that nuclear power yields no carbon emissions and with the reduction in natural gas consumption, managed to reduce the overall CO_2 emission levels in these two scenarios (refer Figure 112). Nonetheless, by taking this pathway, Malaysia's energy security will be negatively compromised since Malaysia will have to rely on consistent imports of uranium fuel that requires replenishing every 12 to 18 months [280, 281]. Moreover, some of the uranium producing countries are politically unstable. This poses a threat to the nation's energy security since the country will be dependent on other countries and not fully in control.

Furthermore, Malaysia is affected by the recurrent floods caused by the seasonal Southwest monsoon and the Northeast monsoon, freak flash floods and also other extreme weather conditions such as the La Nina flooding in 2011 and 2012. It is not rare for the floods to reach over 3m in water heights. None of the states in Malaysia are absolutely secure from flood hazards [282-284], therefore if nuclear power plants are built in Malaysia, then protective measures to secure the power plants from flood threats would be crucial. Besides nuclear power still has a few key drawbacks, amongst it is the rising cost of nuclear fuel [222], management of radioactive toxic waste which can wreak severe health hazard and pollute the environment in the case of a leakage. Above and beyond, Malaysia will be under the constant surveillance by the International Atomic Energy Agency to ensure compliance with the intended use of nuclear technology for power generation [10].

As envisaged by the renewable scenarios, Malaysia could achieve a sustainable, low carbon generation portfolio to meet the electricity demand by 2050. This can be accomplished by progressively substituting fossil fuels with indigenous renewable resources combined with an efficient energy storage system. However, the evaluated renewable scenarios can only be effective if the government would proceed to install the subsea HVDC interconnector by 2030 which will connect both grid networks of the Peninsular and East Malaysia. The government has already planned to construct a 2 GW interconnector system by 2025[152], however, for the renewable scenarios to be meaningful, the interconnector capacity needs to achieve a capacity of at least 10 GW by 2030 and further augmented up to 2050. This HVDC interconnectors will cover approximately a 640 km stretch (refer Figure 113), the estimated installation cost for a submarine HVDC cable is valued at USD 2.9 million per km [104]. Hence, to install a 2 GW HVDC interconnector for the aforementioned distance would come to USD 3.71 billion as two cables need to be laid in a bipolar circuit. In the case of a 10 GW HVDC interconnector, installation cost would rise to USD 18.55 billion.

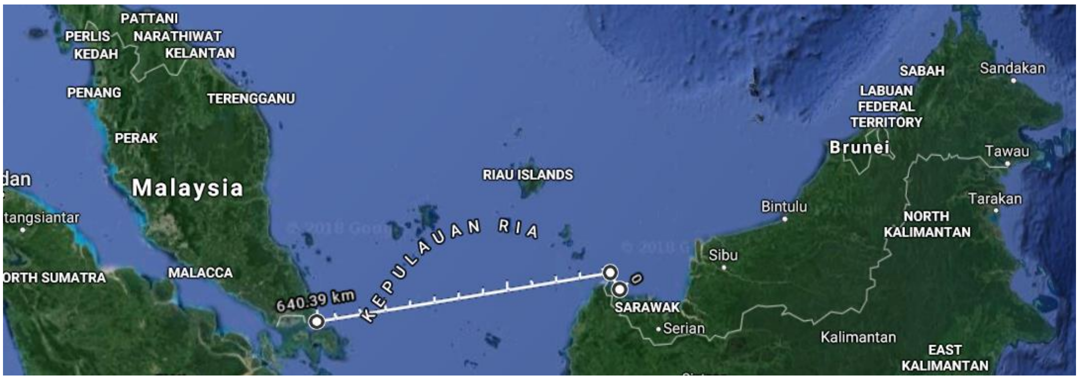


Figure 113. The HVDC interconnector length estimation

All the renewable scenarios produced a low carbon generation profile (refer Figure 112), whereby the emission curve will eventually plateau at 11,490 kt due to the combustion of biomass, biogas, and natural gas. There has been some research that explored the possibility of natural gas to be substituted by biogas to fire cogeneration plants [285-287], however, up to now, this notion is still undergoing vigorous research. On the other hand, the use of alternative cogeneration technologies such as solar photovoltaic-thermal (PVT) technology can be considered too, nevertheless, PVT fittings will require adequate installation area and may require heat pumps to raise the temperature to the specified level required by the industry.

In the RNW7S7 and RNW7S14 scenarios, if offshore wind energy were to be integrated into the generation mix, it is still necessary to undertake an onsite wind speed assessment for one full year at the identified site before the offshore wind farm can be constructed. It is advocated to opt for the renewable pathway as it aligns with the 7th sustainable development goal set by the United Nations that aims for affordable, reliable, sustainable and clean energy. Other than that, the renewable scenarios also surpassed the carbon mitigation targets as agreed in the Paris Agreement. In addition, the NPV for all the renewable scenarios is much higher than the nuclear and BAU scenarios. Thus, based on an investment point of view, the renewable scenarios are more economically feasible for implementation.

To conclude, the MYTEM model managed to provide alternative options for Malaysia's future power generation, whereby Malaysia no longer needs to embrace nuclear technology, as the base load can be sourced from hydropower while peak load can be generated from solar PV. While the intermittent energy issue arising from renewable resources can be stabilized with the pumped hydro storage system in which the model was more in favor of the higher storage capacity levels.

7.12 Limitations

TIMES model has following limitations:

i) The TIMES model will always opt for the least cost arrangement in terms of fuel and technology cost as it is a cost minimization optimization tool; and,

ii) TIMES is not able to give a geographical indication of where the power plants need to be commissioned or installed but instead it can provide solutions to when the power plant needs to be commissioned and how much new capacities needs to be added in order to meet the exogenous demand.

7.13 Chapter summary

The key findings from this assessment are summarized as below:

- Just by committing 0.15% out of Malaysia's total land area for installation of solar PV panels on existing rooftops would produce 26.44% of the total electricity generation mix by 2050. Thus, Malaysia indeed has an abundance of solar PV potential that can be exploited;
- With 9.71% offshore wind penetration in the generation mix by 2050, this consumed 8.35% (4.58 GW) of the total offshore wind power upper boundary, leaving behind 91.65% (50.29 GW) of unexploited offshore wind power potential for future development;
- By 2050, hydropower in the renewable scenarios attained following utilization rate: RNW6S7 (100.00%), RNW6S14 (96.98%), RNW7S7 (84.82%) and RNW7S14 (81.80%). Hence, hydropower potential is left with a balance of 4.34 GW for future development, this figure may increase as and when new potential sites for hydropower development are discovered in future;
- The pumped hydro storage system is a mature technology that is widely applied in other countries when substantial renewable energy is linked to the grid, the model advocated the renewable scenarios with 14 days storage capacity over the 7 days storage, as the NPV is higher for the models with larger storage capacities;
- Out of all the MYTEM models, the RNW7S14 scenario would be the most feasible model from the investment perspective as well as the most effective model for CO_2 abatement followed by RNW7S7, RNW6S14, and RNW6S7 scenarios.

Chapter 8. Conclusion

8.1 Introduction

This thesis has presented a detailed investigation into finding a solution for Malaysia’s future power generation mix using sustainable and renewable energy resources in the country from 2015 up to 2050 through a modelling approach known as the Malaysia TIMES Electric Model (MYTEM). MYTEM presented a comprehensive foresight analysis for power generation options in Malaysia by contrasting the business as usual against other optimized scenarios through a selection of different fuels and advanced technologies to meet the electricity demand by 2050.

This study focused on four objectives which are:

i. To estimate Malaysia’s future electricity demand requirement until 2050;
ii. To assess the renewable energy potential available in Malaysia;
iii. To develop the Reference Electricity System (RES) for Malaysia; and,
iv. To analyze all the MYTEM scenarios according to the 4E (Engineering, Energy, Environment, and Economics) perspective, whereby capacity levels, fuel inputs and electricity outputs will be evaluated, CO_2 emission profile and total system cost will be contrasted.

Through the execution of this study, the outcome of the above objectives were able to be delivered. The key findings of this study will be recapped and summarised in Section 8.2, whereas the novelty and generic contribution of this study will be described in Section 8.3 and the recommendations for future work will be presented in Section 8.4.

8.2 Key findings of the study

Chapter 2 presents a comprehensive background study, reviewing energy models which were then narrowed down to long term power sector analysis, energy-related demand projections, and renewable energy assessment reported by prior scholars. Based on this background scholarship, the methodological research framework for developing MYTEM was established (refer Figure 17). The approach in distinguishing the optimal electricity demand projection by 2050 and the development of MYTEM was detailed in Chapter 3. Whereas Chapter 4 specified the methods involved in the renewable energy potential assessment on various indigenous resources and the economic appraisal on chosen conversion technologies.

Subsequently, Chapter 5 presented an analysis of all the electricity demand projections up to 2050 derived from the simple growth model, the regression (single and multiple) models as well as the more sophisticated ARIMA model. The forecast results were validated by delivering an in-sample forecast with a 5 year holdback period from 2011 until 2015. Guided by the MAPE value, it was discovered that the ARIMA (3,3) model was the best model in terms of forecast accuracy during the holdback period, followed by ARIMA (3,2) and the simple growth model. However, in scenario modelling, it is emphasized that the projection must mirror the real world situation as close as possible in order to create more realistic simulations. For this reason, the projection resulting from the simple growth model was deployed in the development of MYTEM as it aligns closely with the world and regional electricity demand outlooks, the MAPE falls within ± 4.68% which serves as the upper and lower demand forecast margin.

In Chapter 6, the renewable energy potential of various resources available in Malaysia were assessed which includes onshore and offshore wind, solar, tidal, biomass and biogas, wave, hydro and geothermal. Despite the fact that this study recognised that there is no potential for developing utility-scale onshore wind farms, tidal stream and wave energy in Malaysia. Nevertheless, this assessment still managed to unleash some significant findings that are favourable to Malaysia. One of the interesting discoveries is that offshore wind energy can be harnessed at the territorial waters of South China Sea by commissioning class II wind turbines as wind speeds are gushing between 7.5 to 8.5 ms^{-1}. Another notable discovery was the vast potential possessed by solar energy in yielding electricity as the annual mean solar radiation in Malaysia stands at 1,795.27 $kWhm^{-2}$. This study confirmed that just by occupying 0.15% of Malaysia's total land area with PV arrays on existing rooftops, would lead to 36,602 MW of cumulated solar power that is able to output 80,159 GWh electricity per annum which fulfils 32.34% of the electricity demand by 2050. Electrical power from EFB and biogas from POME will eventually touch a ceiling of 1,181 MW and 1,103 MW respectively due to land constraint on the expansion of palm oil crop. Based on secondary data, the total hydropower upper boundary was determined at 24,334 MW, while the geothermal potential is 69 MW.

The MYTEM scenarios were presented in Chapter 7 which represents a comprehensive foresight investigation into the possible pathways for Malaysia's future power generation covering a horizon from 2015 up to 2050. All the MYTEM scenarios were scrutinised and contrasted to the BAU scenario. The results revealed that the BAU, NUC2 and NUC4 scenarios are unsustainable in the long term, as the dependency on fossil fuel is still at the high end of 81.67%, 75.06% and 68.78% respectively. On the other hand, all the renewable plus storage scenarios which include RNW6S7, RNW6S14, RNW7S7 and RNW7S14 indicated that Malaysia could achieve a sustainable and low carbon generation profile to accommodate the electricity demand by 2050. This can be accomplished by progressively substituting fossil fuels with indigenous renewable resources combined with an efficient pumped hydro storage system. Albeit this positive outcome, the evaluated renewable scenarios can only be fully functional if the subsea High Voltage Direct Current (HVDC) interconnector is integrated into the RES by 2030. This HVDC subsea cable will connect both grid networks of the Peninsular and East Malaysia and transmit the hydropower from Sarawak to the Peninsular.

Finally, it can be concluded that this study managed to find several pathways for decarbonizing the electrical power generation in Malaysia and delivered few solutions on transforming the generation portfolio into a sustainable state by optimising the penetration of renewable electricity in the generation mix by 2050.

8.3 Novelty and contribution of the study

In general, this study contributed to knowledge by providing a novel methodological research framework in modelling the long term reference energy system specifically for electrical power in the perspective of energy resource optimisation to decarbonised the power sector and simultaneously enhance the energy security and sustainability level of a country as represented in Figure 17. This unique framework has been consolidated based on the 4E (Engineering, Energy, Environment and Economics) approach. This techno-economic framework can be applied to other countries to carry out similar long term energy resource optimisation studies specific for modelling the electrical power sector. A distinctive feature of this framework is that it is flexible to accommodate different energy policies based on the case study country's interest and concerns, some of the policies include fuel diversification policies from fossil to renewables or alternative energy, and the introduction of certain smart targets such as CO_2 reduction targets, renewable electricity smart targets, implementation of electric vehicles as well as carbon tax.

8.4 Recommendations for future work

In paving the way forward further works as detailed below should be studied in more detail:

(a) The simulations developed in this study were limited to certain fuel resources, it is desirable to expand and include other resources such as Municipal Solid Waste and also the capture of landfill biogas (methane) for electrical power generation.

(b) The measured GHG gas in this study was limited to CO_2, however, the 2006 IPCC guidelines also emphasized the need to monitor the methane (CH_4) and nitrous oxide (N_2O) emissions due to their harmful global warming potential (GWP) properties exhibited. The 2006 IPCC Guidelines included an amendment so that Nitrogen Oxide (NO_x) emissions are assumed to be emitted on a full molecular structure as N_2O. IPCC highlighted that CH_4 is found to be 28 times more lethal in terms of its GWP over a 100 years period as compared to the effects of CO_2. The intriguing fact about CH_4 is that over a shorter span of 20 years period, the GWP is amplified by 84 times, this is due to the ability of methane to stay in the atmosphere for 12.4 years. While N_2O is 265 times more efficient in triggering global warming over a century rather than CO_2, and 264 times more lethal in 20 years span. However, when analysing climate change issues, it is imperative to treat both the GWP20 and GWP100 as equally relevant [230].

(c) The MYTEM model can be stretched to include interconnectors with neighbouring countries such as Indonesia (Kalimantan), Singapore, and Thailand to simulate the inter-regional electricity trade.

This study is expected to benefit the Malaysian government, utility companies and relevant research institutions as an input for intermediate to long term power capacity succession planning in embracing a cleaner and sustainable electrical power fraternity.

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Appendix A

List of commodities in MYTEM

Set Membership	Commodity Name	Description	Unit
DEM	AGRELCD	Agriculture Electricity Demand	PJ
DEM	COMELCD	Commercial Electricity Demand	PJ
DEM	INDELCD	Industrial Electricity Demand	PJ
DEM	RSDELCD	Residential Electricity Demand	PJ
DEM	TFCELCD	Total Final Consumption Electricity Demand	PJ
DEM	TRAELCD	Transport Electricity Demand	PJ
ENV	ELCCO2	Carbon dioxide from Electricity Plants	kt
NRG	BIG	Biogas	PJ
NRG	BIO	Biomass	PJ
NRG	COA	Solid Fuels	PJ
NRG	DSL	Diesel	PJ
NRG	ELC	Electricity	PJ
NRG	ELCAGR	Electricity Agriculture	PJ
NRG	ELCBIG	Electricity Plants Biogas	PJ
NRG	ELCBIO	Electricity Plants Biomass	PJ
NRG	ELCCOA	Electricity Plants Solid Fuels	PJ
NRG	ELCCOM	Electricity Commercial	PJ
NRG	ELCDSL	Electricity Plants Diesel	PJ
NRG	ELCGAS	Electricity Plants Natural Gas	PJ
NRG	ELCGEO	Electricity Plants Geothermal	PJ
NRG	ELCHFO	Electricity Plants Fuel Oil	PJ
NRG	ELCHYD	Electricity Plants Hydro	PJ
NRG	ELCNUC	Electricity Plants Nuclear	PJ
NRG	ELCIND	Electricity Industry	PJ
NRG	ELCPHS	Electricity Pumped Hydro Storage	PJ
NRG	ELCRSD	Electricity Residential	PJ
NRG	ELCSOL	Electricity Plants Solar	PJ
NRG	ELCTRA	Electricity Transport	PJ
NRG	ELCWND	Electricity Plants Wind	PJ
NRG	GAS	Natural Gas	PJ
NRG	GEO	Geothermal	PJ
NRG	HFO	Fuel Oil	PJ
NRG	HYD	Hydro	PJ
NRG	SOL	Solar	PJ
NRG	WND	Wind	PJ
NRG	NUC	Nuclear	PJ

Appendix B

List of technologies in MYTEM

Set Membership	Technology Name	Description	Activity Unit	Capacity Unit
DMD	AGRELCDT	Agriculture Electricity Demand Technology	PJ	PJa
DMD	COMELCDT	Commercial Electricity Demand Technology	PJ	PJa
DMD	INDELCDT	Industrial Electricity Demand Technology	PJ	PJa
DMD	RSDELCDT	Residential Electricity Demand Technology	PJ	PJa
DMD	TFCELCDT	Total Final Consumption Electricity Demand Technology	PJ	PJa
DMD	TRAELCDT	Transport Electricity Demand Technology	PJ	PJa
ELE	ELCREBIG00	Power Plants Existing00 - Biogas	PJ	GW
ELE	ELCREBIO00	Power Plants Existing00 - Biomass	PJ	GW
ELE	ELCREHYD_LRG00	Power Plants Existing00 - Large Hydro	PJ	GW
ELE	ELCREHYD_MIN00	Power Plants Existing00 - Mini Hydro	PJ	GW
ELE	ELCRESOL00	Power Plants Existing00 - Solar	PJ	GW
ELE	ELCNNNUC00	Power Plants New00 - Nuclear	PJ	GW
ELE	ELCRNBIG00	Power Plants New00 - Biogas	PJ	GW
ELE	ELCRNBIO00	Power Plants New00 - Biomass	PJ	GW
ELE	ELCRNGEO00	Power Plants New00 - Geothermal	PJ	GW
ELE	ELCRNHYD_LRG00	Power Plants New00 - Large Hydro	PJ	GW
ELE	ELCRNHYD_MIN00	Power Plants New00 - Mini Hydro	PJ	GW
ELE	ELCRNPHS00	Power Plants New00 - Pumped Hydro Storage	PJ	GW
ELE	ELCRNSOL00	Power Plants New00 - Solar	PJ	GW
ELE	ELCRNWND00	Power Plants New00 - Offshore Wind	PJ	GW
ELE	ELCTECOA_PCS00	Power Plants Existing00 - Pulverised Coal Supercritical	PJ	GW
ELE	ELCTEDSL00	Power Plants Existing00 - Diesel Generators	PJ	GW
ELE	ELCTEGAS_CCGT00	Power Plants Existing00 - Natural Gas Combined Cycle	PJ	GW
ELE	ELCTEGAS_OCGT00	Power Plants Existing00 - Natural Gas Open Cycle	PJ	GW
ELE	ELCTEGAS00	Power Plants Existing00 - Conventional gas	PJ	GW
ELE	ELCTEHFO00	Power Plants Existing00 - Conventional oil (hfo/mfo)	PJ	GW
ELE	ELCTNCOA_PCS00	Power Plants New00 - Pulverised Coal Supercritical	PJ	GW
ELE	ELCTNCOA_SFB00	Power Plants New00 - Supercritical Fluidized Bed	PJ	GW
ELE	ELCTNDSL00	Power Plants New00 - Diesel Generators	PJ	GW
ELE	ELCTNGAS_CCGT00	Power Plants New00 - Natural Gas Combined Cycle	PJ	GW
ELE	ELCTNGAS_CHP00	Power Plants New00 - Natural Gas Combined Heat Power	PJ	GW
IRE	EXPCOA1	Export of Solid Fuels Step 1	PJ	PJa
IRE	EXPDSL1	Export of Diesel Step 1	PJ	PJa
IRE	EXPGAS1	Export of Natural Gas Step 1	PJ	PJa

Set Membership	Technology Name	Description	Activity Unit	Capacity Unit
IRE	EXPHFO1	Export of Fuel Oil Step 1	PJ	PJa
IRE	IMPCOA1	Import of Solid Fuels Step 1	PJ	PJa
IRE	IMPDSL1	Import of Diesel Step 1	PJ	PJa
IRE	IMPGAS1	Import of Natural Gas Step 1	PJ	PJa
IRE	IMPHFO1	Import of Fuel Oil Step 1	PJ	PJa
IRE	IMPNUC1	Import of Nuclear Step 1	PJ	PJa
IRE	MINBIG1	Domestic Supply of Biogas Step 1	PJ	PJa
IRE	MINBIO1	Domestic Supply of Biomass Step 1	PJ	PJa
IRE	MINCOA1	Domestic Supply of Solid Fuels Step 1	PJ	PJa
IRE	MINDSL1	Domestic Supply of Diesel Step 1	PJ	PJa
IRE	MINGAS1	Domestic Supply of Natural Gas Step 1	PJ	PJa
IRE	MINGEO1	Domestic Supply of Geothermal Step 1	PJ	PJa
IRE	MINHFO1	Domestic Supply of Fuel Oil Step 1	PJ	PJa
IRE	MINHYD1	Domestic Supply of Hydro Step 1	PJ	PJa
IRE	MINSOL1	Domestic Supply of Solar Step 1	PJ	PJa
IRE	MINWND1	Domestic Supply of Wind Step 1	PJ	PJa
PRE	FTE-ELCBIO	Existing Electricity Plants Biomass Technology	PJ	PJa
PRE	FTE-ELCCOA	Existing Electricity Plants Solid Fuels Technology	PJ	PJa
PRE	FTE-ELCDSL	Existing Electricity Plants Diesel Technology	PJ	PJa
PRE	FTE-ELCGAS	Existing Electricity Plants Natural Gas Technology	PJ	PJa
PRE	FTE-ELCHFO	Existing Electricity Plants Fuel Oil Technology	PJ	PJa
PRE	FTE-ELCHYD	Existing Electricity Plants Hydro Technology	PJ	PJa
PRE	FTN-ELCBIG	New Electricity Plants Biogas Technology	PJ	PJa
PRE	FTN-ELCBIO	New Electricity Plants Biomass Technology	PJ	PJa
PRE	FTN-ELCCOA	New Electricity Plants Solid Fuels Technology	PJ	PJa
PRE	FTN-ELCGAS	New Electricity Plants Natural Gas Technology	PJ	PJa
PRE	FTN-ELCGEO	New Electricity Plants Geothermal Technology	PJ	PJa
PRE	FTN-ELCHFO	New Electricity Plants Fuel Oil Technology	PJ	PJa
PRE	FTN-ELCHYD	New Electricity Plants Hydro Technology	PJ	PJa
PRE	FTN-ELCNUC	New Electricity Plants Nuclear Technology	PJ	PJa
PRE	FTN-ELCPHS	New Electricity Pumped Hydro Storage Technology	PJ	PJa
PRE	FTN-ELCSOL	New Electricity Plants Solar Technology	PJ	PJa
PRE	FTN-ELCWND	New Electricity Plants Wind Technology	PJ	PJa

Appendix C

List of capacity addition for Peninsular Malaysia

Region	Technology	Fuel type	Year	Addition (MW)	Project
Peninsular	Combined Cycle Gas Turbine	gas	2016	1,071.43	TNB Prai
	Combined Cycle Gas Turbine	gas	2016	375	CBPS Redevelopment
	Large hydro	hydro	2016	15	Hulu Terengganu (Tembat)
	Coal (pulverised ultra-supercritical)	coal	2016	1,000	Tanjung Bin Energy
	Large hydro	hydro	2016	372	Ulu Jelai
	Solar photovoltaic	solar	2017	200	Solar farm
	Combined Heat Power	gas	2017	400	Pengerang Cogeneration
	Coal (pulverised ultra-supercritical)	coal	2017	1,000	Manjung Five
	Solar photovoltaic	solar	2018	200	Solar farm
	Combined Heat Power	gas	2019	200	Pengerang Cogeneration (additional)
	Combined Cycle Gas Turbine	gas	2019	1,400	SIPP Pasir Gudang (Track 4A)
	Coal (pulverised ultra-supercritical)	coal	2019	2,000	Jimah East Power (Track 3B)
	Solar photovoltaic	solar	2019	200	Solar farm
	Solar photovoltaic	solar	2020	200	Solar farm
	Combined Cycle Gas Turbine	gas	2021	2,400	Edra Global Energy
	Large hydro	hydro	2021	168	Tekai
	Coal (pulverised ultra-supercritical)	coal	2023	1,000	New project
	Large hydro	hydro	2024	300	Nenggiri
	Large hydro	hydro	2024	190	Telom
	Large hydro	hydro	2024	137	Lebir U1
	Large hydro	hydro	2025	137	Lebir U2
	High Voltage Direct Current Interconnector	-	2025	2,000	Sarawak import

Appendix D

List of capacity addition for Sabah

Region	Technology	Fuel type	Year	Addition (MW)	Project
Sabah	Biogas plant	biogas	2016	3	TSH Biogas
	Biogas plant	biogas	2016	2	QL
	Biogas plant	biogas	2016	3.8	Mistral Engineering
	Biogas plant	biogas	2016	3.8	Cahaya Bumijasa
	Biogas plant	biogas	2016	2	Our Energy Group
	Biomass Steam Turbine	biomass	2016	10	IOI Bio Energy
	Biomass Steam Turbine	biomass	2016	7.6	SD Resources
	Biomass Steam Turbine	biomass	2016	10	Bell Tech
	Large hydro	hydro	2016	27.5	One River
	Combined Cycle Gas Turbine	gas	2016	5	Ranhill Powertron II
	Diesel Engine	diesel	2016	18	Melawa(relocation)
	Geothermal plant	geothermal	2017	30	Tawau Green Energy
	Combined Cycle Gas Turbine	gas	2017	30	New Lahad Datu
	Combined Cycle Gas Turbine	gas	2017	30	New Sandakan
	Combined Cycle Gas Turbine	gas	2018	30	New Sandakan
	Combined Cycle Gas Turbine	gas	2019	200	New project
	Combined Cycle Gas Turbine	gas	2020	100	New project
	Combined Cycle Gas Turbine	gas	2021	100	New project
	Large hydro	hydro	2023	180	Upper Padas HEP
	Large hydro	hydro	2025	100	Sabah hydro

Appendix E

List of capacity addition for Sarawak

Region	Technology	Fuel type	Year	Addition (MW)	Project
Sarawak	Coal (supercritical fluidized bed)	coal	2017	600	Balingian I
	Coal (pulverised ultra-supercritical)	coal	2019	300	Merit Pila
	Combined Cycle Gas Turbine	gas	2019	800	Samalaju
	Combined Cycle Gas Turbine	gas	2019	400	Tanjung Kidurong
	Large hydro	hydro	2025	1295	Baleh
	Large hydro	hydro	2030	562	Pelagus
	Large hydro	hydro	2030	220	Belaga
	Large hydro	hydro	2030	42	Limbang 1
	Large hydro	hydro	2030	140	Limbang 2
	Large hydro	hydro	2030	38	Lawas
	Large hydro	hydro	2030	240	Trusan
	Large hydro	hydro	2030	1200	Baram 1
	Large hydro	hydro	2030	295	Baram 3
	Coal (supercritical fluidized bed)	coal	2030	600	Mukah West I

Appendix F

Linear regression model

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.962
R Square	0.926
Adjusted R Square	0.924
Standard Error	11204.479
Observations	43

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	63963659451	6.4E+10	509.5067456	9.6679E-25
Residual	41	5147154694	1.26E+08		
Total	42	69110814145			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-6149726.0	274555.8225	-22.3988	1.29602E-24	-6704202.7	-5595249.3
Year	3107.936	137.6883178	22.57226	9.6679E-25	2829.869	3386.003

Appendix G

Multiple linear regression model

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.996
R Square	0.992
Adjusted R Square	0.991
Standard Error	3757.860
Observations	43

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	68545953628	3.43E+10	2427.004597	1.76972E-42
Residual	40	564860517.4	14121513		
Total	42	69110814145			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-39738.3	4204.66866	-9.451	9.59028E-12	-48236.3	-31240.4
GDP (X1)	0.064099	0.004903878	13.07117	5.04644E-16	0.054188	0.074011
POP (X2)	0.003193	0.000274302	11.64119	2.02374E-14	0.002639	0.003748

Appendix H

BY 2015

Table A1. Base year available capacity stock by technology

Technology type	Available capacity (GW)	Percentage (%)
Mini Hydro	0.03	0.12
Large Hydro	4.30	17.17
Gas-Combined Cycle (CCGT)	9.19	36.65
Gas-Open Cycle (OCGT)	2.08	8.29
Gas-Conventional Thermal (GT)	0.56	2.24
Coal-Pulverized Supercritical (ST)	8.49	33.89
Biomass (ST)	0.06	0.25
Diesel Engine	0.28	1.13
Fuel Oil Engine	0.07	0.26

Table A2. Base year electricity output by technology

Technology type	Electricity output (PJ)	Percentage (%)
Mini Hydro	0.40	0.07
Large Hydro	57.46	10.63
Gas-Combined Cycle (CCGT)	194.48	35.97
Gas-Open Cycle (OCGT)	43.96	8.13
Gas-Conventional Thermal (GT)	11.89	2.20
Coal-Pulverized Supercritical (ST)	221.68	41.00
Biomass (ST)	4.87	0.90
Diesel Engine	5.79	1.07
Fuel Oil Engine	0.16	0.03

Applied to all scenarios

Table B1. Electricity generation and demand 2015-2050

Year	Electricity generation (PJ)	Electricity demand (PJ)
2015	540.68	475.92
2020	720.38	554.40
2025	818.33	630.32
2030	851.05	675.69
2035	905.42	724.34
2040	970.60	776.48
2045	1040.47	832.38
2050	1115.37	892.30

Table B2. Electricity demand by end user sectors 2015-2050

Demand (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
RSD	101.89	118.70	134.95	144.67	155.08	166.24	178.21	191.04
COM	153.10	178.35	202.77	217.37	233.02	249.79	267.78	287.05
IND	218.30	254.30	289.13	309.94	332.25	356.17	381.81	409.30
AGR	1.67	1.94	2.21	2.36	2.54	2.72	2.91	3.12
TRA	0.95	1.11	1.26	1.35	1.45	1.55	1.66	1.78
Total	**475.92**	**554.40**	**630.32**	**675.69**	**724.34**	**776.48**	**832.38**	**892.30**

BAU

Table C1. BAU scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	11.08	11.67	10.61	11.91	15.41	17.71	21.08
Coal-Fluidised Bed	0.00	0.53	0.60	0.94	1.20	1.20	2.40	2.40
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	12.10	11.53	7.43	6.36	5.53	4.93	4.28
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	4.88	7.22	9.96	10.78	10.42	10.06	9.99
Mini Hydro	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Biomass	0.06	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Biogas	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Geothermal	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Solar PV	0.00	0.58	0.80	0.80	0.80	0.80	0.80	0.80
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**25.06**	**32.99**	**35.39**	**31.23**	**31.96**	**34.28**	**36.83**	**39.47**

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Table C2. BAU scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	244.50	312.81	284.36	337.95	437.47	502.76	598.30
Coal-Fluidised Bed	0.00	14.30	16.08	25.27	32.17	32.17	64.33	64.33
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	232.70	229.10	210.98	180.48	156.87	140.05	121.35
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	146.23	216.42	298.42	322.82	312.08	301.34	299.31
Mini Hydro	0.40	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Biomass	4.87	5.48	5.48	5.48	5.48	5.48	5.48	5.48
Biogas	0.00	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Geothermal	0.00	0.80	0.90	0.90	0.90	0.90	0.90	0.90
Solar PV	0.00	4.56	6.31	6.31	6.31	6.31	6.28	6.31
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**540.68**	**720.38**	**818.33**	**851.04**	**905.42**	**970.60**	**1040.47**	**1115.36**

Table C3. BAU scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	33.94	38.23	33.41	37.32	45.07	48.32	53.64
Coal-Fluidised Bed	0.00	1.98	1.97	2.97	3.55	3.31	6.18	5.77
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	32.30	28.00	24.79	19.93	16.16	13.46	10.88
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	20.30	26.45	35.07	35.65	32.15	28.96	26.84
Mini Hydro	0.07	0.12	0.10	0.10	0.09	0.09	0.08	0.08
Biomass	0.90	0.76	0.67	0.64	0.60	0.56	0.53	0.49
Biogas	0.00	0.04	0.04	0.04	0.04	0.03	0.03	0.03
Geothermal	0.00	0.11	0.11	0.11	0.10	0.09	0.09	0.08
Solar PV	0.00	0.63	0.77	0.74	0.70	0.65	0.60	0.57
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

BAU

Table C4. BAU scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	531.52	680.03	618.17	734.66	951.03	1092.96	1300.65
Coal-Fluidised Bed	0.00	34.04	38.29	56.16	71.48	71.48	142.96	142.96
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0	0	0	0	0	0
Gas-Combined Cycle	442.00	387.83	381.84	351.63	300.80	261.44	233.42	202.25
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	153.93	227.81	314.13	339.81	328.51	317.20	315.06
Mini Hydro	0.44	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Biomass	14.31	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Biogas	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Geothermal	0.00	5.33	5.99	5.99	5.99	5.99	5.99	5.99
Solar PV	0.00	26.80	37.10	37.10	37.10	37.10	36.95	37.10
Nuclear	0	0	0	0	0	0	0	0
Total	**1256.01**	**1334.50**	**1455.95**	**1430.90**	**1537.56**	**1703.27**	**1877.19**	**2051.83**

Table C5. BAU scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	39.83	46.71	43.20	47.78	55.84	58.22	63.39
Lignite	0.00	2.55	2.63	3.93	4.65	4.20	7.62	6.97
Natural gas	47.36	42.33	30.82	26.66	21.50	17.10	14.02	11.31
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	11.60	15.71	22.02	22.16	19.34	16.95	15.40
Biomass	1.14	1.21	1.11	1.13	1.05	0.95	0.86	0.78
Biogas	0.00	0.07	0.06	0.06	0.06	0.05	0.05	0.04
Geothermal	0.00	0.40	0.41	0.42	0.39	0.35	0.32	0.29
Solar	0.00	2.01	2.55	2.59	2.41	2.18	1.97	1.81
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

BAU

Table C6. BAU scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	51,400	64,331	58,479	69,499	89,967	103,394	123,041
Coal-Fluidised Bed	0	3,438	3,868	5,673	7,220	7,220	14,439	14,439
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	22,508	21,421	19,726	16,875	14,667	13,095	11,346
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	1,610	1,610	1,610	1,610	1,610	1,610	1,610
Biogas	0	49	49	49	49	49	49	49
Total	**89,873**	**88,941**	**95,035**	**87,208**	**96,924**	**115,184**	**134,258**	**152,162**

Table C7. BAU scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	57.79	67.69	67.06	71.71	78.11	77.01	80.86
Coal-Fluidised Bed	0.00	3.87	4.07	6.50	7.45	6.27	10.75	9.49
Gas-Conventional Thermal	2.32	2.34	2.19	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.30	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	25.31	22.54	22.62	17.41	12.73	9.75	7.46
Gas-Combined Heat Power	0.00	1.53	1.76	1.92	1.72	1.45	1.24	1.10
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	1.81	1.69	1.85	1.66	1.40	1.20	1.06
Biogas	0.00	0.05	0.05	0.06	0.05	0.04	0.04	0.03
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC2

Table D1. NUC2 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	11.08	11.67	10.61	11.91	15.41	17.71	21.08
Coal-Fluidised Bed	0.00	0.53	0.60	0.94	1.20	1.20	2.40	2.40
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	12.10	11.53	6.30	4.36	3.53	2.93	2.28
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	4.88	7.22	9.96	10.78	10.42	10.06	9.99
Mini Hydro	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Biomass	0.06	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Biogas	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Geothermal	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Solar PV	0.00	0.58	0.80	0.80	0.80	0.80	0.80	0.80
Nuclear	0.00	0.00	0.00	1.14	2.00	2.00	2.00	2.00
Total	**25.06**	**32.99**	**35.39**	**31.24**	**31.96**	**34.28**	**36.83**	**39.47**

NUC2

Table D2. NUC2 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	244.50	312.81	284.36	337.95	437.47	502.76	598.30
Coal-Fluidised Bed	0.00	14.30	16.08	25.27	32.17	32.17	64.33	64.33
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	232.70	229.10	178.75	123.72	100.10	83.28	64.59
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	146.23	216.42	298.42	322.82	312.08	301.34	299.31
Mini Hydro	0.40	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Biomass	4.87	5.48	5.48	5.48	5.48	5.48	5.48	5.48
Biogas	0.00	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Geothermal	0.00	0.80	0.90	0.90	0.90	0.90	0.90	0.90
Solar PV	0.00	4.56	6.31	6.31	6.31	6.31	6.28	6.31
Nuclear	0.00	0.00	0.00	32.44	56.76	56.76	56.76	56.76
Total	**540.68**	**720.38**	**818.33**	**851.25**	**905.43**	**970.60**	**1040.47**	**1115.37**

Table D3. NUC2 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	33.94	38.23	33.40	37.32	45.07	48.32	53.64
Coal-Fluidised Bed	0.00	1.98	1.97	2.97	3.55	3.31	6.18	5.77
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	32.30	28.00	21.00	13.66	10.31	8.00	5.79
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	20.30	26.45	35.06	35.65	32.15	28.96	26.84
Mini Hydro	0.07	0.12	0.10	0.10	0.09	0.09	0.08	0.08
Biomass	0.90	0.76	0.67	0.64	0.60	0.56	0.53	0.49
Biogas	0.00	0.04	0.04	0.04	0.04	0.03	0.03	0.03
Geothermal	0.00	0.11	0.11	0.11	0.10	0.09	0.09	0.08
Solar PV	0.00	0.63	0.77	0.74	0.70	0.65	0.60	0.57
Nuclear	0.00	0.00	0.00	3.81	6.27	5.85	5.46	5.09
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC2

Table D4. NUC2 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	531.52	680.03	618.17	734.66	951.03	1092.96	1300.65
Coal-Fluidised Bed	0.00	34.04	38.29	56.16	71.48	71.48	142.96	142.96
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	442.00	387.83	381.84	297.92	206.20	166.83	138.80	107.65
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	153.93	227.81	314.13	339.81	328.51	317.20	315.06
Mini Hydro	0.44	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Biomass	14.31	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Biogas	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Geothermal	0.00	5.33	5.99	5.99	5.99	5.99	5.99	5.99
Solar PV	0.00	26.80	37.10	37.10	37.10	37.10	36.95	37.10
Nuclear	0.00	0.00	0.00	85.36	149.38	149.38	149.38	149.38
Total	**1256.01**	**1334.50**	**1455.95**	**1462.55**	**1592.34**	**1758.04**	**1931.96**	**2106.62**

Table D5. NUC2 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	39.83	46.71	42.27	46.14	54.10	56.57	61.74
Lignite	0.00	2.55	2.63	3.84	4.49	4.07	7.40	6.79
Natural gas	47.36	42.33	30.82	22.41	14.82	11.18	8.73	6.53
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	11.60	15.71	21.54	21.40	18.74	16.47	15.00
Biomass	1.14	1.21	1.11	1.10	1.01	0.92	0.83	0.76
Biogas	0.00	0.07	0.06	0.06	0.06	0.05	0.05	0.04
Geothermal	0.00	0.40	0.41	0.41	0.38	0.34	0.31	0.28
Solar	0.00	2.01	2.55	2.54	2.33	2.11	1.91	1.76
Nuclear	0.00	0.00	0.00	5.84	9.38	8.50	7.73	7.09
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC2

Table D6. NUC2 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	51,400	64,331	58,479	69,499	89,967	103,394	123,041
Coal-Fluidised Bed	0	3,438	3,868	5,673	7,220	7,220	14,439	14,439
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	22,508	21,421	16,713	11,568	9,359	7,787	6,039
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	1,610	1,610	1,610	1,610	1,610	1,610	1,610
Biogas	0	49	49	49	49	49	49	49
Total	**89,873**	**88,941**	**95,035**	**84,194**	**91,616**	**109,876**	**128,950**	**146,855**

Table D7. NUC2 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	57.79	67.69	69.46	75.86	81.88	80.18	83.78
Coal-Fluidised Bed	0.00	3.87	4.07	6.74	7.88	6.57	11.20	9.83
Gas-Conventional Thermal	2.32	2.34	2.19	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.30	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	25.31	22.54	19.85	12.63	8.52	6.04	4.11
Gas-Combined Heat Power	0.00	1.53	1.76	1.98	1.82	1.52	1.30	1.14
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	1.81	1.69	1.91	1.76	1.47	1.25	1.10
Biogas	0.00	0.05	0.05	0.06	0.05	0.04	0.04	0.03
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC4

Table E1. NUC4 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	11.08	11.67	10.61	11.91	15.41	17.71	21.08
Coal-Fluidised Bed	0.00	0.53	0.60	0.94	1.20	1.20	2.40	2.40
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	12.10	11.53	8.10	4.36	2.38	0.93	0.28
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	4.88	7.22	9.96	10.78	10.42	10.06	9.99
Mini Hydro	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Biomass	0.06	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Biogas	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Geothermal	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Solar PV	0.00	0.58	0.80	0.80	0.80	0.80	0.80	0.80
Nuclear	0.00	0.00	0.00	1.14	2.00	3.14	4.00	4.00
Total	**25.06**	**32.99**	**35.39**	**33.04**	**31.96**	**34.28**	**36.83**	**39.47**

NUC4

Table E2. NUC4 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	244.50	312.81	284.36	337.95	437.47	502.76	598.30
Coal-Fluidised Bed	0.00	14.30	16.08	25.27	32.17	32.17	64.33	64.33
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	232.70	229.10	178.75	123.71	67.67	26.52	7.81
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	146.23	216.42	298.42	322.82	312.08	301.34	299.31
Mini Hydro	0.40	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Biomass	4.87	5.48	5.48	5.48	5.48	5.48	5.48	5.48
Biogas	0.00	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Geothermal	0.00	0.80	0.90	0.90	0.90	0.90	0.90	0.90
Solar PV	0.00	4.56	6.31	6.31	6.31	6.31	6.28	6.31
Nuclear	0.00	0.00	0.00	32.44	56.76	89.20	113.53	113.53
Total	**540.68**	**720.38**	**818.33**	**851.25**	**905.42**	**970.60**	**1040.47**	**1115.36**

Table E3. NUC4 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	33.94	38.23	33.40	37.32	45.07	48.32	53.64
Coal-Fluidised Bed	0.00	1.98	1.97	2.97	3.55	3.31	6.18	5.77
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	32.30	28.00	21.00	13.66	6.97	2.55	0.70
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	20.30	26.45	35.06	35.65	32.15	28.96	26.84
Mini Hydro	0.07	0.12	0.10	0.10	0.09	0.09	0.08	0.08
Biomass	0.90	0.76	0.67	0.64	0.60	0.56	0.53	0.49
Biogas	0.00	0.04	0.04	0.04	0.04	0.03	0.03	0.03
Geothermal	0.00	0.11	0.11	0.11	0.10	0.09	0.09	0.08
Solar PV	0.00	0.63	0.77	0.74	0.70	0.65	0.60	0.57
Nuclear	0.00	0.00	0.00	3.81	6.27	9.19	10.91	10.18
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC4

Table E4. NUC4 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	531.52	680.03	618.17	734.66	951.03	1092.96	1300.65
Coal-Fluidised Bed	0.00	34.04	38.29	56.16	71.48	71.48	142.96	142.96
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	442.00	387.83	381.84	297.92	206.19	112.78	44.20	13.02
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	153.93	227.81	314.13	339.81	328.51	317.20	315.06
Mini Hydro	0.44	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Biomass	14.31	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Biogas	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Geothermal	0.00	5.33	5.99	5.99	5.99	5.99	5.99	5.99
Solar PV	0.00	26.80	37.10	37.10	37.10	37.10	36.95	37.10
Nuclear	0.00	0.00	0.00	85.36	149.38	234.74	298.76	298.76
Total	**1256.01**	**1334.50**	**1455.95**	**1462.55**	**1592.34**	**1789.34**	**1986.73**	**2161.37**

Table E5. NUC4 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	39.83	46.71	42.27	46.14	53.15	55.01	60.18
Lignite	0.00	2.55	2.63	3.84	4.49	3.99	7.20	6.61
Natural gas	47.36	42.33	30.82	22.41	14.82	7.97	3.72	1.99
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	11.60	15.71	21.54	21.40	18.41	16.01	14.62
Biomass	1.14	1.21	1.11	1.10	1.01	0.90	0.81	0.75
Biogas	0.00	0.07	0.06	0.06	0.06	0.05	0.05	0.04
Geothermal	0.00	0.40	0.41	0.41	0.38	0.33	0.30	0.28
Solar	0.00	2.01	2.55	2.54	2.33	2.07	1.86	1.72
Nuclear	0.00	0.00	0.00	5.84	9.38	13.12	15.04	13.82
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NUC4

Table E6. NUC4 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	51,400	64,331	58,479	69,499	89,967	103,394	123,041
Coal-Fluidised Bed	0	3,438	3,868	5,673	7,220	7,220	14,439	14,439
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	22,508	21,421	16,713	11,567	6,327	2,480	731
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	1,610	1,610	1,610	1,610	1,610	1,610	1,610
Biogas	0	49	49	49	49	49	49	49
Total	**89,873**	**88,941**	**95,035**	**84,194**	**91,616**	**106,844**	**123,643**	**141,547**

Table E7. NUC4 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	57.79	67.69	69.46	75.86	84.20	83.62	86.93
Coal-Fluidised Bed	0.00	3.87	4.07	6.74	7.88	6.76	11.68	10.20
Gas-Conventional Thermal	2.32	2.34	2.19	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.30	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	25.31	22.54	19.85	12.63	5.92	2.01	0.52
Gas-Combined Heat Power	0.00	1.53	1.76	1.98	1.82	1.56	1.35	1.18
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	1.81	1.69	1.91	1.76	1.51	1.30	1.14
Biogas	0.00	0.05	0.05	0.06	0.05	0.05	0.04	0.03
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S7

Table F1. RNW6S7 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	7.43	6.37	5.31	4.25	3.18	2.12	0.00
Coal-Fluidised Bed	0.00	0.53	0.60	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	7.54	4.59	1.16	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	5.35	13.62	13.77	13.05	16.16	19.41	23.84
Mini Hydro	0.03	0.03	0.03	0.29	0.49	0.49	0.49	0.49
Biomass	0.06	1.03	1.06	1.08	1.11	1.13	1.16	1.18
Biogas	0.00	0.97	0.99	1.01	1.03	1.06	1.08	1.10
Geothermal	0.00	0.03	0.03	0.05	0.07	0.07	0.07	0.07
Solar PV	0.00	0.58	0.80	21.72	37.40	37.41	37.40	37.40
Pumped Hydro Storage	0.00	0.00	0.00	0.31	0.56	0.60	0.65	0.69
Total	**25.06**	**26.99**	**31.32**	**45.85**	**58.56**	**60.69**	**62.97**	**65.37**

RNW6S7

Table F2. RNW6S7 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	210.92	180.79	150.66	120.53	90.39	60.26	0.00
Coal-Fluidised Bed	0.00	14.30	16.08	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	213.86	130.28	32.81	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	160.28	407.92	412.45	390.94	484.10	581.56	714.21
Mini Hydro	0.40	0.84	0.84	8.31	13.91	13.91	13.91	13.91
Biomass	4.87	22.84	23.35	23.87	24.40	24.95	25.50	26.07
Biogas	0.00	21.33	21.80	22.29	22.78	23.29	23.81	24.34
Geothermal	0.00	0.80	0.90	1.57	2.07	2.07	2.07	2.07
Solar PV	0.00	4.56	6.31	171.21	294.88	294.88	294.85	294.88
Pumped Hydro Storage	0.00	0.00	0.00	9.73	17.75	18.85	20.34	21.67
Total	**540.68**	**720.38**	**818.33**	**851.05**	**905.42**	**970.60**	**1040.47**	**1115.37**

Table F3. RNW6S7 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	29.28	22.09	17.70	13.31	9.31	5.79	0.00
Coal-Fluidised Bed	0.00	1.98	1.97	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	29.69	15.92	3.86	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	22.25	49.85	48.46	43.18	49.88	55.89	64.03
Mini Hydro	0.07	0.12	0.10	0.98	1.54	1.43	1.34	1.25
Biomass	0.90	3.17	2.85	2.81	2.70	2.57	2.45	2.34
Biogas	0.00	2.96	2.66	2.62	2.52	2.40	2.29	2.18
Geothermal	0.00	0.11	0.11	0.18	0.23	0.21	0.20	0.19
Solar PV	0.00	0.63	0.77	20.12	32.57	30.38	28.34	26.44
Pumped Hydro Storage	0.00	0.00	0.00	1.14	1.96	1.94	1.96	1.94
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S7

Table F4. RNW6S7 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	458.52	393.02	327.52	262.01	196.51	131.01	0.00
Coal-Fluidised Bed	0.00	34.04	38.29	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	442.00	356.44	217.13	54.68	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	168.71	429.39	434.15	411.52	509.57	612.17	751.80
Mini Hydro	0.44	0.94	0.94	9.23	15.45	15.45	15.45	15.45
Biomass	14.31	65.27	66.72	66.31	67.79	65.65	67.11	68.61
Biogas	0.00	56.13	57.38	55.72	56.96	55.46	56.69	54.09
Geothermal	0.00	5.33	5.99	10.44	13.78	13.78	13.78	13.78
Solar PV	0.00	26.80	37.10	856.03	1474.39	1474.39	1474.26	1474.39
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumped Hydro Storage	0.00	0.00	0.00	11.44	20.88	22.18	23.93	25.49
Total	**1256.01**	**1349.28**	**1312.90**	**1855.31**	**2352.57**	**2382.78**	**2424.18**	**2433.49**

Table F5. RNW6S7 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	33.98	29.94	17.65	11.14	8.25	5.40	0.00
Lignite	0.00	2.52	2.92	0.00	0.00	0.00	0.00	0.00
Natural gas	47.36	39.54	21.64	4.55	1.27	1.25	1.23	1.23
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	12.57	32.78	24.51	19.04	22.97	26.88	32.58
Biomass	1.14	4.84	5.08	3.57	2.88	2.76	2.77	2.82
Biogas	0.00	4.16	4.37	3.00	2.42	2.33	2.34	2.22
Geothermal	0.00	0.39	0.46	0.56	0.59	0.58	0.57	0.57
Solar	0.00	1.99	2.83	46.14	62.67	61.88	60.81	60.59
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S7

Table F6. RNW6S7 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	44,340	37,180	30,983	24,786	18,590	12,393	0
Coal-Fluidised Bed	0	3,438	3,868	0	0	0	0	0
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	20,686	12,181	3,068	0	0	0	0
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	6,527	6,672	6,631	6,779	6,565	6,711	6,861
Biogas	0	3,065	3,133	3,042	3,110	3,028	3,095	2,953
Total	**89,873**	**87,992**	**66,789**	**45,395**	**36,346**	**29,853**	**23,870**	**11,490**

Table F7. RNW6S7 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	50.39	55.67	68.25	68.20	62.27	51.92	0.00
Coal-Fluidised Bed	0.00	3.91	5.79	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.32	2.37	3.12	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.38	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	23.51	18.24	6.76	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	1.55	2.50	3.68	4.60	5.60	7.00	14.59
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	7.42	9.99	14.61	18.65	21.99	28.12	59.71
Biogas	0.00	3.48	4.69	6.70	8.56	10.14	12.97	25.70
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S14

Table G1. RNW6S14 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	7.43	6.37	4.97	3.62	2.52	1.41	0.00
Coal-Fluidised Bed	0.00	0.53	0.60	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	7.54	4.59	1.16	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	5.35	13.62	13.77	13.05	16.16	19.41	23.12
Mini Hydro	0.03	0.03	0.03	0.29	0.49	0.49	0.49	0.49
Biomass	0.06	1.03	1.06	1.08	1.11	1.13	1.16	1.18
Biogas	0.00	0.97	0.99	1.01	1.03	1.06	1.08	1.10
Geothermal	0.00	0.03	0.03	0.05	0.07	0.07	0.07	0.07
Solar PV	0.00	0.58	0.80	21.72	37.40	37.41	37.40	37.40
Pumped Hydro Storage	0.00	0.00	0.00	0.62	1.13	1.20	1.29	1.37
Total	**25.06**	**26.99**	**31.32**	**45.82**	**58.49**	**60.63**	**62.90**	**65.34**

RNW6S14

Table G2. RNW6S14 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	210.92	180.79	140.93	102.78	71.54	39.92	0.00
Coal-Fluidised Bed	0.00	14.30	16.08	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	213.86	130.28	32.81	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	160.28	407.92	412.45	390.94	484.10	581.56	692.55
Mini Hydro	0.40	0.84	0.84	8.31	13.91	13.91	13.91	13.91
Biomass	4.87	22.84	23.35	23.87	24.40	24.95	25.50	26.07
Biogas	0.00	21.33	21.80	22.29	22.78	23.29	23.81	24.34
Geothermal	0.00	0.80	0.90	1.57	2.07	2.07	2.07	2.07
Solar PV	0.00	4.56	6.31	171.21	294.88	294.88	294.85	294.88
Pumped Hydro Storage	0.00	0.00	0.00	19.45	35.49	37.71	40.69	43.33
Total	**540.68**	**720.38**	**818.33**	**851.05**	**905.42**	**970.60**	**1040.47**	**1115.37**

Table G3. RNW6S14 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	29.28	22.09	16.56	11.35	7.37	3.84	0.00
Coal-Fluidised Bed	0.00	1.98	1.97	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	29.69	15.92	3.86	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	22.25	49.85	48.46	43.18	49.88	55.89	62.09
Mini Hydro	0.07	0.12	0.10	0.98	1.54	1.43	1.34	1.25
Biomass	0.90	3.17	2.85	2.81	2.70	2.57	2.45	2.34
Biogas	0.00	2.96	2.66	2.62	2.52	2.40	2.29	2.18
Geothermal	0.00	0.11	0.11	0.18	0.23	0.21	0.20	0.19
Solar PV	0.00	0.63	0.77	20.12	32.57	30.38	28.34	26.44
Pumped Hydro Storage	0.00	0.00	0.00	2.29	3.92	3.88	3.91	3.88
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S14

Table G4. RNW6S14 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	458.52	393.02	306.38	223.43	155.52	86.78	0.00
Coal-Fluidised Bed	0.00	34.04	38.29	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	442.00	356.44	217.13	54.68	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	168.71	429.39	434.15	411.52	509.57	612.17	729.00
Mini Hydro	0.44	0.94	0.94	9.23	15.45	15.45	15.45	15.45
Biomass	14.31	65.27	66.72	66.31	67.79	65.65	67.11	68.61
Biogas	0.00	56.13	57.38	55.72	56.96	55.46	56.69	54.09
Geothermal	0.00	5.33	5.99	10.44	13.78	13.78	13.78	13.78
Solar PV	0.00	26.80	37.10	856.03	1474.39	1474.39	1474.26	1474.39
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumped Hydro Storage	0.00	0.00	0.00	22.89	41.76	44.36	47.87	50.98
Total	**1256.01**	**1349.28**	**1312.90**	**1845.61**	**2334.86**	**2363.97**	**2403.89**	**2436.18**

Table G5. RNW6S14 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	33.98	29.94	16.60	9.57	6.58	3.61	0.00
Lignite	0.00	2.52	2.92	0.00	0.00	0.00	0.00	0.00
Natural gas	47.36	39.54	21.64	4.58	1.28	1.26	1.24	1.23
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	12.57	32.78	25.26	20.08	24.09	28.10	32.65
Biomass	1.14	4.84	5.08	3.59	2.90	2.78	2.79	2.82
Biogas	0.00	4.16	4.37	3.02	2.44	2.35	2.36	2.22
Geothermal	0.00	0.39	0.46	0.57	0.59	0.58	0.57	0.57
Solar	0.00	1.99	2.83	46.38	63.15	62.37	61.33	60.52
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW6S14

Table G6. RNW6S14 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	44,340	37,180	28,983	21,137	14,712	8,210	0
Coal-Fluidised Bed	0	3,438	3,868	0	0	0	0	0
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	20,686	12,181	3,068	0	0	0	0
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	6,527	6,672	6,631	6,779	6,565	6,711	6,861
Biogas	0	3,065	3,133	3,042	3,110	3,028	3,095	2,953
Total	**89,873**	**87,992**	**66,789**	**43,395**	**32,696**	**25,976**	**19,687**	**11,490**

Table G7. RNW6S14 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	50.39	55.67	66.79	64.65	56.64	41.70	0.00
Coal-Fluidised Bed	0.00	3.91	5.79	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.32	2.37	3.12	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.38	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	23.51	18.24	7.07	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	1.55	2.50	3.85	5.11	6.43	8.49	14.59
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	7.42	9.99	15.28	20.73	25.27	34.09	59.71
Biogas	0.00	3.48	4.69	7.01	9.51	11.66	15.72	25.70
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW7S7

Table H1. RNW7S7 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	7.43	6.37	3.59	1.12	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	0.53	0.60	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	7.54	4.59	1.16	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	5.35	13.62	13.77	13.05	16.03	18.03	20.22
Mini Hydro	0.03	0.03	0.03	0.29	0.49	0.49	0.49	0.49
Biomass	0.06	1.03	1.06	1.08	1.11	1.13	1.16	1.18
Biogas	0.00	0.97	0.99	1.01	1.03	1.06	1.08	1.10
Geothermal	0.00	0.03	0.03	0.05	0.07	0.07	0.07	0.07
Solar PV	0.00	0.58	0.80	21.72	37.40	37.41	37.40	37.40
Pumped Hydro Storage	0.00	0.00	0.00	0.31	0.56	0.60	0.65	0.69
Offshore Wind	0.00	0.00	0.00	2.06	3.75	3.99	4.30	4.58
Total	**25.06**	**26.99**	**31.32**	**46.20**	**59.18**	**61.36**	**63.77**	**66.34**

RNW7S7

Table H2. RNW7S7 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	210.92	180.79	102.02	31.80	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	14.30	16.08	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	213.86	130.28	32.81	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	160.28	407.92	412.45	390.94	480.22	540.10	605.89
Mini Hydro	0.40	0.84	0.84	8.31	13.91	13.91	13.91	13.91
Biomass	4.87	22.84	23.35	23.87	24.40	24.95	25.50	26.07
Biogas	0.00	21.33	21.80	22.29	22.78	23.29	23.81	24.34
Geothermal	0.00	0.80	0.90	1.57	2.07	2.07	2.07	2.07
Solar PV	0.00	4.56	6.31	171.21	294.88	294.88	294.85	294.88
Pumped Hydro Storage	0.00	0.00	0.00	9.73	17.75	18.85	20.34	21.67
Offshore Wind	0.00	0.00	0.00	48.63	88.73	94.27	101.72	108.33
Total	**540.68**	**720.38**	**818.33**	**851.04**	**905.42**	**970.59**	**1040.46**	**1115.37**

Table H3. RNW7S7 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	29.28	22.09	11.99	3.51	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	1.98	1.97	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	29.69	15.92	3.86	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	22.25	49.85	48.46	43.18	49.48	51.91	54.32
Mini Hydro	0.07	0.12	0.10	0.98	1.54	1.43	1.34	1.25
Biomass	0.90	3.17	2.85	2.81	2.70	2.57	2.45	2.34
Biogas	0.00	2.96	2.66	2.62	2.52	2.40	2.29	2.18
Geothermal	0.00	0.11	0.11	0.18	0.23	0.21	0.20	0.19
Solar PV	0.00	0.63	0.77	20.12	32.57	30.38	28.34	26.44
Pumped Hydro Storage	0.00	0.00	0.00	1.14	1.96	1.94	1.96	1.94
Offshore wind	0.00	0.00	0.00	5.71	9.80	9.71	9.78	9.71
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW7S7

Table H4. RNW7S7 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	458.52	393.02	221.79	69.13	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	34.04	38.29	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0	0	0	0	0	0
Gas-Combined Cycle	442.00	356.44	217.13	54.68	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	168.71	429.39	434.15	411.52	505.49	568.52	637.78
Mini Hydro	0.44	0.94	0.94	9.23	15.45	15.45	15.45	15.45
Biomass	14.31	65.27	66.72	66.31	67.79	65.65	67.11	68.61
Biogas	0.00	56.13	57.38	55.72	56.96	55.46	56.69	54.09
Geothermal	0.00	5.33	5.99	10.44	13.78	13.78	13.78	13.78
Solar PV	0.00	26.80	37.10	856.03	1474.39	1474.39	1474.26	1474.39
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumped Hydro Storage	0.00	0.00	0.00	11.44	20.88	22.18	23.93	25.49
Offshore Wind	0.00	0.00	0.00	108.07	197.18	196.39	211.91	225.68
Total	**1256.01**	**1349.28**	**1312.90**	**1857.65**	**2356.86**	**2378.57**	**2461.45**	**2545.15**

Table H5. RNW7S7 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	33.98	29.94	11.94	2.93	0.00	0.00	0.00
Lignite	0.00	2.52	2.92	0.00	0.00	0.00	0.00	0.00
Natural gas	47.36	39.54	21.64	4.55	1.26	1.25	1.21	1.17
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	12.57	32.78	24.48	19.00	22.83	24.70	26.67
Biomass	1.14	4.84	5.08	3.57	2.88	2.76	2.73	2.70
Biogas	0.00	4.16	4.37	3.00	2.42	2.33	2.30	2.13
Geothermal	0.00	0.39	0.46	0.56	0.58	0.58	0.56	0.54
Solar	0.00	1.99	2.83	46.08	62.56	61.99	59.89	57.93
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	5.82	8.37	8.26	8.61	8.87
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

RNW7S7

Table H6. RNW7S7 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	44,340	37,180	20,981	6,539	0	0	0
Coal-Fluidised Bed	0	3,438	3,868	0	0	0	0	0
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	20,686	12,181	3,068	0	0	0	0
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	6,527	6,672	6,631	6,779	6,565	6,711	6,861
Biogas	0	3,065	3,133	3,042	3,110	3,028	3,095	2,953
Total	**89,873**	**87,992**	**66,789**	**35,393**	**18,099**	**11,264**	**11,477**	**11,490**

Table H7. RNW7S7 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	50.39	55.67	59.28	36.13	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	3.91	5.79	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.32	2.37	3.12	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.38	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	23.51	18.24	8.67	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	1.55	2.50	4.72	9.23	14.83	14.56	14.59
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	7.42	9.99	18.74	37.45	58.29	58.47	59.71
Biogas	0.00	3.48	4.69	8.60	17.18	26.88	26.97	25.70
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

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Table I1. RNW7S14 scenario capacity level by technology

Capacity (GW)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	8.49	7.43	6.37	3.25	0.49	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	0.53	0.60	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	0.56	0.56	0.56	0.56	0.00	0.00	0.00	0.00
Gas-Open Cycle	2.08	2.08	2.08	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	9.19	7.54	4.59	1.16	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	0.49	0.60	0.60	0.60	0.60	0.60	0.60
Fuel Oil Engine	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	0.28	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	4.30	5.35	13.62	13.77	13.05	15.40	17.35	19.50
Mini Hydro	0.03	0.03	0.03	0.29	0.49	0.49	0.49	0.49
Biomass	0.06	1.03	1.06	1.08	1.11	1.13	1.16	1.18
Biogas	0.00	0.97	0.99	1.01	1.03	1.06	1.08	1.10
Geothermal	0.00	0.03	0.03	0.05	0.07	0.07	0.07	0.07
Solar PV	0.00	0.58	0.80	21.72	37.40	37.41	37.40	37.40
Pumped Hydro Storage	0.00	0.00	0.00	0.62	1.13	1.20	1.29	1.37
Offshore Wind	0.00	0.00	0.00	2.06	3.75	3.99	4.30	4.58
Total	**25.06**	**26.99**	**31.32**	**46.16**	**59.12**	**61.33**	**63.73**	**66.30**

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Table I2. RNW7S14 scenario electricity output by technology

Electricity output (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	221.68	210.92	180.79	92.30	14.05	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	14.30	16.08	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	11.89	11.89	11.89	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	43.96	43.96	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	194.48	213.86	130.28	32.81	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	14.80	18.16	18.16	18.16	18.16	18.16	18.23
Fuel Oil Engine	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	57.46	160.28	407.92	412.45	390.94	461.37	519.76	584.22
Mini Hydro	0.40	0.84	0.84	8.31	13.91	13.91	13.91	13.91
Biomass	4.87	22.84	23.35	23.87	24.40	24.95	25.50	26.07
Biogas	0.00	21.33	21.80	22.29	22.78	23.29	23.81	24.34
Geothermal	0.00	0.80	0.90	1.57	2.07	2.07	2.07	2.07
Solar PV	0.00	4.56	6.31	171.21	294.88	294.88	294.85	294.88
Pumped Hydro Storage	0.00	0.00	0.00	19.45	35.49	37.71	40.69	43.33
Offshore Wind	0.00	0.00	0.00	48.63	88.73	94.27	101.72	108.33
Total	**540.68**	**720.38**	**818.33**	**851.05**	**905.42**	**970.59**	**1040.47**	**1115.37**

Table I3. RNW7S14 scenario electricity generation mix by technology

Electricity mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	41.00	29.28	22.09	10.85	1.55	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	1.98	1.97	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.20	1.65	1.45	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	8.13	6.10	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	35.97	29.69	15.92	3.86	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	2.05	2.22	2.13	2.01	1.87	1.75	1.63
Fuel Oil Engine	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	10.63	22.25	49.85	48.46	43.18	47.53	49.95	52.38
Mini Hydro	0.07	0.12	0.10	0.98	1.54	1.43	1.34	1.25
Biomass	0.90	3.17	2.85	2.81	2.70	2.57	2.45	2.34
Biogas	0.00	2.96	2.66	2.62	2.52	2.40	2.29	2.18
Geothermal	0.00	0.11	0.11	0.18	0.23	0.21	0.20	0.19
Solar PV	0.00	0.63	0.77	20.12	32.57	30.38	28.34	26.44
Pumped Hydro Storage	0.00	0.00	0.00	2.29	3.92	3.88	3.91	3.88
Offshore wind	0.00	0.00	0.00	5.71	9.80	9.71	9.78	9.71
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

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Table I4. RNW7S14 scenario fuel level by technology

Fuel input (PJ)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	568.41	458.52	393.02	200.66	30.54	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	34.04	38.29	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	37.16	37.16	37.16	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	115.70	115.69	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	442.00	356.44	217.13	54.68	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	24.26	29.78	29.78	29.78	29.78	29.78	29.88
Fuel Oil Engine	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Hydro	60.48	168.71	429.39	434.15	411.52	485.65	547.11	614.97
Mini Hydro	0.44	0.94	0.94	9.23	15.45	15.45	15.45	15.45
Biomass	14.31	65.27	66.72	66.31	67.79	65.65	67.11	68.61
Biogas	0.00	56.13	57.38	55.72	56.96	55.46	56.69	54.09
Geothermal	0.00	5.33	5.99	10.44	13.78	13.78	13.78	13.78
Solar PV	0.00	26.80	37.10	856.03	1474.39	1474.39	1474.26	1474.39
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumped Hydro Storage	0.00	0.00	0.00	22.89	41.76	44.36	47.87	50.98
Offshore Wind	0.00	0.00	0.00	108.07	197.18	196.39	211.91	225.68
Total	**1256.01**	**1349.28**	**1312.90**	**1847.96**	**2339.15**	**2380.91**	**2463.97**	**2547.83**

Table I5. RNW7S14 scenario fuel mix

Fuel mix (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal	45.26	33.98	29.94	10.86	1.31	0.00	0.00	0.00
Lignite	0.00	2.52	2.92	0.00	0.00	0.00	0.00	0.00
Natural gas	47.36	39.54	21.64	4.57	1.27	1.25	1.21	1.17
Fuel oil	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	4.85	12.57	32.78	25.23	20.04	22.91	24.77	26.74
Biomass	1.14	4.84	5.08	3.59	2.90	2.76	2.72	2.69
Biogas	0.00	4.16	4.37	3.02	2.44	2.33	2.30	2.12
Geothermal	0.00	0.39	0.46	0.57	0.59	0.58	0.56	0.54
Solar	0.00	1.99	2.83	46.32	63.03	61.93	59.83	57.87
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	5.85	8.43	8.25	8.60	8.86
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

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Table I6. RNW7S14 scenario CO_2 emission level

CO_2 (kt)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	53,772	44,340	37,180	18,982	2,889	0	0	0
Coal-Fluidised Bed	0	3,438	3,868	0	0	0	0	0
Gas-Conventional Thermal	2,085	2,085	2,085	0	0	0	0	0
Gas-Open Cycle	6,491	6,490	0	0	0	0	0	0
Gas-Combined Cycle	24,796	20,686	12,181	3,068	0	0	0	0
Gas-Combined Heat Power	0	1,361	1,671	1,671	1,671	1,671	1,671	1,677
Fuel Oil Engine	38	0	0	0	0	0	0	0
Diesel Engine	1,261	0	0	0	0	0	0	0
Biomass	1,431	6,527	6,672	6,631	6,779	6,565	6,711	6,861
Biogas	0	3,065	3,133	3,042	3,110	3,028	3,095	2,953
Total	**89,873**	**87,992**	**66,789**	**33,394**	**14,449**	**11,264**	**11,477**	**11,490**

Table I7. RNW7S14 scenario emission percentage by technology

CO_2 (%)	2015	2020	2025	2030	2035	2040	2045	2050
Coal-Pulverised Supercritical	59.83	50.39	55.67	56.84	20.00	0.00	0.00	0.00
Coal-Fluidised Bed	0.00	3.91	5.79	0.00	0.00	0.00	0.00	0.00
Gas-Conventional Thermal	2.32	2.37	3.12	0.00	0.00	0.00	0.00	0.00
Gas-Open Cycle	7.22	7.38	0.00	0.00	0.00	0.00	0.00	0.00
Gas-Combined Cycle	27.59	23.51	18.24	9.19	0.00	0.00	0.00	0.00
Gas-Combined Heat Power	0.00	1.55	2.50	5.00	11.56	14.83	14.56	14.59
Fuel Oil Engine	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Engine	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	1.59	7.42	9.99	19.86	46.92	58.29	58.47	59.71
Biogas	0.00	3.48	4.69	9.11	21.53	26.88	26.97	25.70
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**