Department of Mechanical and Aerospace Engineering

Investigating of Hybrid Energy Systems in Southern Region of Thailand

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Signed: Napat Damrongsri Date: 24/08/2018

Abstract

Due to rapid growth of industrial sector and current status of power production system in Southern region of Thailand, this area has high possibility of energy shortage in the near future. The government drew up a solution to tackle this problem by suggesting to add 3 coal-fired power plants to accommodate the increasing demand in the future. However, there are several negative public opinions against this plan. Therefore, this project is aimed at investigating a suitable design of hybrid combination, which consists of at least 30% of renewable systems according to Thailand energy policy, under criteria of financial, social and environmental aspects.

The design of hybrid combination is validated by using HOMER (Hybrid Optimisation of Model with Multiple Energy Resources) software. The software has the potential to create a huge number of hybrid combinations to account for energy resource availability and other variables. Before simulation, the current electricity demand in the region was taken into account, future demand over the next 20 years was projected to use in the combination. In the same way, renewable resources, such as average monthly solar radiation, wind speed, water speed, and biomass fuel, were carried out as the input parameters of the simulation. However, there are some limitations of HOMER, such as a small number of component types and a lack of analysis on social impact and information regarding input data.

The results of the project can be divided into 4 models of hybrid combination or Scenario 1-4, which represent a configuration of 30%, 50%, 70%, and 100% of renewable systems, respectively. Although higher renewable fraction systems could decrease more environmental impacts, they would require a larger size of construction area and capital cost due to higher components. Overall, the most feasible and appropriate configuration seems to be Scenario 1 since it has the lowest investment capital cost, cost of electricity (COE), and social impact. It is hoped that this alternative energy systems would be more efficient given improvements of their technology and government support.

Acknowledgements

This dissertation would not have been complete without the support from a several number of people. Firstly, I would like to thank my supervisor, Dr Nickolas Kelly, who provide valuable support and guidance during the whole individual project period.

I would also like to thank my parents who financial support and being my motivation throughout the course in the University. Without them, I would not have been able to study toward this Master’s degree.

Many thanks to Sibil, who taught me how to modelling HOMER software, and also P’Yang, who contacted his friend to provide current electricity demand from EGAT. The simulation of the project would not have been accomplished without them.

Finally, thanks to all of the lecturers, my friends and fellow students, who have helped me throughout times I lived in Glasgow. I have met many amazing people from across the world that made an unforgettable experience of my life.

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Nomenclature

AC – Alternative current

AEDP - Alternative Energy Development Plan

CO_2 – Carbon dioxide

COE – Cost of electricity ($/kWh)

DC – Direct current

EGAT - The Electricity Generation Authority of Thailand

FITs - Feed-in Tariffs

GW – Gigawatt

IPPs - Independent Power Produces

IRENA - The International Renewable Energy Agency

kW – Kilowatt

kWh – Kilowatt-hours

Li-ion – Lithium ion

m/s – Meter per second

MEA – The Metropolitan Electricity Authority

MoAC - The Ministry of Agriculture and Cooperatives

mph – miles per hour

MW – Megawatt

MWh – Megawatt-hours

NGCC – Natural gas combined cycle

NPC – Net present cost ($)

O&M – Operation & Maintenance

PEA - The Provincial Electricity Authority

PDP – Thailand Power Development Plan

PV – Photovoltaic

SPPs – Small Power Producers

VSPPs – Very Small Power Producers

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1. Introduction

As the global population is expanding and industrialization is rising in developing countries, humanity's desire for energy has reached the unprecedented level. More than 60% of the energy comes from fossil fuels such as oil, gas, and coal. Since an initial oil drilling started in the 1850s, it is estimated that more than 135 billion tons of crude oil were used for heating and cooling our homes, driving our cars and fueling our power stations. This figure will increase everyday (Gray, 2017). However, burning these fossil fuels is the main reason for the rising levels of greenhouse gases in the atmosphere, which leads to climate change and global warming. This problem is currently almost universally accepted as a crucial issue caused by human activities (Schreiber, 2007).

The similar situation is also happening in the southern region of Thailand, which is an example area of a developing country that has a high possibility to face energy shortage in the future. Southern Thailand, which is shown in the red area of Figure 1, is on the Malay Peninsula with an area of approximately 70,700 km^2 divided into 14 provinces and around 9.2 million residents (Kongprasit et al., 2017). As of 2017, the gap between the amounts of power demand and supply was extremely close in this area. Total power generation in this region is around 3,000 MW, which 2,400 MW produced by 2 of conventional power plants (930MW + 1470MW) that can operate 24 hours with variable load controls, another 600 MW is generated by hydro plants, wind energy and is also imported electricity from the central region (300 MW) and neighbor countries to support peak demands. However, for the demand side, the statistics showed that the peak load reached 2,624 MW in the hot summer of April 2017 (IRENA, 2017).

Figure 1: Southern region of Thailand (Kongprasit et al., 2017)

Thus, it can be seen that power system situation in southern region has high risk of energy shortage. For example, if an incident occurs to one of the main power plants causing it to trip out of the power system, total capacity of another power plant combined with renewable energy and imported electricity in the area cannot accommodate the peak demand. Moreover, electricity demand in Southern region is expected to rise around 3.4% annually (IRENA, 2017). For this reason, the government drew up a plant to build 3 coal-fired power plants with total capacity of 2,800 MW, but this plan faced many negative public attitudes due to the concern of the environment and social impacts.

In order to increase power generation with less harmful impacts to environment, renewable energy is the one of the best options for this target. Renewable energy is the power that is collected from nature resources such as wind, sunlight, rain, waves, tides, biomass and geothermal heat. Unlike conventional resources, generating power from renewable energy releases much fewer potentially harmful emissions into the atmosphere and also improves public health (Richardson, 2018). For this reason, renewable energy is selected to be the first priority to allocate in the southern region of Thailand.

However, there are many challenges that renewable energy is facing. Firstly, this technology has limited potential in some locations. For instance, the average wind speed in Southern Thailand is around 2 m/s, which is considered to be low level for wind power. Secondly, when using renewable energy resources, back-up storage should be included with the power generation opportunity. Since sunlight does not shine at night and wind speed is not consistent, the storage capacities are required to store the power for the flexibility of energy demand, which making it easier to balance the power system. Lastly, the most widely publicized barrier for sustainable energy is cost, especially, the capital costs, or the expense of installing and building wind and solar farms (IRENA, 2017).

As a result, this project will focus on an investigation of the possibility to increase the capacity of renewable energy in the Southern region of Thailand. For energy resources, biomass and solar energy tend to be suitable types of power system in the area. In contrast, wind energy might not perform with high efficiency due to low wind speed in the region. In terms of hydropower, run a river could be an interesting option for hybrid combination. Overall, this project needs to collect relevant information and simulate these hybrid combinations to find an optimal model under criteria of financial aspects, electricity costs, renewable fraction, CO2 emission and environmental impacts.

1.1 Aim and Objectives

The aim of this project is to investigate the feasibility design of hybrid combination, which achieves at least 30% renewable fraction in Southern Thailand to lower the risk of energy shortage and harmful impacts to the environment and communities. In order to achieve the aim of this project, there are 3 objectives to accomplish the outcome.

- To take into account the current electricity demand and to calculate projected demand over the next 20 years as well as renewable resources in target area for use as simulation inputs.
- To identify and justify the most optimization hybrid combination under criteria of the project.
- To suggest suitable location for hybrid combination to benefit from energy resource and create less environmental and social impacts.

As regard the hybrid combination model for energy system, it should meet the following criteria.

- Renewable fraction should be at least 30%.
- Carbon dioxide (CO_2) emissions should be at a minimum level.
- Cost of electricity (COE) should be managerially wise.
- Social impacts should be at a minimum level.

1.2 Scope of the Project

What will be included in the project:

- Target location will be Southern region of Thailand (14 provinces).
- Thailand Power Development Plan (PDP2015) is a standard for at least 30% renewable fraction criteria.
- According to renewable energy resources in the area, biomass, solar PV, wind energy and hydrokinetic are chosen to add in the hybrid combination.
- Social impacts and public acceptance are also factors of concern when addressing additional power systems

What will not be included in the project:

- PDP2015 or Energy policy that might be changed due to political aspects.

1.3 Methodology

To achieve of the objectives of this project, following steps are required to be completed.

Step 1. **Analysing daily demand profile**: Current daily electricity demand will be classified throughout a year to understand its variation patterns in different period of the year and also in a day. Furthermore, future demand will be estimated to be use for simulation in the target area.

Step 2. **Identifying power generation status:** Types of fuel and resource will be carried out to be the base for an improvement. In addition, the characteristics and capacity of existing power plants will be classified to understand their abilities and be able to manage the energy system with more efficiency. For example, variable outputs are possible in conventional power plants, but not possible in power production from renewable sources.

Step 3. **Describing renewable resources**: Similar to demand profile, weather data such as wind speed and solar radiation will be identified for their variation patterns during a year in order to analyze their performance in different period of a year.

Step 4. **Costs of components:** After energy resources are carried out, cost of installation, O&M, and replacement cost of each technology will be classified in order to use for input parameter of each component.

Step 5. **Using HOMER software:** To present the efficient design of hybrid combination, a tool is required to ensure that the objectives of the project can be achieved. For this project, HOMER is selected to be the software as it can support in optimization of hybrid combination design and providing emissions and financial data for scenarios.

Step 6. **Suggesting suitable location for hybrid combination:** Since HOMER cannot cover social impacts of the result, location to allocate configuration of the model is suggested to analyze and minimize adverse effects on communities, as well as benefitting from fuel resources.

Step7. **Results and Conclusion:** This step includes discussing and comparing advantages and disadvantages of each scenario from the hybrid combination, then concluding the results. Lastly, suggesting the future work of the project.

2. Literature Review

The literature review will illustrate the in-depth background knowledge of this project in various aspects. There are 7 sections in this literature review that are carried out in detail:

- Thailand’s electricity infrastructure
- Energy production in Thailand
- Demand profile in Thailand
- Renewable resources potential in Thailand
- Thailand energy policies
- Power storage technologies
- HOMER Software

2.1 Thailand’s Electricity Infrastructure

The Kingdom of Thailand, which is in Southeast Asia, is home to around 68.8 million people in the area of 513,000 km2 that is divided into 76 provinces (excluding Bangkok, which is defined as a Special Administration Zone). There are 6 regions in Thailand, namely Northern region (9 provinces), Northeastern region (20 provinces), Eastern region (7 provinces), Western region (5 provinces), Central region (21 provinces) and Southern region (14 provinces) (Kongprasit et al., 2017).

For organization of Thailand’s power system as shown below in Figure 2, The Electricity Generation Authority of Thailand (EGAT), which is a state-owned utility organization, operates and owns most of the nation’s power production capacity and all of its transmission networks. EGAT also purchases electricity from neighboring countries through interconnected grid and private power producers then sells all the power it generates or purchases to another 2 state-owned enterprises: the Provincial Electricity Authority (PEA) and the Metropolitan Electricity Authority (MEA). The PEA and MEA own distribution networks and distribute power to residential, commercial and industrial consumers in Thailand in their regions of operation. MEA sells power to end users in Bangkok Metropolitan area, whereas all other areas are under PEA’s responsibility (Thanawattano, 2017).

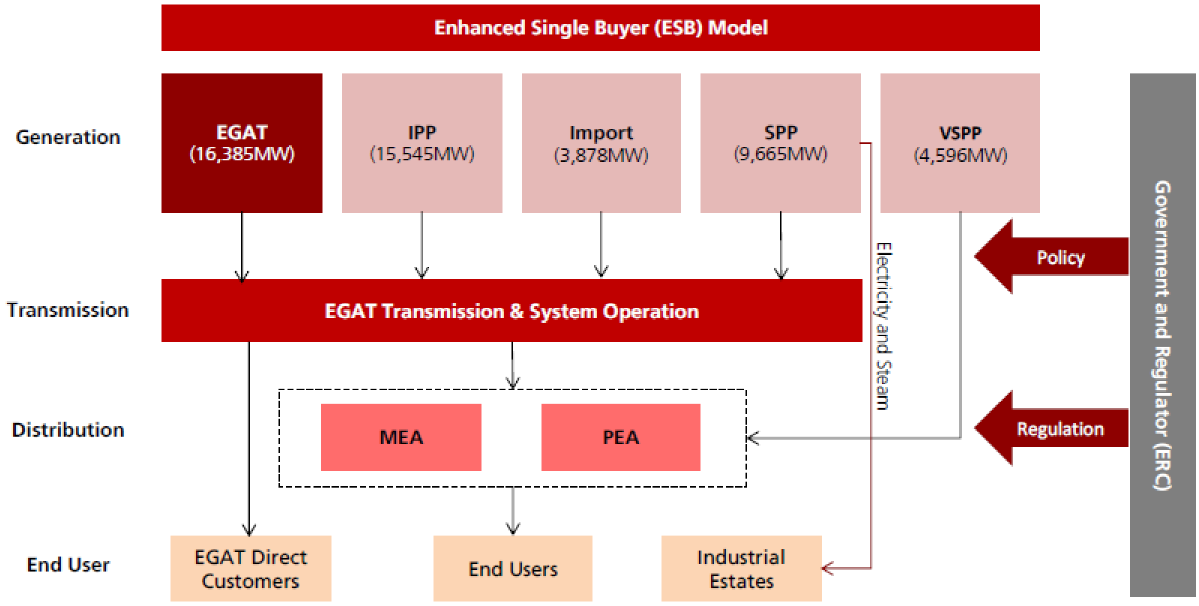


Figure 2: Thailand's electricity Industry Structure (Thanawattano, 2017)

The private sector has been permitted by the government to participate in power generation since early 1990s in order to alleviate EGAT's responsibility in building power plants to accommodate the fast-growing demand. Private power producers can be divided into 3 types:

- **Independent Power Producers (IPPs)** - generation of capacity more than 90 MW, under long-term power purchase agreements (PPAs) with EGAT
- **Small Power Producers (SPPs)** – generation capacity of 10-90 MW, and under PPAs with EGAT and electricity sales to industrial estates.
- **Very Small Power Producers (VSPPs)** – generation capacity no greater than 10 MW, and direct electricity sales to MEA and PEA.

Figure 3 below shows Thailand's installed capacity allocation. Even EGAT's capacity has decreased from more than 50% in 2006, it remains the highest among various producers at 36% of total capacity. IPPs account for 33% of the nation's capacity followed by 14% of SPPs. The capacity of VSPPs has increased from only 350 MW to 4600 MW, which is 7.7% of overall capacity, and is expected to reach around 12,000 MW over the next 20 years (Thanawattano, 2017).

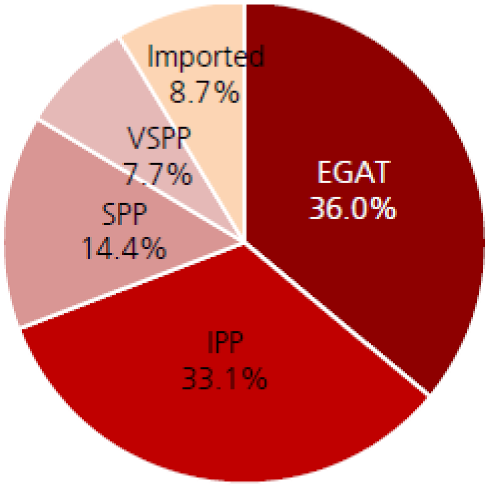


Figure 3: Thailand's installed capacity breakdown (Thanawattano, 2017)

As regards power transmission networks operated by EGAT, the standard voltage levels are 69 kV, 115 kV, 132 kV, 230 kV, 300 kV, and 500 kV at the operating frequency of 50 hertz. In 2017, transmission lines were connected with more than 200 substations with total length around 33,400 circuit-kilometers (IRENA,2017).

For the distribution networks, MEA has the standard voltage levels of 69 kV, 115 kV and 230 kV with total length of distribution lines at around 1,700 circuit-kilometers as of December 2015. In addition, PEA, which takes care of electricity supply within 99.4% of the country's area, has standard voltage levels of 22-33 kV, 69 kV and 115 kV with approximately 11,800 circuit-kilometers of total distribution lines in 2015 (IRENA, 2017).

2.2 Energy Production in Thailand

The installed capacity of energy generation in Thailand as of 2017 stood at around 44,500 MW, including the capacity of VSPPs and power imports from coal-fired power plants and hydropower in Laos. In terms of capacity breakdown by fuel types as illustrated below in Figure 4, power production relies heavily on fossil fuels, with 63.2% being generated from natural gas, 18.6% from coal and lignite, 9.9% imported from neighboring countries. Renewable energy sources account for only 6.2%, but this figure is expected to increase its share in total Thailand's power generation because of fluctuating prices for fossil fuel, fuel shortages, and promotion of alternative energy from the government (Thanawattano, 2017).

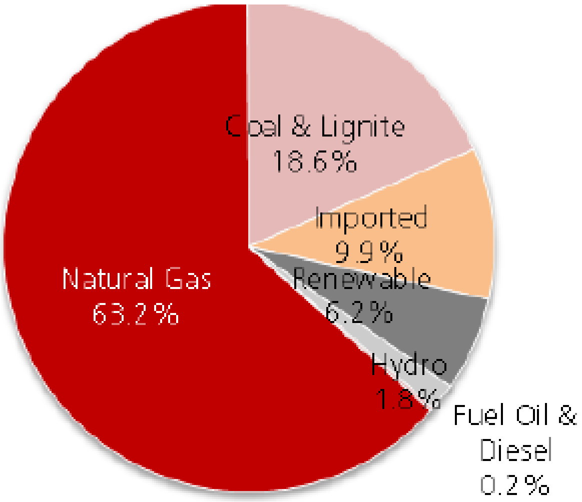


Figure 4: Type of fuel in power generation (Thanawattano, 2017)

Power station or power plant can be classified by many categories. For example, classification by resources such as fossil fuel, nuclear, geothermal, biomass, hydro power, solar and wind energy or classification by prime mover such as steam turbine, gas turbine, and combined-cycle, including gas turbine, boiler and steam turbine and using exhaust gas from gas turbine to generate electricity. In terms of classification by duty, it can be categorized into 2 types which are:

- **Base load power plants** operate almost continuously to produce electricity that does not vary within a day or a week. These plants are highly optimized for low price of fuel, but they may not start or shut down quickly within changes in load system. Nonetheless, power output from base-load plants can be predicable and controllable or vary following operation system, which it is called 'dispatchable plants'. Examples for these plants would include coal-fired and natural gas combined cycle stations, or predicable water supply hydro plants (Phdungsilp, 2015).
- **Peaking power plants** run to meet daily peak demand, which could be only a few hours each day. Operating cost of these plants is usually higher than conventional base-load power plants, thus they are required to supply only short peak periods and ensure security of the power system. Peaking plants would include single cycle gas turbine and hydro plants that designed for peaking use, which can be rapidly started up to supply when system peaks are predicted. In addition, renewable energy would be included in peaking plants since its power production cannot be deferred and controllable. In other words, it is called' non-dispatchable plants' (Phdungsilp, 2015).

As this project focuses on Southern Thailand, the following will identify power plants in the target area. According to EGAT (2017), Table 1 demonstrates power supply sources and explains their operating ability according to the above categories in the target area.

Power Plant	Resource	Operation	Capacity (MW)
1.Chana	Natural gas	Base load	1,476
2. Khanom	Natural gas	Base load	930
3. Krabi	Fuel oil (high operating cost)	Peaking load	315
4. Rajjaprabha Dam	Hydro	Peaking load	240
5. Bang Lang Dam	Hydro	Peaking load	72
6. Overall VSPPs (Wind + biomass)	Renewable	Peaking load	56
7. Surat Thani	Disel (high operating cost)	Peaking load	26
Total Capacity = 3,115 MW			

Table 1: List of power plants in Southern Thailand

In addition, Southern Thailand also imports 200 to 600 MW/day of electricity from Central region of Thailand through high-voltage transmission lines with the distance around 600 kilometers. Overall, power generation in Southern Thailand can be illustrated in Figure 5.

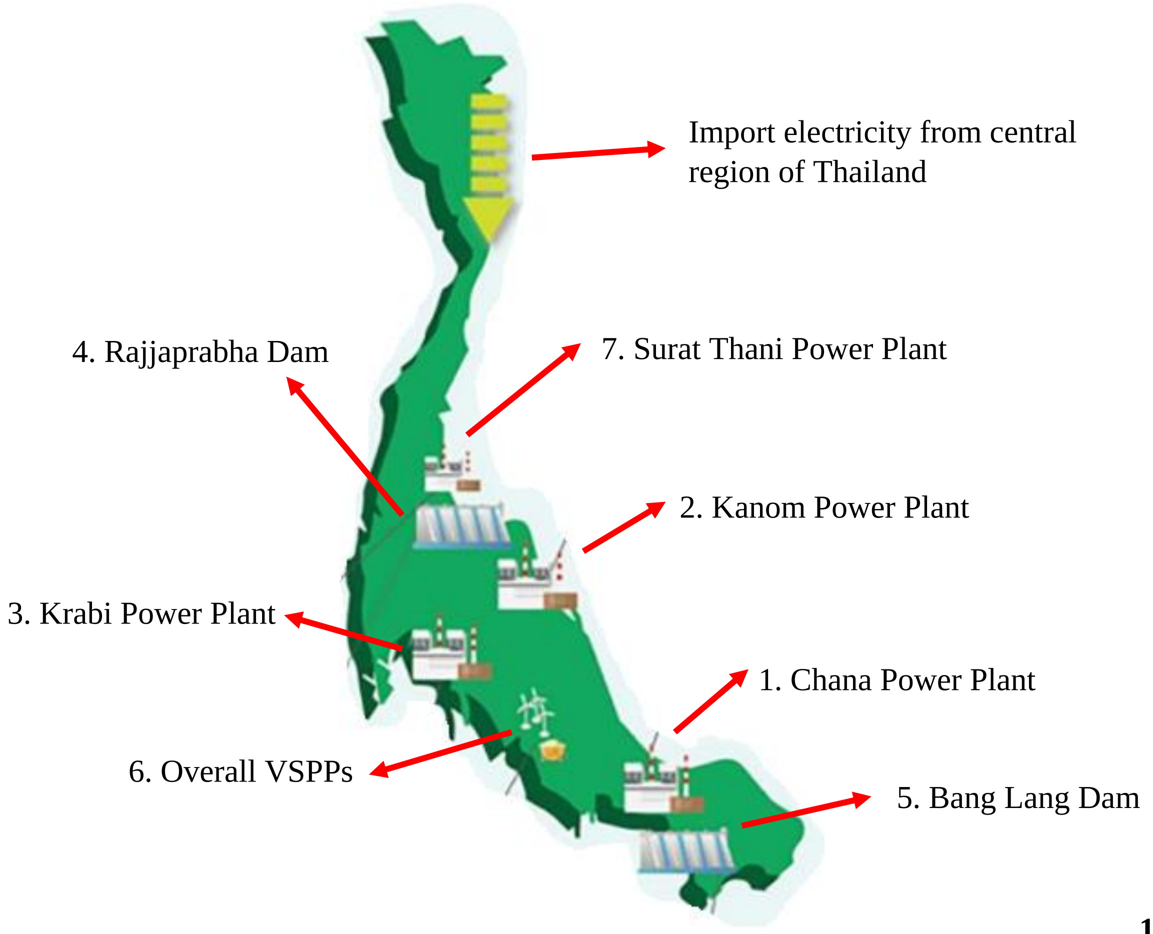


Figure 5: Location of power generation in Southern Thailand (Kongprasit et al., 2017)

2.3 Energy Demand in Thailand

Thailand's power demand has moderately predictable seasonal and daily cycles. Normally, peak periods are in hot summer when air-conditions are required to work on full operation, which is different from China, Japan, South Korea and the UK, where the demand increases in winter to meet heating needs. As a result, annual peak of the demand is usually between March-May which is the period of the highest temperature, whereas the lowest load is normally between December-January where they are the coolest months. In 2017, summer heat brought record of peak load with around 34,000 MW in May (Fan, 2017).

Power demand in Thailand can be categorized by consumer into 3 main types which is shown below in Figure 6. The industrial sector is the largest power consumer, which has accounted for around 50% of total power demand since 2007, but slightly decreased to 48% in 2016. Residential and business consumption has averaged 23% and 24%, respectively, with the share of business demand increasing from 20% to 24% throughout the same period. Overall, Thailand energy demand has increased by an annual average of approximately 3.7% between 2002-2016 (Himmler, 2017). In 2017, total power consumption was around 185,300 GWh, or 3.6% higher than the consumption in the previous year with the total of 174,800 GWh. Main reason for growth in the energy consumption is economic recovery, generally in the service, tourism, and construction industries (Fan, 2017).

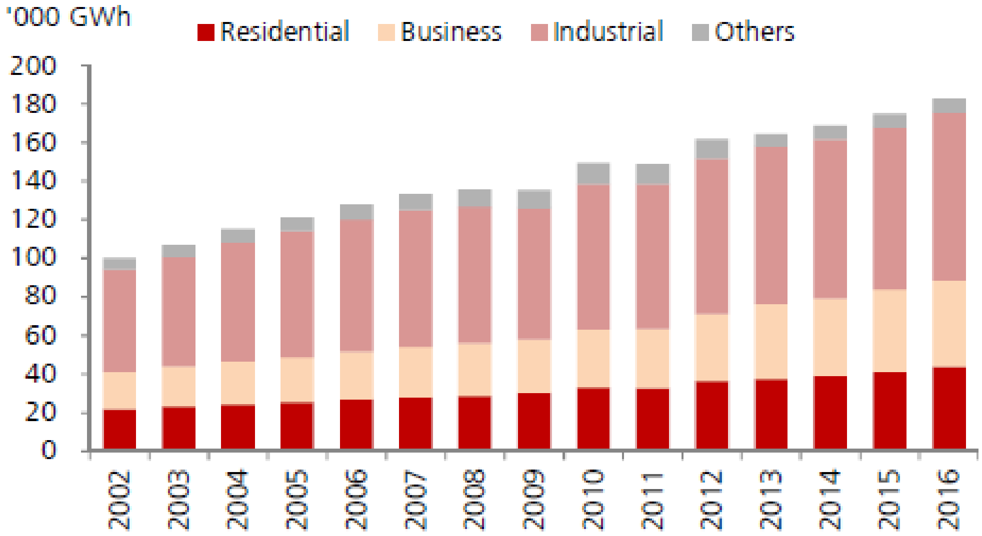


Figure 6: Thailand power consumption by sector (Thanawattano, 2017)

As mentioned above that different season has an effect on power consumption, the following will demonstrate daily demand profile of Southern Thailand in 3 seasons, which are summer season – run from March through to June, rainy season – from June through to October, and winter season – from November to February. In the Figure 7, three typical days in three seasons are selected to show the trend of the power consumption in each season. Further, on March 18, when the highest demand peak was recorded, is chosen for an example for the summer season.

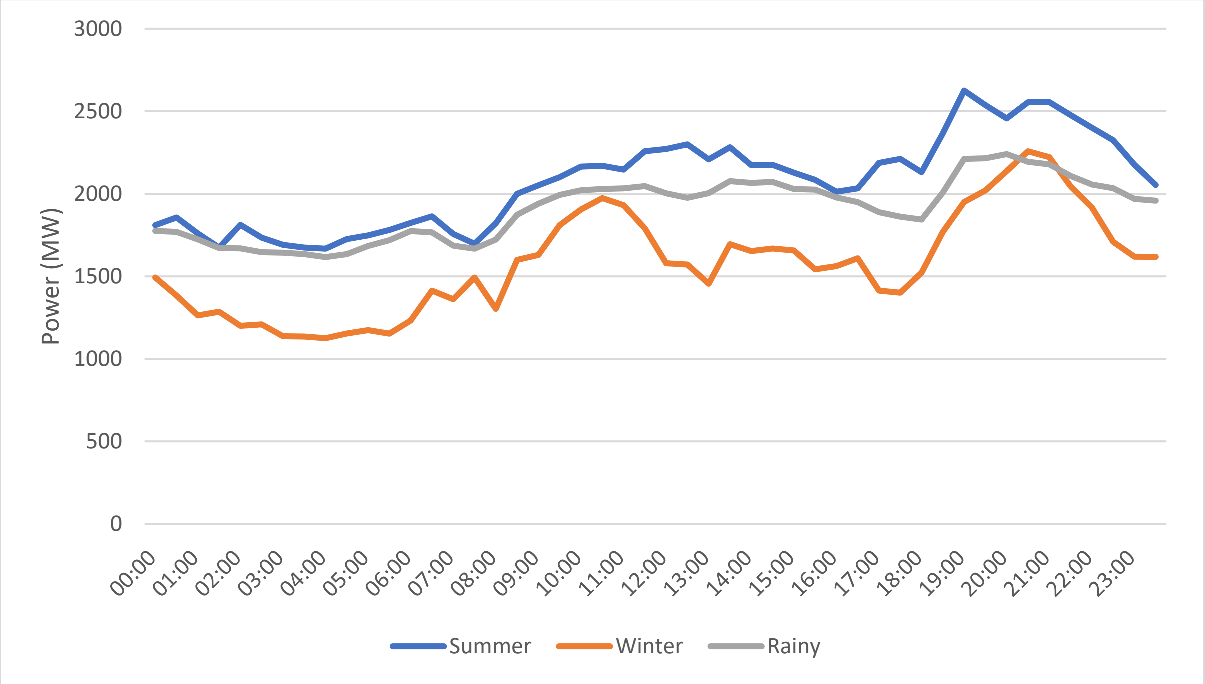


Figure 7: Daily demand profile in Southern Thailand (2017)

The trend of demand for electricity in Southern region of Thailand within typical days in summer, winter, and rainy season is shown in the Figure 7. It can be seen that every season has similar pattern of power demand, wherein the demand is in its maximum between 19:00 to 21:00 hrs. and also there is a sharp rise sharp from 8:00 to 12:00 hrs., while the demand decreases and remains almost constant between 23:00 and 6:00 hrs. when people are sleeping. In winter, the demand declines to its lowest point with around 1,150 MW at 4:00 hrs. On the other hand, during summer times, the demand reaches its peak around 2,600 MW, which is recorded as the highest demand in Southern Thailand. Overall, it is obvious that the highest of total power consumption is in summer, followed by that in rainy season and winter respectively.

In addition, Southern Thailand also imports electricity from central region of Thailand through high-voltage transmission lines. This tends to be a disadvantage of the power system since the long distance from each region creates huge losses of electricity in the transmission lines. Moreover, this seems to lower the reliability of its system because any incidents could happen to these long transmission lines, leading to a system failure.

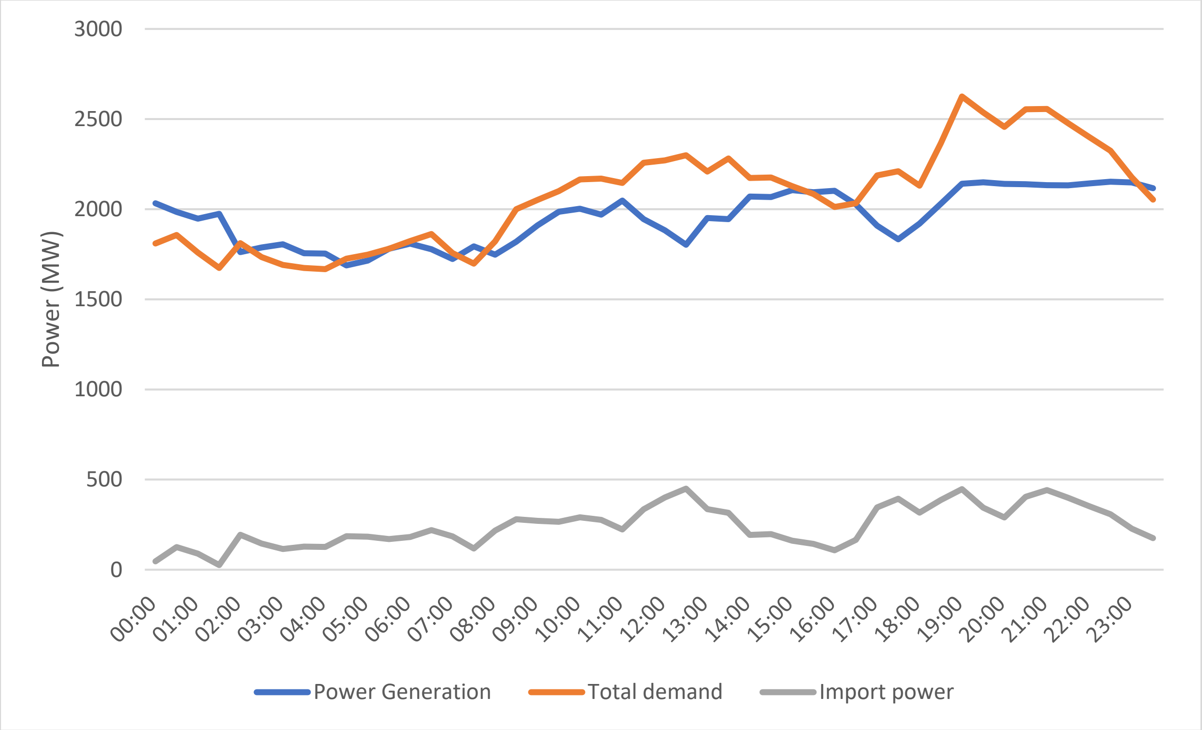


Figure 8: Daily demand and import electricity in Southern Thailand (2017)

A typical day in summer is selected to show the trends between power generated in Southern Thailand and imported from Central region of Thailand as demonstrated in Figure 8. Southern Thailand relies heavily on imported electricity, the highest of which is almost 500 MW and there is only 1 hour without the reliance on it. The imported power and total demand curves have similar pattern during a day, while power generation in the Southern area drop in the peak periods to balance the system. All in all, imported electricity accounts for around 22% of total electricity demand in Southern Thailand.

Discussing the Future of Power Demand and Supply in Southern Thailand

Even total power generation capacity in Southern Thailand is 3,115 MW excluding import electricity from Central Thailand, the base load capacity is only 2,400 MW, which is from two natural gas power plants. With the peaking load cannot continuously operate in full potential and it is aimed to decrease the reliance on import electricity from Central Thailand, the power system management in Southern area seems to face a huge challenge of energy shortage in near future since the peak demand reached to 2,600 MW and it is expected to increase 3.4% annually. In the next 20 years, this peak demand could be double with around 5,000 MW. With the currently system assuming that optional load can perform 60% and maximum import electricity is 400 MW, total power supply would be 3,200 MW, which cannot accommodate the future demand in the next 20 years. Furthermore, according to Ministry of Energy’s policy that requires the minimum reserve margin at 15% of the demand, the total power generation in the next 20 years should be at least 5,750 MW. As a result, Southern Thailand power system requires additional power at least 2,550 MW to accommodate the future demand.

2.4 Renewable Resources Potential in Thailand

Thailand has been supporting and promoting the development of energy, particularly in the field of renewable energy and energy conservation, to improve energy security and enhance well-being of the population. With the rising use of sustainable energy and improved energy efficiency, import of fossil fuel is expected to decline in the same way as the risks of long-term energy expenditure on power importation. Moreover, integration of these clean energies could provide multiple benefits such as economic, social, and environmental advantages, including job creation (IRENA, 2017).

Thailand is the leader on wind and solar energy production in Southeast Asia, although the contribution of renewable energies to the nation’s total power generation is currently small, or only around 8% of total power consumption. According to IRENA (2017), total amount of renewable energy in Thailand is around 9,700 MW, about 3,350 MW is from solid biomass, 2,600 MW from solar PV and hydropower, 620 MW from onshore wind power, and 475 MW from biogas. The proportion of these capacities is shown below in Figure 9.

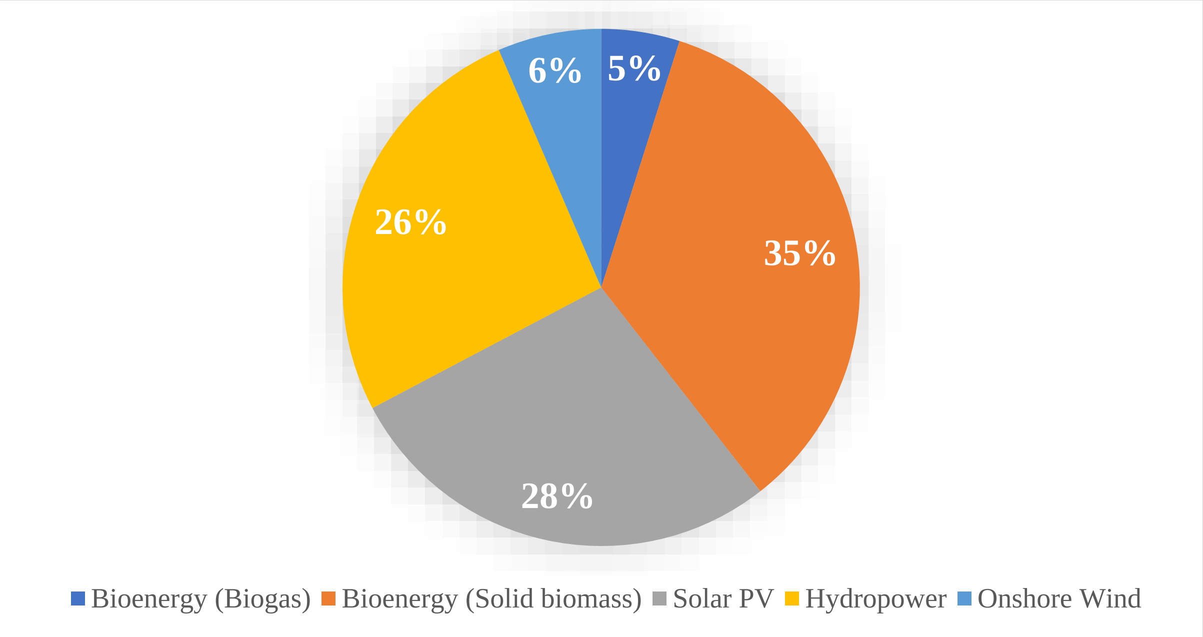
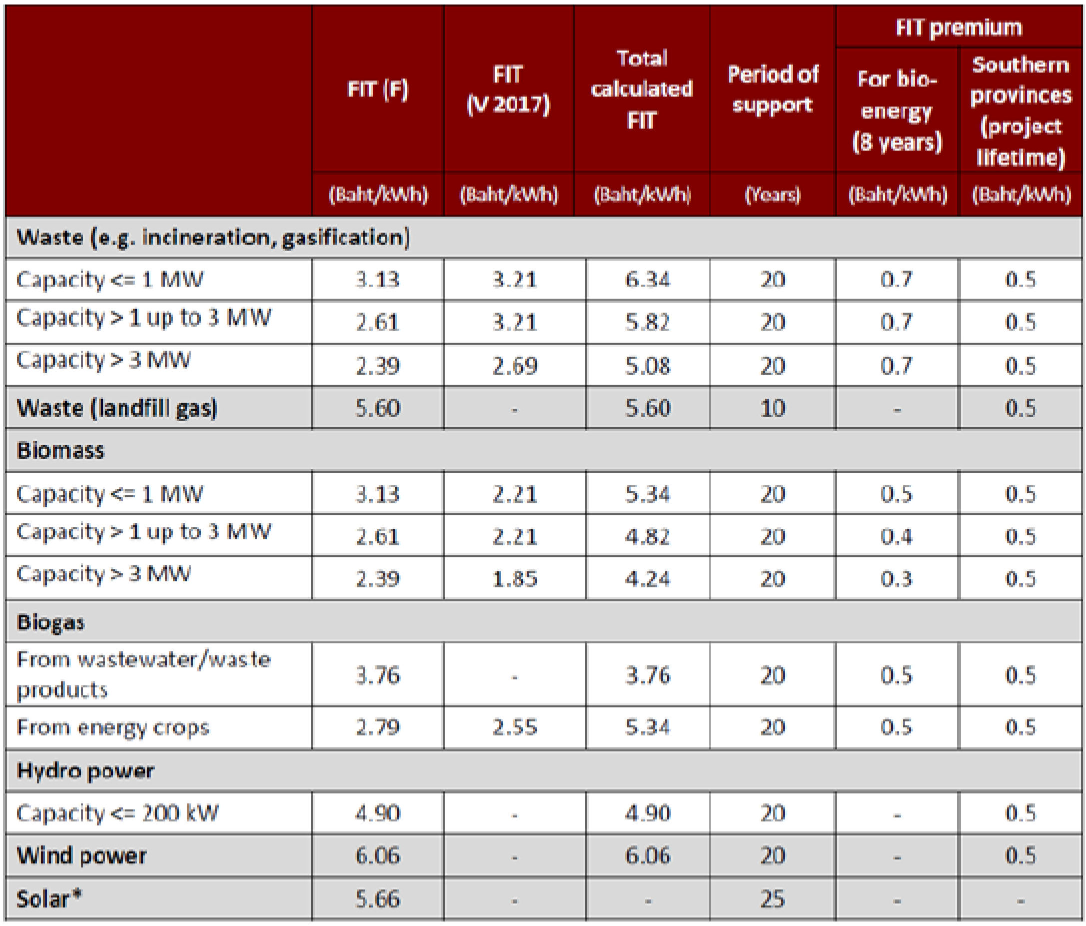


Figure 9: Total renewable capacity breakdown (2017)

The government had created inducement to private sectors throughout the initial phase of alternative energy in Thailand by providing 'adder' to attract more investors given investment on SPPs and VSPPs scale. The adder rate is added up to the normal wholesale price. However, after three years of operation with 'adder' scheme, several drawbacks were reported, such as uncertainty with the calculation of tariffs paid to consumers. The variation of global energy commodity prices cause uncertainty in the long-term tariffs paid to investors and also end users, further it does not precisely reflect on the levelised cost of energy (LCOE). Meanwhile, the government had the risks of over-subsidising compared to large cost reductions of onshore wind and solar PV installations around the world (Thanawattano, 2017).

As a result, the policy was changed from the 'adder' to the fixed Feed-in Tariffs (FITs) in 2013, which aim at determining the suitable prices for renewable electricity and improve investors' confidence. In comparison, FITs are lower than the adder but are in a longer timeframe of 20 to 25 years compared with the 10-year duration of the adder. Hence, according to this regulation, IRENA (2017) believed that it could still be favorable for investors. FIT rate of each type of sustainable energy are illustrated below in Figure 10.



	FIT (F)	FIT (V 2017)	Total calculated FIT	Period of support	FIT premium	
					For bio-energy (8 years)	Southern provinces (project lifetime)
	(Baht/kWh)	(Baht/kWh)	(Baht/kWh)	(Years)	(Baht/kWh)	(Baht/kWh)
Waste (e.g. incineration, gasification)						
Capacity <= 1 MW	3.13	3.21	6.34	20	0.7	0.5
Capacity > 1 up to 3 MW	2.61	3.21	5.82	20	0.7	0.5
Capacity > 3 MW	2.39	2.69	5.08	20	0.7	0.5
Waste (landfill gas)	5.60	-	5.60	10	-	0.5
Biomass						
Capacity <= 1 MW	3.13	2.21	5.34	20	0.5	0.5
Capacity > 1 up to 3 MW	2.61	2.21	4.82	20	0.4	0.5
Capacity > 3 MW	2.39	1.85	4.24	20	0.3	0.5
Biogas						
From wastewater/waste products	3.76	-	3.76	20	0.5	0.5
From energy crops	2.79	2.55	5.34	20	0.5	0.5
Hydro power						
Capacity <= 200 kW	4.90	-	4.90	20	-	0.5
Wind power	6.06	-	6.06	20	-	0.5
Solar*	5.66	-	-	25	-	-

Figure 10: FITs for VSPPs renewable energy projects (Thanawattano, 2017)

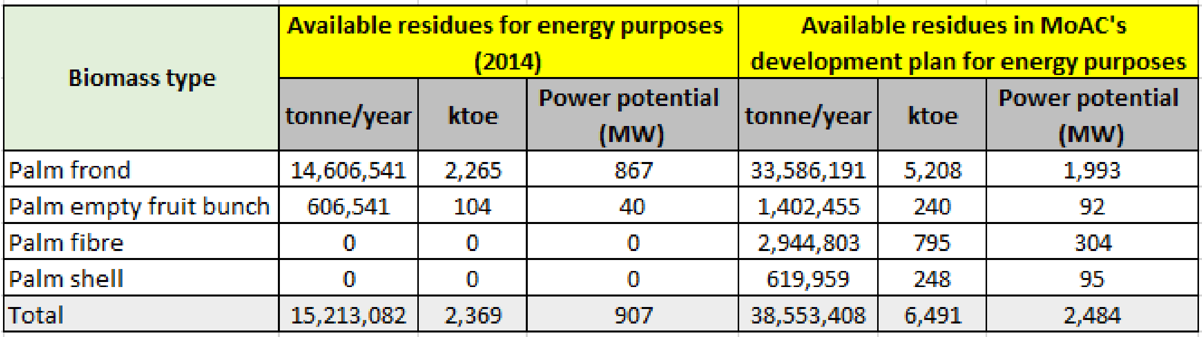
According to Figure 10, it is appeared that the variation of FIT rates depends on the fuel type, power plant size, and technology. In 2017, Total FIT rates range from 3.76 THB/kWh to 6.34 THB/kWh. For bioenergy projects, there is an additional FIT Premium of 0.3 – 0.7 THB/kWh for 8-year project period. In addition, another FIT premium is also added within the lifetime of the projects, which are located in Southern Thailand. The FIT rates favor for small-scale system, similar to biogas and biomass. This government intention is to promote alternative energy within communities, which mainly focusing on biogas, biomass, and waste energy.

The following part will explain the potential of bioenergy, wind and solar power in Southern Thailand in order to analyse their abilities in the hybrid combinations.

2.4.1 Biomass

Although the rising of tourism and industrial sectors, agriculture, which is Thailand's traditional economy, remains important since there is significant number of registered farmers who living in poor conditions. Thus, the government has large incentives to provide opportunities for farmers to increase their incomes by setting FIT, which is shown in Figure 10, to attract more people to invest in bioenergy business.

As reported by the Ministry of Agriculture and Cooperatives (MoAC), geographically, residues from agriculture such as bagasse, rice husk and cassava are widely distributed in the Northern, Northeastern, and Central regions, whereas oil palm residues exist mostly in the Southern region. According to Alternative Energy Development Plan (AEDP 2015), it is expected that the biomass-fueled electricity production is doubling the installed producing capacity, which will be represented almost half of total additional to alternative energy by 2036 (IRENA,2017).



Biomass type	Available residues for energy purposes (2014)			Available residues in MoAC's development plan for energy purposes		
	tonne/year	ktoe	Power potential (MW)	tonne/year	ktoe	Power potential (MW)
Palm frond	14,606,541	2,265	867	33,586,191	5,208	1,993
Palm empty fruit bunch	606,541	104	40	1,402,455	240	92
Palm fibre	0	0	0	2,944,803	795	304
Palm shell	0	0	0	619,959	248	95
Total	15,213,082	2,369	907	38,553,408	6,491	2,484

Table 2: Biomass residue potential in Thailand

As mentioned above that oil palms are widely planted in Southern Thailand, Table 2 focused on the oil-palm-fueled potential according to AEDP 2015. The figures shown in this table are only the amounts made available for energy purposes. Currently, there are two small biomass power plants operating in Southern Thailand, of which the power output is combined in the overall VSPPs in Figure 5:

- Yallah power plant – Power capacity 20 MW - Resource: Scrapped Rubber Trees
- Slattani power plant – Power capacity 10.4 MW – Resource: Palm empty fruit bunch

From Table 2, total power production from biomass can be increased from only 30 to 907 MW according to a study from IRENA (2014), this figure could reach almost 2,500 MW regardless of MoAC's development plan, but this seems to be more difficult for achievement.

2.4.2 Wind Power

According to current assessment of wind potential by Department of Alternative Energy Development and Efficiency (DEDE), the average Thailand's wind speed is around 5 m/s measured at a height of 90 meters, as illustrated below in Figure 11. Recently, total installed wind energy capacity is 620 MW, but this figure has a potential to reach 13 GW within 21 areas across the country (IRENA, 2017). A research from Manomaiphiboon et al. (2017) stated that Thailand has potential to increase wind power capacity up to 17 GW if modern low-speed technology wind turbines are adopted, and conventional wind turbines can still be used by one-third of this approach. Geographically, the highest wind speed is in the western, northeast, and southern regions of Thailand.

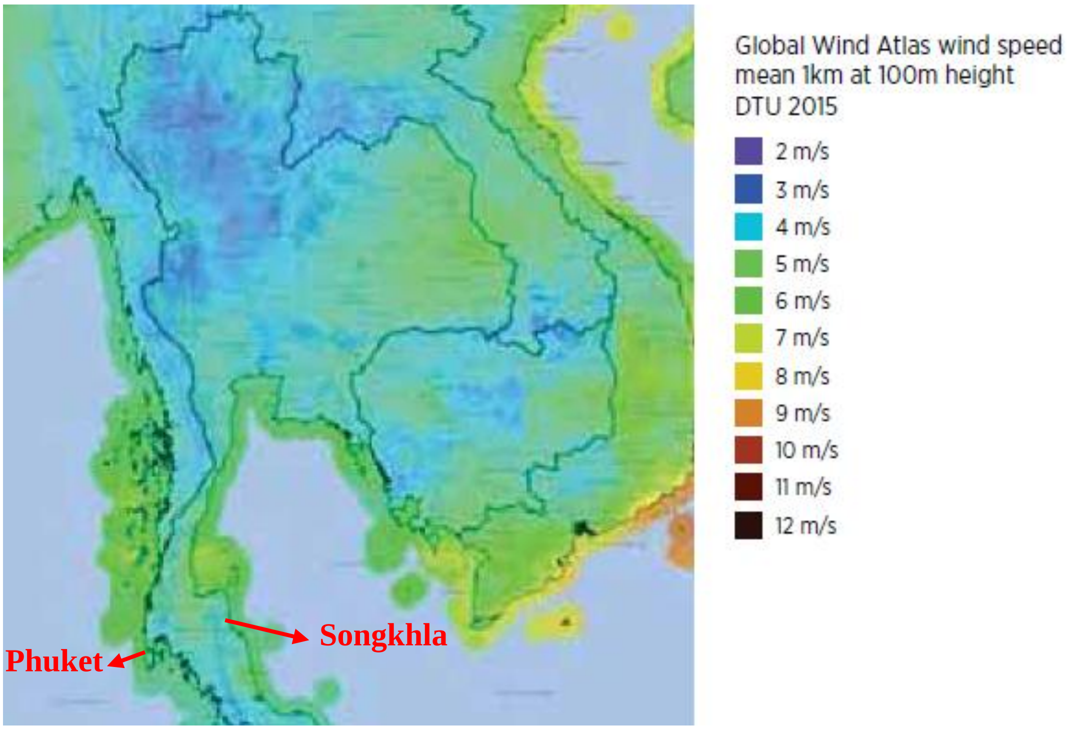


Figure 11: Wind potential map for Thailand at 90 meters (IRENA,2017)

Phuket and Songkhla, the locations of which being shown in Figure 11, are expected to be target areas for wind energy in this project. Since these two cities are in the Southeast and Southwest Thailand, the annual average wind speeds of both cities are in the different patterns due to a variation of wind directions in a year. The wind usually blows from west to east for 7 months, from April to October, while it often comes from east to west in another 5 months (Weatherspark, 2018). This diverges the period of high wind speed from Phuket and Songkhla, which is shown below in Figure 12.

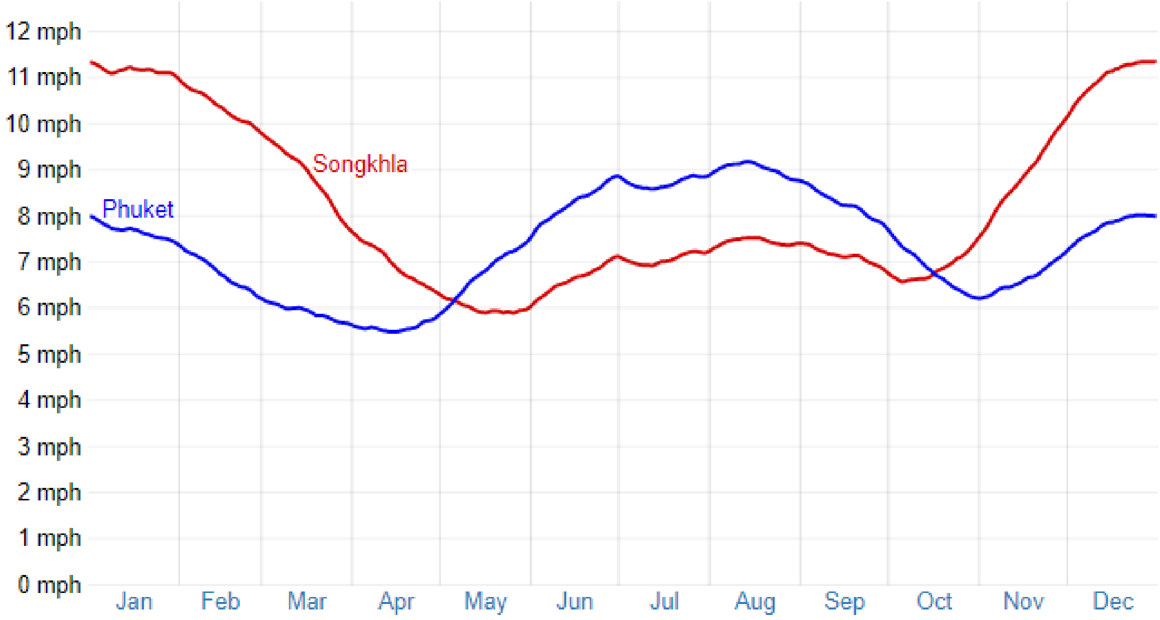


Figure 12: The average of hourly wind speeds at 10 meters above the ground (Weatherspank, 2018)

Figure 12 illustrated the average of hourly wind speed in Songkhla and Phuket at 10 meters above the ground. The average wind speed in this figure could be slightly lower than in Figure 11 because the height of this measure is only 10 meters above the ground and could not be sufficient for additional wind turbine, but the main purpose of this section is to compare both wind speed trends of these two cities.

Nonetheless, it appears that both trends experience significant seasonal variation during a year. In Songkhla, the windier period of the year lasts for around 4 months, from November to March, with an hourly average wind speed of 11.3 mph (5 m/s). The calmer time lasts longer for almost 8 months with an hourly average speed of 5.9 mph (2.6 m/s). On the other hand, Phuket's windier part lasts from May to October with an average wind speed around 9.2 mph (4.1 m/s) and the calmer period lasts in different time of the year with a mean wind speed of 5.5 mph (2.45 m/s). Overall, both trends from two locations can compensate a wind speed of on another in most of the year, which will be beneficial for the whole power system.

According to AEDP 2015, the annual growth rate is expected at an average of 12-13% over the next twenty years. The majority of wind projects will be executed by the private sector such as VSPPs, SPPs and IPPs as EGAT plans to reduce its wind capacity to less than 6% of total wind energy contribution. However, this development in Thailand still faces many challenges, such as suitable land use or financial investment (IRENA,2017).

2.4.3 Solar PV

Thailand is located in the tropical area and, as a result, contains significant solar power source across the country, with high solar potential in Northeast, Central regions and coastal areas of Southern Thailand. These locations receive both direct solar radiation, which can produce greater electricity and heat, and diffuse solar radiation (Ministry of Energy, 2015).

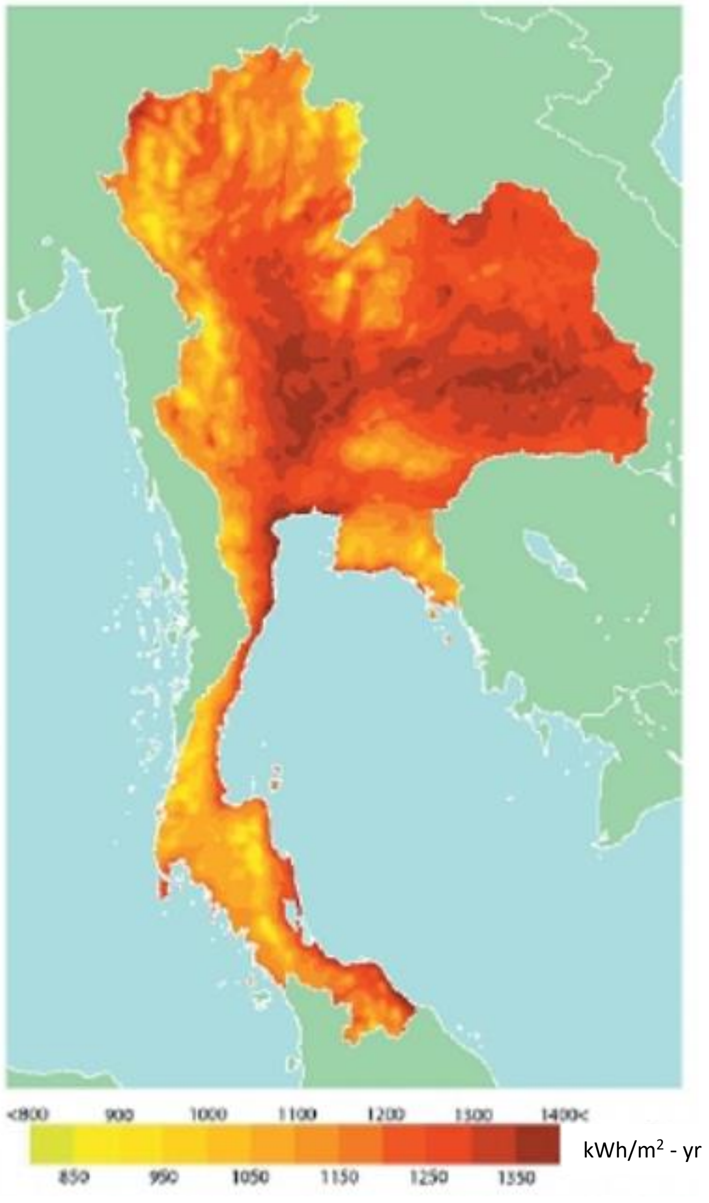


Figure 13: Thailand solar energy resource potential (MoE, 2017)

According to Figure 13, the peak direct radiation density in Thailand is around 1,350 – 1,400 kWh/m^2/ year, covering 4.3% of the nation’s area in southern part of Northeast region and Central region, whereas almost 20% of the country’s area has generally 1,200 – 1,300 kWh/m^2/year. The peak density of solar radiation is usually in April, then descending to the lowest point in December. At the end of 2016, Thailand had total solar PV installed capacity of 2,750 MW, more in solar energy than all the rest of Southeast Asia combined (IRENA, 2017).

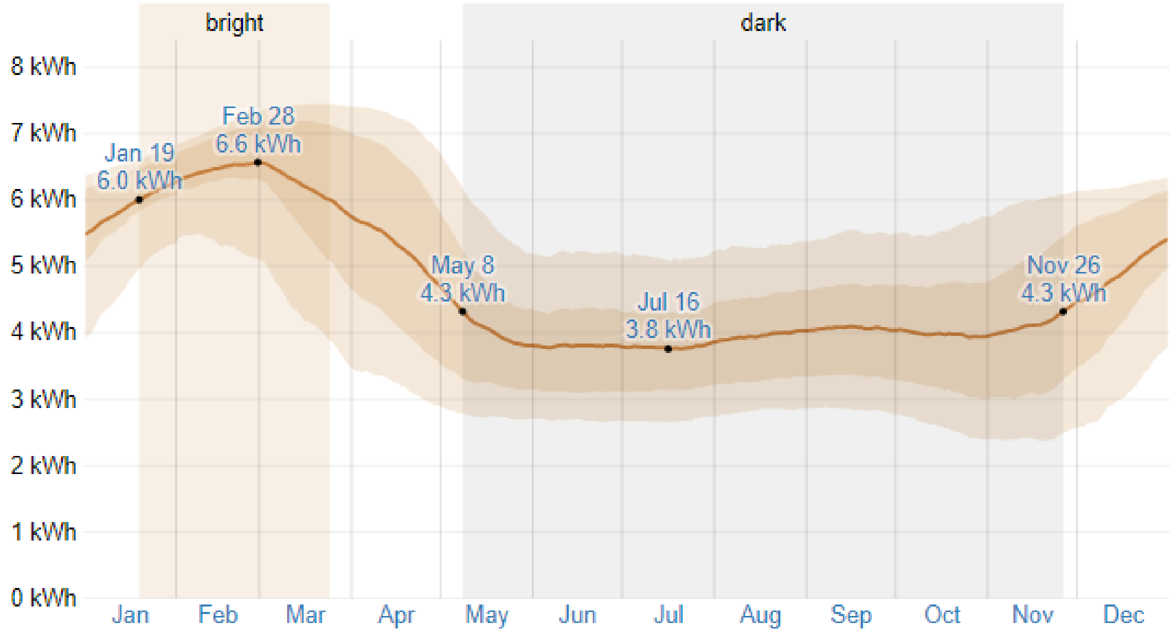


Figure 14: The average daily incident shortwave solar energy reaching the ground per square meter in Songkhla (Weatherspark, 2018)

Songkhla is selected as the sample area to demonstrate the pattern of solar energy within a year as it gains the highest solar energy in Southern Thailand. However, the pattern, which is shown in Figure 14, from Weatherspark (2018) is slightly different from a research from IRENA (2017), which stated that the solar energy is usually peak in April. To avoid confusion, this project will focus on the data from Weatherspark (2018) since it was specifically reported from Songkhla, while a research from IRENA (2017) was based on information of the average solar energy in the large scale across the whole country.

According to Figure 14, in Songkhla, the average daily shortwave solar energy reaching the ground experiences some seasonal variation during a year. The brighter part of the year lasts around 2 months from January to March, with the peak incident shortwave energy of 6.6 kWh/m^2 and average of 6 kWh/m^2. The darker part of the year lasts for approximately 7 months from May to November, with the lowest incident shortwave energy of 3.8 kWh/m^2.

As regard of AEDP 2015, it is expected that current 2,750 MW of total solar energy capacity will increase to 6,000 MW in 2036, and also the reduction of capital cost from a competition between private sectors such as activity in the rooftop solar PV market (IRENA, 2017).

Hydropower

Aroonrat and Wongwises (2015) stated that development of hydropower electricity production in Thailand is the main duty of three agencies: EGAT, PEA, and DEDE. Based on capacity and productivity, hydropower plants can be classified by 4 categories:

- **Micro hydropower:** lower than 200 kW
- **Small or mini hydropower:** 200 kW – 6 MW
- **Medium hydropower:** 6 MW – 20 MW
- **Large hydropower:** more than 20 MW

By the end of 2013, the on-grid productivity of Thailand's hydropower reached around 3,500 MW, accounting for about 11% of the whole power generation system. A study by Aroonrat and Wongwises (2015) reported that the current potential of Thailand's hydropower is at 15,200 MW or almost four times the current capacity. Additionally, there are 25 river areas across the country that could accommodate small-scale hydropower plants with an overall potential of more than 1,500 MW.

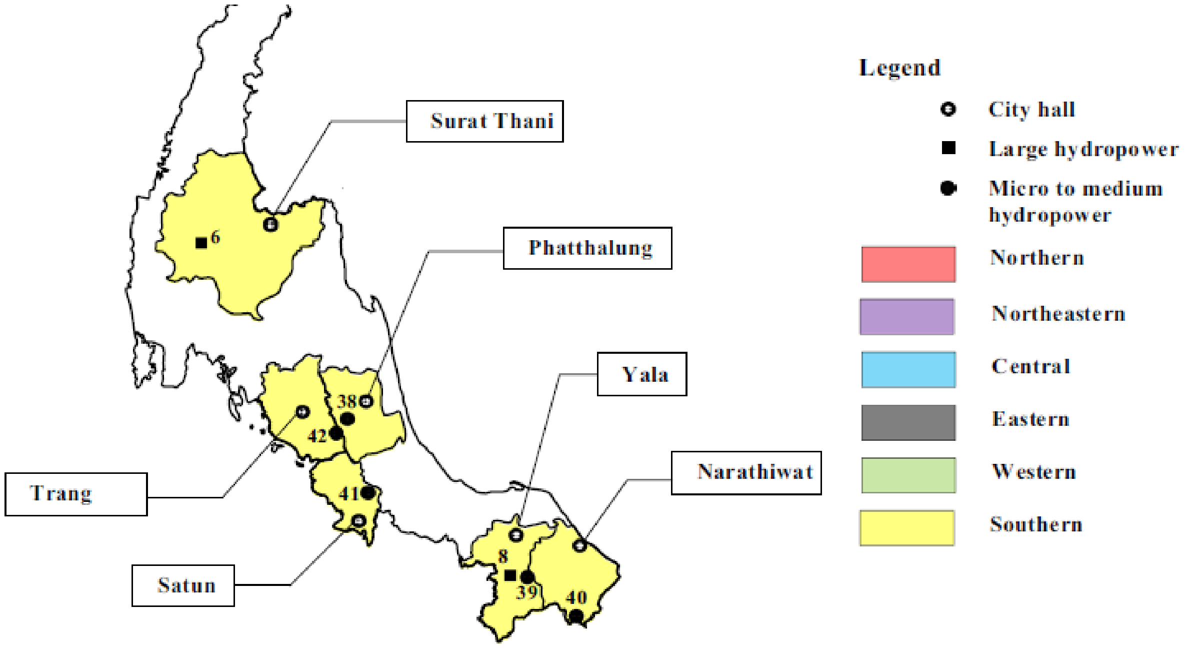


Figure 15: Map of hydropower plants in Southern Thailand (Aroonrat & Wongwises , 2015)

As presented above in Figure 15, there are seven installed hydropower plants in Southern Thailand including two large hydropower plants and five micro to medium plants which are:

- 6. Rajjaprabha plant – 240 MW
- 8. Bang Lang plant – 72 MW
- 38. Huai Lam Sin plant – 958 kW
- 39. Ban Santi plant – 1,275 kW
- 40. Aikapoa plant – 200 kW
- 41. Khlong Lam Plok – 1,182 kW
- 42. Khlong Du Son – 680 kW

According to above list of hydropower plant, total installed hydropower capacity in Southern Thailand is about 315 MW. Aroonrat and Wongwises (2015) admitted that the building of a medium to large-scale hydropower plant had caused many social and environmental impacts. Thus, it seems to be difficult for a construction of large-scale hydropower plant particularly in community areas. However, small-scale hydropower plants could be an alternative option for hydropower project. Given uncomplicated operation and shorter duration of construction, small-scale hydropower plants are appropriate for developing countries like Thailand. In addition, this type of hydropower not only provides electricity to main energy supply of the nation but also provides direct electricity distribution to local communities.

Nevertheless, a construction of small-scale hydropower is still facing some technical challenges such as low head for turbine and low water speed due to local geology. A study of Chamamahattana et al. (2005) estimated that hydropower potential in Southern Thailand could reach 645 MW or another 330 MW can be added in the area.

2.5 Thailand Power Development Plan 2015-2036 (PDP2015)

In 2014, the Ministry of Energy of Thailand developed 5 plans related to energy development and management to cope with changes in national infrastructure and economic conditions of the ASEAN Economic Community. These plans include:

1. Thailand Power Development Plan: PDP
2. Energy Efficient Development Plan: EEDP
3. Alternative Energy Development Plan: AEDP
4. Natural Gas Supply
5. Petroleum Management Plan

In alignment with the National Economic and Social Development Plan, these energy-related plans have been directed towards increasing power generation along with reasonable energy costs and lower CO_2 intensity from power production. Being the most recent energy policies of Thailand at the time, focus of this project will be placed on PDP2015 and AEDP2015 as the simulation standard and target.

Main emphasis of PDP2015 is to improve the reliability of the power system through reduction of reliance on natural gas, increase of coal power generation via clean coal technology, imports of hydropower from Thailand's neighbors and adoption of renewable energy. In parallel with such implementation, the plan incorporates transmission and distribution system development to facilitate renewable energy improvement and to accommodate rising demand for energy in the AEC. The estimated fuel requirements under PDP2015 are described in the Table 3: (Ministry of Energy, 2015)

Fuel	Proportion in 2015	Proportion in 2036
Imported hydropower	7%	10-15%
Clean coal and lignite	20%	15-20%
Renewable energy and hydropower	8%	25-30%
Natural gas	64%	30-40%
Nuclear	-	0-5%
Diesel/Fuel oil	1%	-

Table 3: An estimation of fuel requirements for the PDP2015

Alternative Energy Development Plan (AEDP)

Although the "Alternative Energy" and "Renewable Energy" have played an increasingly important role in the power generation system for some time, their investment and production costs remain higher than energy generation from conventional resources, for instance natural gas and coal. However, the issues of climate changes and global warming from greenhouse gas (GHG) emissions have been recognized as being caused by such conventional energy production. CO_2 – one of the most well-known GHGs – is largely emitted from fossil fuel combustion in the energy and industrial sectors. The Thai government has therefore promoted AEDP to enhance a low-carbon society and in so doing, the Adder System has been introduced to attract investors into the alternative power production. Meanwhile, the current Feed-in Tariff (FIT) serves to realize accurate costs of renewable power production, which is explained in the previous part of the project (Ministry of Energy, 2015).

AEDP2015 has been prepared to implement a renewable energy scheme for the benefits of the society, with reduction of fossil fuel use and management of social impact issues concerning agricultural and solid waste. As its first priority, the plan is aimed at supporting biomass, biogas and waste power generation. In accordance with MoAC policy to increase sugarcane and oil palm plantations in Southern Thailand, the potential of power generation from waste and biomass will likely stand at 500 MW and 2,500 MW, respectively. In the overall, the major objective of the AEDP2015 is to raise the share of renewable energy generation from 8% to 25-30% of total power production by 2036, or to a total of 19,364 MW as displayed in Table 4 below.

Year	Solar	Wind	Hydro	Waste	Biomass	Biogas	Energy Crops	Total
2014	1,298.5	224.5	3,048.4	65.7	2,541.8	311.5	-	7,490.4
2036	6,000	3,002	3,282.4	500	5,570	600	680	19,634.4

Table 4: The Alternative Energy Development Plan (MW) in 2036

According to PDP2015, there is a framework to ensure power system stability and reliability in terms of production, transmission, and distribution of areas that have high feasibilities of energy shortage in near future. Southern Thailand is considered to include in this area. As a result, PDP2015 suggested a plan to increase power generation capacity in the area by adding 3 power plants during 2019-2024 as following list:

• **Krabi Coal-fired Power Plant (2019)**	800	MW
• **Thepa Coal-fired Power Plant unit 1 (2021)**	1,000	MW
• **Thepa Coal-fired Power Plant unit 2 (2024)**	1,000	MW

However, building these power plants faced huge negative public opinions along with environmental and health impacts. At the beginning of 2016, local villagers reported that the construction of these plants would require the relocation of approximately 250 households along with 2 Muslim cemeteries, 2 mosques, a Buddhist temple and a religious school. In February 2018, after a week of several protests and a hunger strike, the Energy Minister said that the Ministry planned for the additional 3 years postponement to study the plans and determine whether coal-fired power plants is needed in Southern Thailand. If the answer is no, policymakers will create a Plan B for renewable resources or appropriate power production systems for the region (Yaikratok, 2018).

For this reason, this project aims at studying feasibility of renewable resources to accommodate future demand in the region, which could receive more positive public opinions than conventional coal-fired power plants. The criteria of the project are in accordance with AEDP2015 which aims at increasing alternative resource generation to reach 30% of total power production system. Therefore, hybrid combination for this project should consist of renewable systems at least 30% of the model.

2.6 Power Storage Technologies

Due to the intermittent availability of the renewable resources, for example sunlight that does not shine at night and wind speed that is not consistent, power back-up storage is necessary to be included in energy generation systems in order to store the power to meet the energy demand, which making it easier to balance the power system. There are many power storage technologies such as pumped hydro, flywheel, and batteries that can be used with the power system.

Pumped hydro

Pumped hydro storage is one of the most popular storage technologies as it can provide high energy capacity with lower capital costs compare to other storage technologies. However, the main disadvantage of this technology is the specific nature of the area that required both water availability and geographical height. Nevertheless, pumped hydro storage is the largest capacity of power storage technologies as it accounts for around 96% of worldwide storage installations, with total installed capacity of 168 GW (Global Energy Storage Database, 2018).

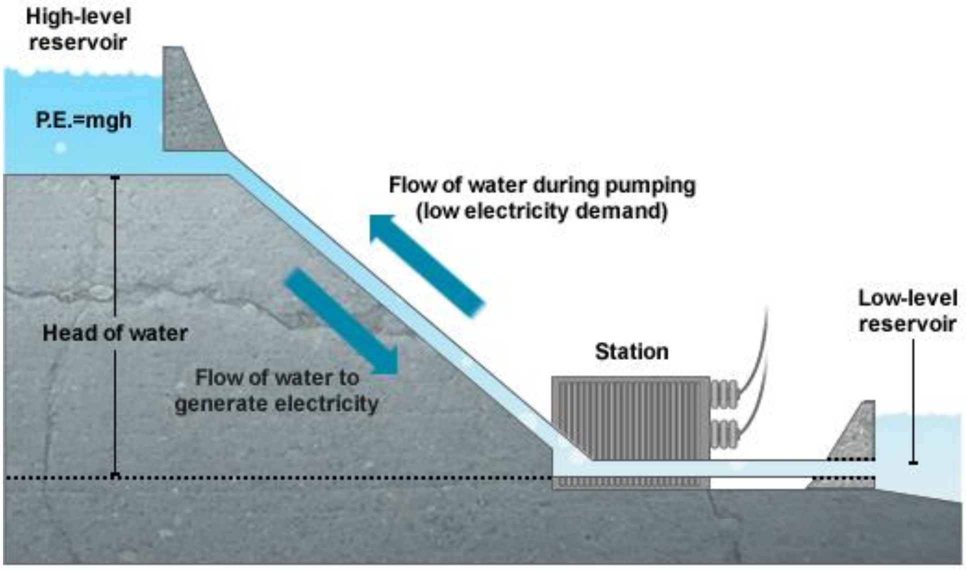


Figure 16: Pumped hydro storage diagram (BBC, 2014)

In terms of operation, pump hydro, as illustrated in Figure 16, will pump the water from the lower reservoir to store in the upper reservoir when the period of low power demand or excess energy. In contrast, the water is released from the upper reservoir through turbines to produce the power during periods of peak energy demand (BBC, 2014).

Flywheel

Flywheel, as shown in Figure 17, consists of a rotating wheel, storing kinetic energy. Motors increase speed of the flywheel to keep energy, and then the energy is released by slowing down its generator. This type of storage has extremely high-power capability, but significantly low using time or energy storage capability. For instance, flywheel, which operates in Stephentown, New York, can produce 20 MW but only for 15 minutes (Lin, 2017).

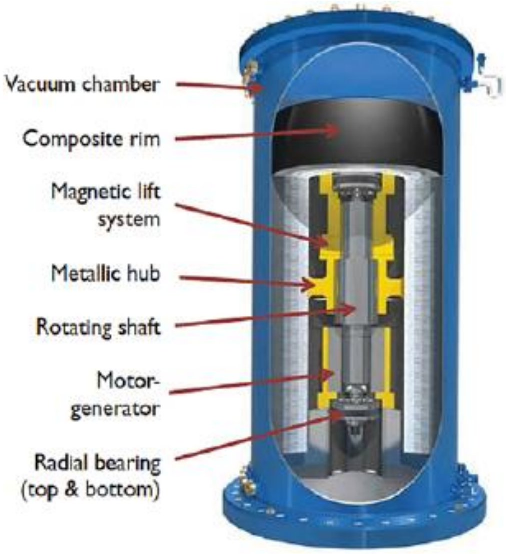


Figure 17: Flywheel Structure (Lin, 2017)

Batteries

One of the most recognized means of power storages is battery – a rechargeable equipment of energy storage that uses a reversible chemical reaction to store and release its electrical energy. There are various types of battery such as lead acid, lithium ion, sodium beta alumina and flow batteries, and each type has their specific advantages and disadvantages (Lin, 2017). This project will focus on lithium ion battery as it is available in HOMER to use for simulation.

2.7 HOMER Software

HOMER (Hybrid Optimisation of Model with Multiple Energy Resources) is the program for optimizing on-grid and off-grid hybrid combination of power system or microgrid design in all size of sectors, from small villages and grid-connection islands to military bases and community scale. In addition, this software evaluates financial and technical aspects of each possible scenario, which allow users to consider a huge number of suitable options to account for energy resource availability and other variables (HOMER, 2018). However, Cherni et al., (2007) stated that the outcomes of this software are based upon only technical and economic aspects and do not include the consideration of environmental and social impacts. Nonetheless, a newer version of HOMER Pro is included the consideration of environmental aspects such as carbon dioxide, sulfur dioxide emissions and particulate matter, which make this tool more efficient in power system analysis even it has some limitation on components for simulation.

Since the aim of this project is to investigate suitable design of hybrid combinations under factors of renewable fraction, the levelized cost of energy (COE), and percentage of the carbon dioxide (CO_2) emission reduction, the following part will explain the definition and calculation of renewable fraction and COE and the net present cost (NPC), which are more complex than carbon dioxide emission.

The renewable fraction is defined as the fraction of the energy delivered to the load that originated from renewable energy resources, which can be identified in the Equation 1 below (HOMER, 2018).

Equation 1 – Renewable fraction

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

Where: E_{nonren} = nonrenewable energy production and grid import [kWh/year]

E_{served} = total energy served to the load [kWh/year]

The levelized cost of energy (COE) is defined as the average cost per kWh of useful electrical energy generated by the system, which can be explained in the Equation 2 below (HOMER, 2018).

Equation 2 – The leverlized cost of energy (COE)

$$COE = \frac{C_{ann,tot}}{E_{served}}$$

Where: $C_{ann,tot}$ = total annualized cost of the overall system [£/year]

E_{served} = total energy served to the load [kWh/year]

The net present cost (NPC) can be called as life-cycle cost of a component, is the present value of all the installation, operation and maintenance cost of the component during the project lifetime, which can be illustrated in the Equation 3 below (HOMER, 2018).

Equation 3 – The net present cost (NPC)

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})}$$

Where: $C_{ann,tot}$ = total annualized cost of the overall system [£/year]

i = the annual discount rate [%]

R_{proj} = the project lifetime [year]

CRF( ) = a function returning the capital recovery factor

The percentage of the reduction of CO_2 emission is the proportion of amount level of CO_2 of the hybrid combination model that is decreased compare to the base model, which can be identified in the Equation 4 below.

Equation 4 – % CO_2 emission decreased

$$\% = 1 - \frac{CO_2\ emission\ of\ hybrid\ combination\ (\frac{kg}{year})}{CO_2\ emission\ of\ base\ model\ (\frac{kg}{year})}$$

3. HOMER Simulations

As explained before in Chapter 2.7 that HOMER has the potential to calculate financial and technical aspects of each possible hybrid combination and allow users to consider a huge number of suitable options to account for energy resource availability and other variables, HOMER is selected to be the software for simulations in order to find appropriate design of hybrid combination under factors of renewable fraction, COE, and CO_2 emission. The following chapter will demonstrate the in-depth relevant data to use for simulation in this software.

An explanation of HOMER simulations will be divided into 2 main sections, which are input data, constrains and assumptions, and scenario results and discussions will be in the next Chapter. In this project, input data is relevant to electricity demand in Southern Thailand and power system components including renewable resources, battery and converter. Constrains and assumptions of the simulation are conditions that directly influence the results. Since some parameters in HOMER cannot adjust to match likelihood outcome and some renewable resources are difficult to find an accurate result, constrains and assumptions are set in this simulation in order to access the most realistic outcomes as possible. Results of this project are related to base model and all design of hybrid combinations, which are carried out after two previously steps.

3.1 Input Parameters of the Project

In the project, daily electricity demand in the area of Southern Thailand is the first aspect to research. After that, hybrid combinations were designed using HOMER to find suitable models to achieve the aim of the project. Hybrid combination model consists of electricity load, battery, converter and power generation systems from conventional resources for example natural gas combined cycle plant (NGCC), and from renewable resources such as solar PV, wind turbine, biomass power plant, and hydrokinetic. The following section will break down each component and identify important parameters relevant to simulations.

3.1.1 Electricity Demand

Since the project investigates hybrid combinations to accommodate future demand in the next 20 years of Southern Thailand, daily electricity demand during 2017 – which is collected by EGAT, is used to calculate for the future demand with an annual 3.4% demand increasing rate. A typical day within 12 different months is selected to represent the average demand in each month, then the future demand is determined by Equation 5 below.

Equation 5 – Next 20 years increasing demand

$$Future\ demand = (Current\ demand \times 1.034^{20}) - Current\ demand$$

For the average future daily demand with some seasonal variation throughout the course and the average of 45,082,848 kWh/day and peak at 3,831,358 kW, but with 10% of the reserve margin condition, the highest demand reaches 4,243,170 kW in March as shown below in Figure 18. The lowest average demand is in January, which is winter, then reaches the highest point at the beginning of summer in March and slightly drops in the middle of summer. This figure reaches almost its peak again at the beginning of the rainy season and finally decreases during winter from the end of October to January.

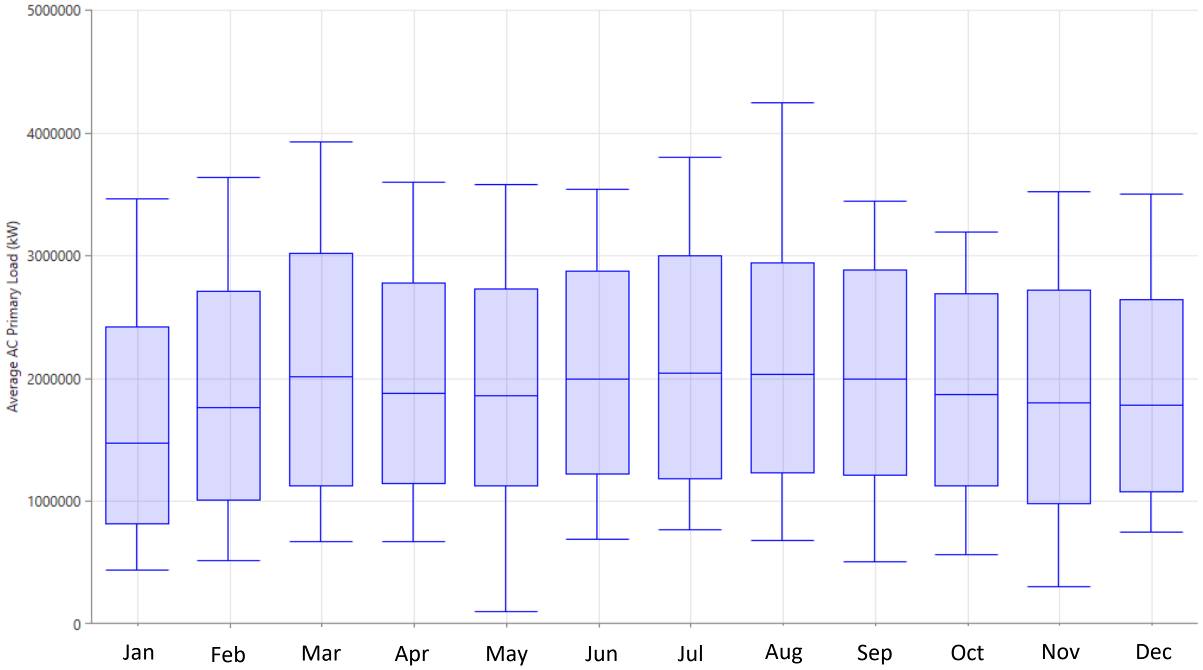


Figure 18: Average monthly projected demand in the next 20 years in Southern Thailand

There are 3 seasons in Thailand, which are summer –from March through to June, rainy season – from June through to October, and winter – from November to February. In the Figure 19 below, three typical days in March, October, and January are selected to demonstrate the pattern of daily demand over the next 20 years in Southern Thailand using in HOMER in each season.

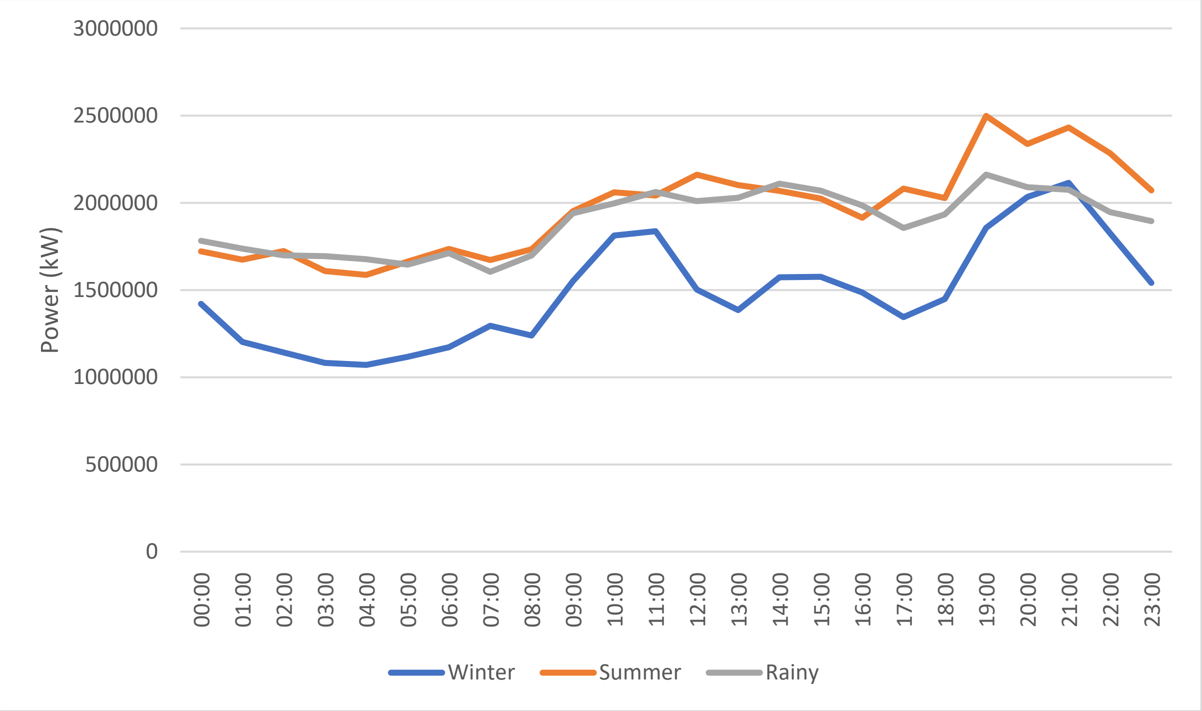


Figure 19: Seasonal projected daily demand in Southern Thailand

Over the next 20 years, daily demand for electricity in Southern Thailand tends to increase within typical days in winter, summer, and rainy season, as shown in the Figure 18. It appears that every season has a similar pattern of daily demand, which is at its maximum between 19:00 to 21:00 hrs, and there is also a sharp rise sharp from 8:00 to 12:00 hrs., while the demand drops to the lowest and remain almost constant between 1:00 and 6:00 hrs. when people are sleeping. In winter, the demand decreases to its lowest point at around 1,070 MW at 4:00 hrs. On the other hand, during summer times, the demand reaches its peak around 2,500 MW. Overall, it is clear that the highest of total future daily increasing demand is in summer with around 47.17 GWh/day of energy use, followed by the rainy season with 45.41 GWh/day and winter with only 35.62 GWh/day of total energy consumption.

3.1.2 Natural Gas Combined Cycle (NGCC)

NGCC plant is considered to be base load power generation of hybrid combinations. However, HOMER does not have the model of fully NGCC plant. For the solution, Jenbacher Type 6 Gas Engines, a manufacturing from GE that use natural gas for fuel, is selected to represent a model of NGCC in the simulation. There are 3 different capacities of NGCC plants that were applied for 5 scenarios to optimize power system, which are 3.5 GW, 2.5 GW, and 1.5 GW. Based on a report from U.S Department of Energy (2016), capital cost of NGCC plant is 978 $/kW and O&M cost is 1 $/operate hour and it is assumed that replacement cost is half of capital cost. Specification and properties and this turbine are stated below in Table 5.

Specification	**Value**
Type	Jenbacher Type 6 Gas Engines
Fuel	Natural Gas
Capacity (GW)	3.5, 2.5, 1.5
Capital cost ($/kW)	978
Replacement cost ($/kW)	489
O&M ($/operate hour)	1
Efficiency (%)	40
Lifetime (years)	20
Fuel price ($/m^3)	0.3
Fuel curve slope (m^3/hour/kW)	0.253
Emissions	
CO (g/m^3 fuel)	6.42
Particulates (g/m^3 fuel)	0.181
NO_x (g/m^3 fuel)	13.47

Table 5: Natural gas combined cycle model specification

3.1.3 Solar PV

In HOMER, there are numerous types of solar PV panels, of which a generic flat plate PV panel is selected as one of the renewable energies in the simulation. Capital cost and O&M cost are based on a research from IRENA (2018) and it is assumed that replacement cost is half of the capital cost. Specification of this model of solar PV is shown below in Table 6.

Specification	Value
Type	Generic flat plate PV
Capacity (kW)	1
Capital cost ($)	1,388
Replacement cost ($)	700
O&M ($/year)	10
Panel Efficiency (%)	16
Lifetime (years)	20

Table 6: Generic flat plate PV specification

Thailand has a significant solar resource during a year which can potentially apply with photovoltaic (PV) technology to convert this resource into electricity. Solar PV technology is rapidly growing across the world including Thailand (Limmeechokchai & Peerapong, 2017). While various markets and financial companies have invested and competed in this field, there is a huge reduction of capital cost of solar PV from an average cost of around 4,400 $/kW in 2010 to currently 1,388 $/kW (IRENA, 2018). However, the major drawback of PV systems is the efficiency, which averages around 10-25% and 16% for this model in the simulation. Nevertheless, utilization of solar PV in hybrid combinations in Thailand still plays an important role in power distribution. In HOMER, the average monthly solar radiation and clearness index used for the simulation were carried out by Solar Energy Database and NASA Surface Meteorology, which are illustrated below in Figure 20.

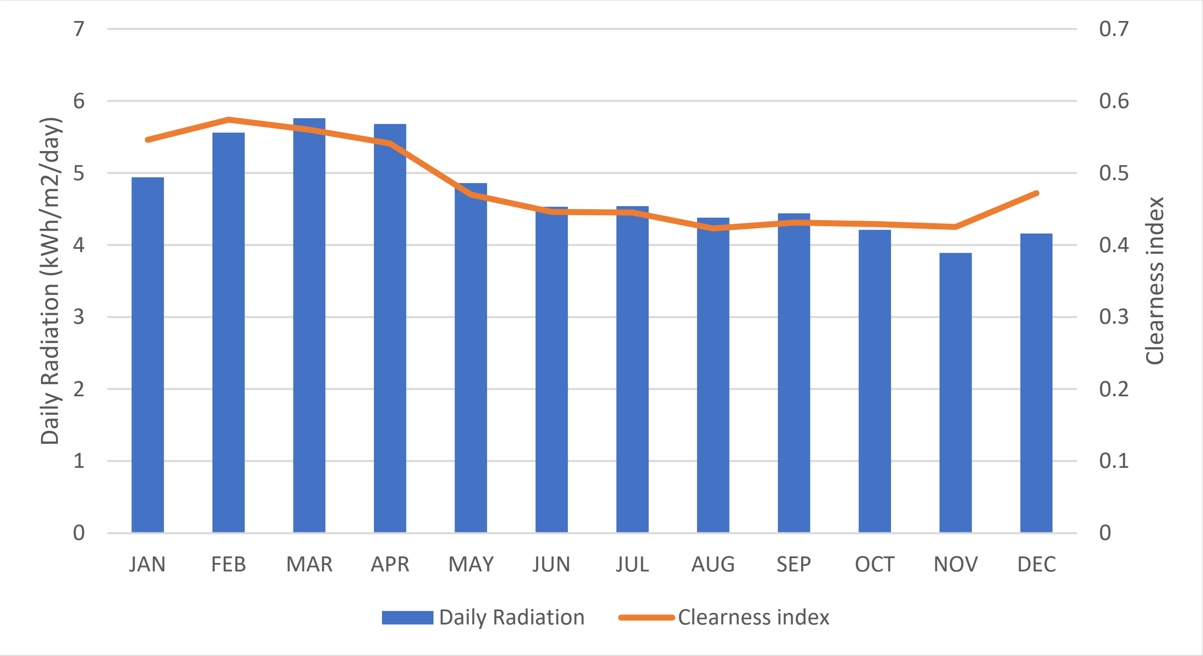


Figure 20: Monthly average Solar Global Horizontal Irradiance (GHI) data (NASA, 2018)

Figure 20 shows average daily radiation and clearness index during a year. Solar radiation is radian energy released by the sun including direct and diffuse radiations which are explained in the Literature part in this project. In terms of the clearness index, it is a measure the level of clearness of atmosphere in the particular area. The range of clearness index value is between 0 to 1, which is defined as the ratio of the surface radiation and the extraterrestrial radiation. When the sky is clear or sunny, the value of clearness index is high, while a low value occurs in cloudy conditions (HOMER, 2018).

The location of solar GHI resource from NASA is set in Nakhon Si Thammarat, which is the biggest province in Southern Thailand, to represent the whole southern region. The trend of solar radiation has similar pattern with solar resource in Songkhla from Weatherspark (2018) that was mentioned in the Literature chapter of this project. Solar radiation has the rising trend from January to reach its peak in March. There is a reasonable reason that the demand is also peak in March because the use of air conditioner to compensate the heat. After April, the trend generally decreases and remains steady throughout rainy reason then drop to the lowest point in November. In the same way, clearness index trend has almost similar pattern with solar radiation within a year. Sunny conditions allow more solar radiation to contact with solar PV than cloudy condition, especially direct radiation.

3.1.4 Wind Turbine

There are many types of wind turbine available in HOMER. For these simulations, XANT M-24 (95 kW), a manufacture from Belgium, is selected as one of the renewable systems in the hybrid combinations. Capital cost and O&M cost based on a research from IRENA (2018) and it is assumed that replacement cost is half of the capital cost. Specification of this type of wind turbine is shown below in Table 7.

Specification	Value
Type	XANT M-24
Capacity (kW)	95
Capital cost ($)	140,315
Replacement cost ($)	70,000
O&M ($/year)	2,526
Hub height (m)	38
Lifetime (years)	20

Table 7: XANT M-24 Wind Turbine specification

Similar to solar PV technology, onshore wind capital costs have significantly decreased over the past 30 years. The capital cost fell from around 4,900 $/kW to 1,477 $/kW between 1983-2017 and O&M cost is 2,526 $/year (IRANA, 2018). With 95 kW rated capacity of XANT M-24 wind turbine, total capital cost is $140,315. The size of this turbine is in moderate level with the hub height of 38 meters or equal to 10 floors building. In addition, this turbine is suitable for low wind speed area in Southern Thailand since cut-in speed is power curve less than other types of turbine.

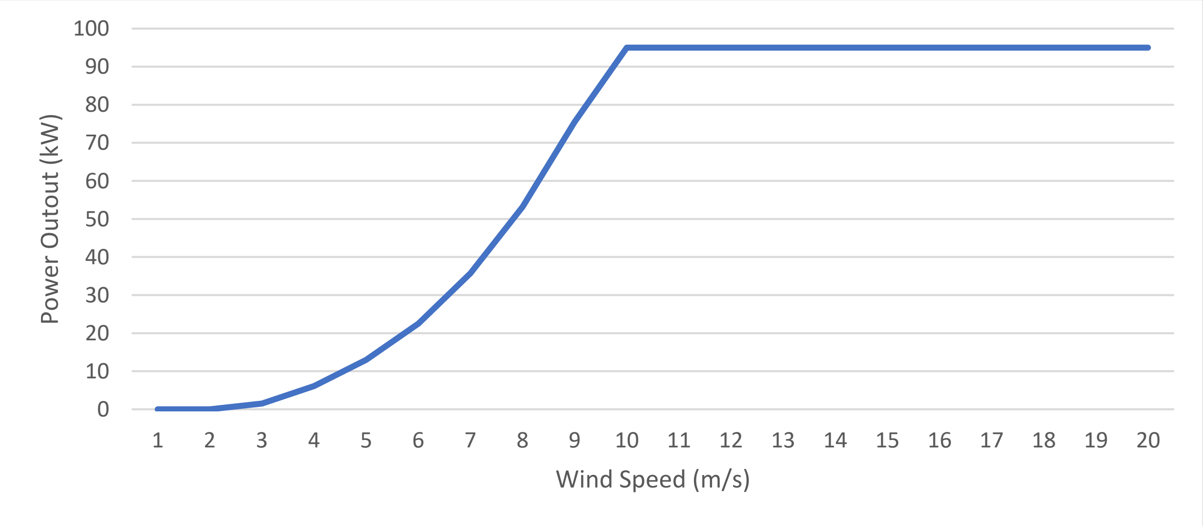


Figure 21: Power curve of XANT M-24 wind turbine

Figure 21 above shows the power curve of XANT M-24 wind turbine. The turbine starts to generate power when wind speed exceeds 3 m/s. Power output increases significantly until wind speed reach to 10 m/s and remain steady at rated output of 95 kW and finally shut down for safety aspect when wind speed is more than 20 m/s. To utilize this turbine with hybrid combinations, wind resource from Solar Energy Database and NASA Surface Meteorology in the target area was downloaded to use in the simulation, as displayed below in Table 8.

Month	Average wind speed (m/s)
January	4.45
February	3.81
March	3.54
April	2.88
May	3.5
June	4.79
July	4.59
August	5.14
September	4.25
October	3.6
November	4.56
December	5.61

Table 8: Monthly average wind speed at anemometer height of 50 meters (NASA, 2018)

Table 8 illustrates monthly average wind speed in Nakhon Si Thammarat, which is assumed to be an average of Southern Thailand area. Unlike solar radiation resource, high wind speed occurs during winter and the beginning of rainy season while low wind speed is in summer. For this reason, solar PV and wind energy can potential compensate power output from the different patterns of their resources. Although the lowest average wind speed (2.88 m/s in April) is less than cut-in speed of XANT M-24 wind turbine, it is the most suitable type of turbine in HOMER in terms of the size, available power output and financial aspect for the simulation.

3.1.5 Hydrokinetic

Hydrokinetic is another renewable technology applied for hybrid combinations. There are a few models of hydrokinetic in HOMER and all of them cannot vary their power capacity. Thus, generic hydrokinetic (40kW), which can represent wave energy or tidal power or anything with negligible head, is considered to be a suitable model for the simulation. Capital cost – 1535 $/kW and O&M cost – 61.4 $/kW/year, are based on a report from IRENA (2018) whereas replacement cost is assumed to be 50% of its capital cost. Specification of this type of hydrokinetic is shown below in Table 9.

Specification	Value
Type	Generic hydrokinetic
Capacity (kW)	40
Capital cost ($)	61,400
Replacement cost ($)	30,700
O&M ($/year)	2,456
Quantity	8,250
Lifetime (years)	10

Table 9: Generic hydrokinetic turbine specification

According to a study from Chamamahattana et al. (2005) estimated that there is a 330 MW potential of small hydropower can be increased in Southern Thailand, quantity of hydrokinetic turbines is fixed for 8,250 in all hybrid combinations. Power output of the turbine varies with the water speed of located area, of which the power curve is shown in Figure 22.

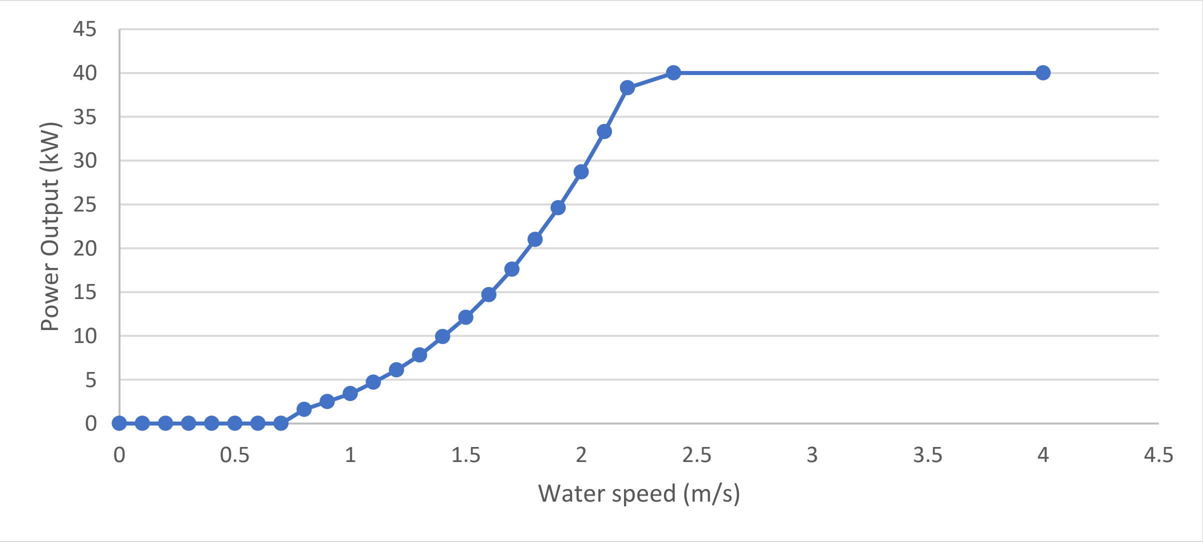


Figure 22: Power curve generic hydrokinetic 40kW turbine

Figure 21 above illustrates power curve of generic hydrokinetic 40 kW turbine. The turbine starts to generate power when water speed exceeds 0.8 m/s. Power output increases significantly until water speed reach to 2.5 m/s and remain steady at rated output of 40 kW then stop produce power when water speed is more than 4 m/s. For this simulation, Pattani river, the longest river in Southern Thailand with 214 km from Gulf of Thailand to the town of Pattani, is selected to be the location of hydrokinetic for the simulations. Due to lack of information from Pattani river water speed resource, it is assumed that average water speed in the river is 2 m/s and has a seasonal variation during a year based on a study from Wiberg, et al. (2016).

Month	Average water speed (m/s)
January	2
February	2
March	1.5
April	1.5
May	1.5
June	1.5
July	2.5
August	2.5
September	2.5
October	2.5
November	2
December	2

Table 10: Monthly average water speed of Pattani river

Table 10 shows the monthly average water speed of Pattani river. It is assumed that water speed separated into 3 levels within 3 different seasons in Thailand. The highest water speed would be in rainy season – from July to October, at 2.5 m/s following by in winter – from November to February, at 2 m/s and the lowest speed in summer – from March to June, at 1.5 m/s.

3.1.6 Biomass

Biomass plant is considered one of alternative power generations of hybrid combinations. Generic Biomass generator is the selected option in the simulations of which the capacity varies to suit with each hybrid combination. There are 3 different capacity biomass plants that were applied for 4 scenarios to optimize power system, which are 500 MW, 200 MW, and 20 GW. According to a study from IRENA (2017), oil palm parts including palm frond, palm empty fruit bunch, palm fiber and palm shell are widely used in Southern Thailand and they would be used as fuel for this model. Since a MoAC's development plan is the only resource related to potential oil palm resource with average use of 38,553,408 tons/year, the input for fuel resource in HOMER is forced to use equally 105,625 tons/day during a year.

Based on a report from IRENA (2018), capital cost of biomass plant is 1,400 $/kW and O&M cost is 30 $/operate hour and it is assumed that replacement cost is half of capital cost. Specification and properties and this biomass plant are stated below in Table 11.

Specification	**Value**
Type	Generic Biomass
Fuel	Oil palm
Capacity (MW)	500, 200, 20
Capital cost ($/kW)	1,400
Replacement cost ($/kW)	700
O&M ($/operate hour)	30
Efficiency (%)	30
Lifetime (years)	20
Fuel price ($/ton)	10
Fuel resource (tons/day)	105,625
Fuel curve slope (kg/hour/kW)	2
Emissions	
CO (g/kg fuel)	2
Particulates (g/m^3)	0
NO$_x$ (g/kg fuel)	1.25

Table 11: Biomass plant specification

3.1.7 Lithium-ion Battery

Li-ion battery is chosen as an energy storage technology for the simulations. Due to intermittent power outputs from renewable energy sources, li-ion plays an important role to increase stability of hybrid combinations by increasing period to store or generate energy when needed. According to a study from Kelly (2017), the average capital cost of li-ion battery is 652 $/kWh and lifespan around 15 years. For assumption, the replacement cost is half of the battery capital cost. Specification of li-ion battery is shown below in Table 12.

Specification	Value
Type	Li-ion battery
Capacity (MWh)	1
Capital cost ($)	652,000
Replacement cost ($)	326,000
O&M ($/year)	10,000
Roundtrip efficiency (%)	90
Lifetime (years)	15

Table 12: Lithium-ion specification

3.1.8 Converter

Converter is a device that converts alternative current (AC) to direct current (DC) or the other way around. Since battery is on DC side and power generations are on AC side in all of hybrid combinations, converter is required in the systems. Specification of converter is shown below in Table 13.

Specification	Value
Type	Generic converter
Capacity (kW)	1
Capital cost ($)	300
Replacement cost ($)	150
O&M ($/year)	0
Roundtrip efficiency (%)	90
Lifetime (years)	15

Table 13: Converter specification

3.2 Project Constrains and Assumptions in HOMER

After project inputs are carried out, constraints and assumptions are next step to determine. Constraints and assumptions of the simulation are conditions that directly influence the results. Since some parameters in HOMER cannot adjust to match likely outcome and some renewable resources are difficult to find accurately result, constraints and assumptions are set in this simulation in order to access the most realistic outcomes as possible. In the chapter 3.1, some constraints and assumptions are stated in an explanation of each component, but this part will summarize them in the list of order for easy understanding.

Project Constrains

- Project lifetime 25 years
- 6% discount rate
- Maximum 0.1% annual capacity shortage
- Reserve margin 10% of peak demand
- Electricity load 45,082,848 kWh/day

Project Assumptions

- Generic natural gas generator is represented by natural gas combined-cycle (NGCC), which investment cost, fuel and emissions properties are set following NGCC conditions.
- Replacement cost of each component is 50% of capital cost
- 330 MW of hydrokinetic development plan can be achieved and included in all simulations
- With an average water speed of 2 m/s in Pattani river, seasonal speed variation could be 1.5 m/s in summer, 2 m/s in winter, and 2.5 m/s in rainy season
- An average biomass resource is equal during a year

4. Scenario Results and Discussions

After data on project inputs, constrains and assumptions are gathered, HOMER is able to calculate the results of hybrid combinations. The results can be divided into 4 scenarios and a base model as follow:

- Base model – hybrid combination consisting of only NGCC
- Scenario 1 – hybrid combination with 30% of renewable fraction
- Scenario 2 – hybrid combination with 50% of renewable fraction
- Scenario 3 – hybrid combination with 70% of renewable fraction
- Scenario 4 – hybrid combination with 100% of renewable fraction

For each scenario, optimization was carried out by varying capacity of NGCC, renewable systems and energy storage. Only hydrokinetic system is fixed in Scenario 1-4 with the similar capacity. The following part will identify configuration and the results including financial and technical aspects of each scenario.

4.1 Base Model

This model is considered the standard to compare the results with scenario 1-4 such as COE, initial capital cost, and percentage of CO_2 reduction since it is non-renewable system. The model consists of one power generation, which is NGCC with capacity of 3.5 GW, to supply electricity load. A schematic of the model is shown below in Figure 23.

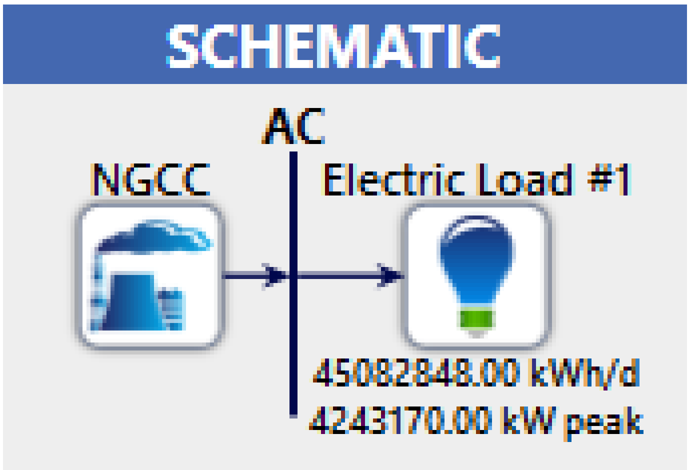


Figure 23: Schematic of Base model

4.1.1 Base Model Results

Characteristic	Value
Renewable Fraction (%)	0
COE ($/kWh)	0.111
CO_2 emissions (kg/year)	8.052B
NPC ($)	23.3B
Initial capital cost ($)	3.42B
Capacity shortage (%/year)	0.0885
Excess electricity (%/year)	0.098

Table 14: The results of Base model

4.1.2 Base Model Discussion

In order to be the standard to compare with scenarios with renewable systems, NGCC plant, which is one of the non-renewable technologies with the highest efficiency, is selected to be a power supply for the system. For the electricity demand of 45,082,848 kWh/day, the minimum capacity of NGCC plant to allow annual capacity shortage less than 0.1% is 3.5 GW. Although the peak demand is 4.24 GW and higher than NGCC plant capacity, it does not affect capacity shortage condition of this model since this peak could be a minor flaw of HOMER as it occurs only once during a year. This is illustrated in the red circle below in Figure 24.

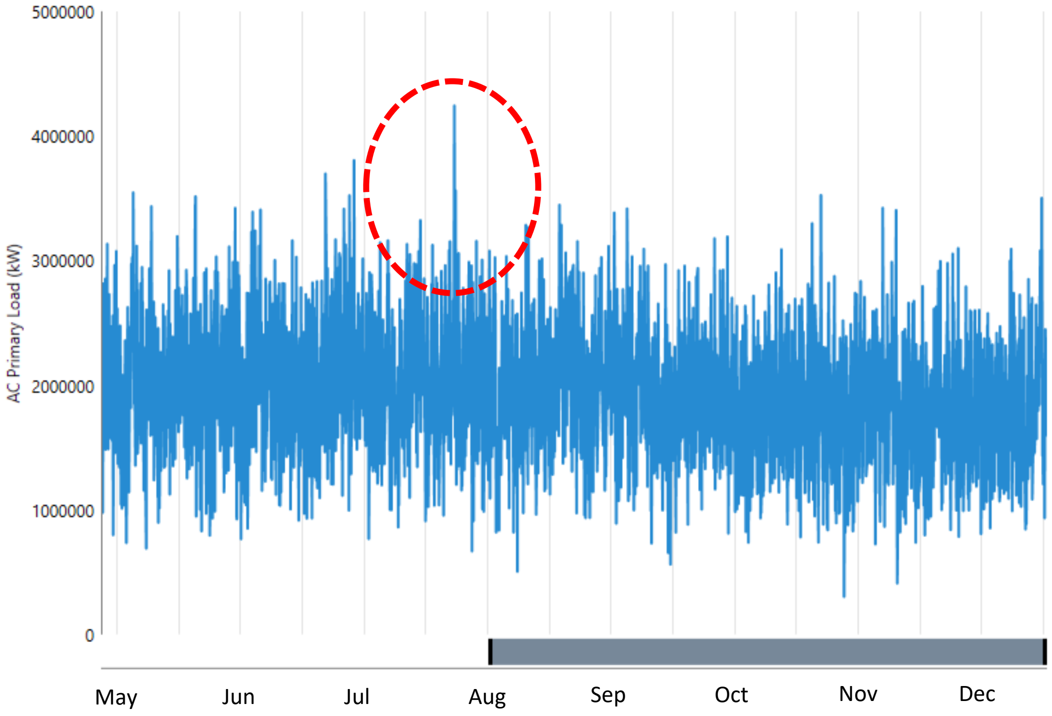


Figure 24: Projected electricity demand in HOMER

As regards COE, this model can represent Thailand power system since COE of both systems are close together. In Thailand, COE is divided by many categories such as by residential, business and industrial sectors or by provinces, but average price is around 0.115 $/kWh while COE of base model is 0.111 $/kWh as mentioned above in Table 14. Thus, people in the Southern region will benefit for building only NGCC plant as COE price is cheaper than the existing price.

In term of power generation, NGCC plant has a pleasant performance suppling the power to accommodate variation of the demand since it can rapidly vary its power output without the need of battery unlike renewable system. For this reason, capacity shortage and excess electricity are only 0.089 and 0.098 %/year respectively.

Although advantages of this model are COE price and power generation performance, CO_2 emissions seem to be a huge drawback for this model. As a NGCC plant is only non-renewable power generation in the model, it produces 8.052 billion kg/year of CO_2 emissions, which is higher than any systems with renewable technology. In addition, this could deteriorate public acceptance towards this technology where its huge amount of CO_2 emissions has long-term effect on global warming.

Nevertheless, NGCC plant still has the highest possibility to build in the power generation system. NGCC plant would require less area for construction and less complication compare with large number of renewable components. This makes initial capital cost of this model lower than alternative systems. As a result, NGCC plant could be the first choice to add in the power system if neglecting the emissions aspect and target of AEDP2015.

4.2 Scenario 1

This scenario is set to reach at least 30% of renewable fraction by varying capacity of NGCC and renewable systems but fixed capacity of hydrokinetic. As a result, configuration of the scenario consists of both AC and DC sides connection. Power generations including NGCC, biomass, wind turbines, solar PV, and hydrokinetic are on the AC side which supply power to electricity load. However, lithium-ion battery is on the DC side where there is a converter that connects both AC and DC sides to pass the power from both ways around. A schematic of Scenario 1 is illustrated below in Figure 25.

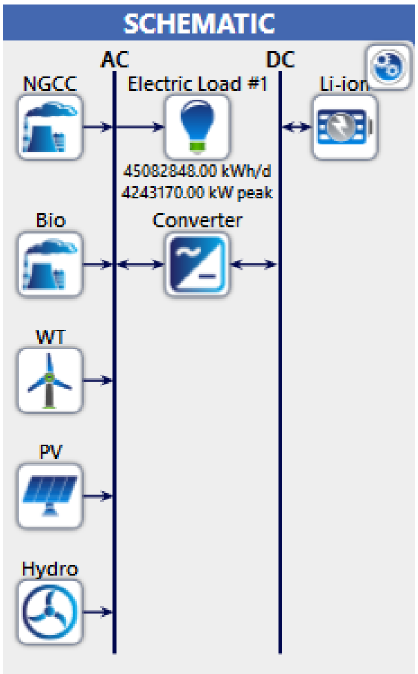


Figure 25: Schematic of Scenario 1

4.2.1 Scenario 1 Configuration Details

Components	Quantity	Production (%/year)	Capacity Factor (%)
NGCC (2.5 GW)	1	67.9	52.4
Biomass (20 MW)	1	0.88	84.9
Wind Turbine (95 kW)	3,322	2.18	13.4
Solar PV (1 kW)	2,118,060	17.5	15.9
Hydrokinetic (40 kW)	8,250	11.5	67.3
Li-ion Battery (1 MWh)	1,424	-	-
Converter (1 kW)	1,043,894	-	-

Table 15: Details of Scenario 1 configuration

4.2.2 Scenario 1 Results

Characteristic	Value
Renewable Fraction (%)	30.2
COE ($/kWh)	0.109
Reduction of CO_2 emissions (%)	30.26
NPC ($)	23B
Initial capital cost ($)	7.63B
Capacity shortage (%/year)	0.0898
Excess electricity (%/year)	2.56

Table 16: The results of scenario 1

4.2.3 Characteristic of Scenario 1 Power Systems in Summer and Winter

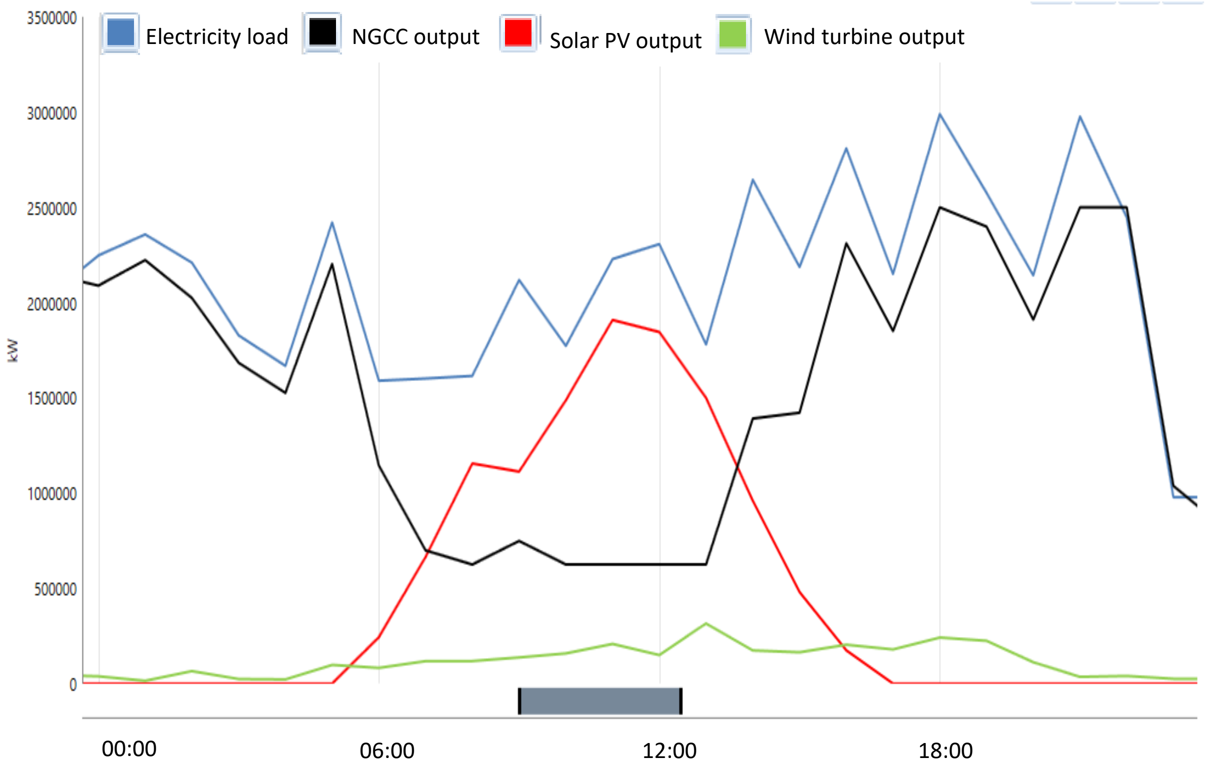


Figure 26: Characteristic of Scenario 1 power output in summer (17th March)

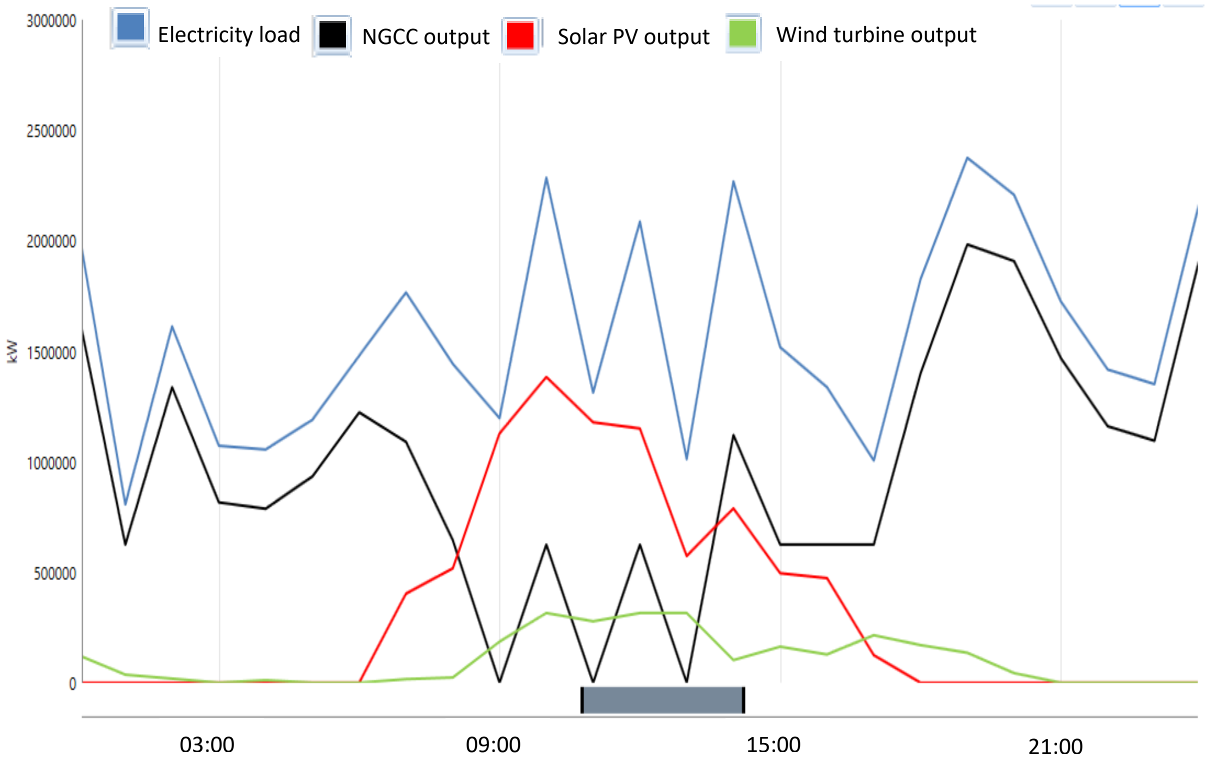


Figure 27: Characteristic of Scenario 1 power output in winter (17th December)

4.2.4 Scenario 1 Discussion

For the Scenario 1, the most optimal configuration to achieve renewable fraction of at least 30% consists of 2,118,060 panels of solar PV, 3,322 of wind turbines, 8,250 of hydrokinetic turbines, 1,424 of Li-ion batteries, 1,043,894 of converters, a 2.5 GW NGCC plant and a 20 MW biomass power plant, which are shown above in Table 16. In this system, NGCC plant is still the main power supply source that produces 67.9% of total system generation. Solar PV is the second place by generating power of 17.5% of total system following by hydrokinetic, wind energy and biomass. In contrast, biomass is the highest capacity factor, which is the average power output of particular component divided by its nominal capacity, with 84.9% following by hydrokinetic and NGCC plant, while both solar PV and wind turbine have small capacity factor of 15.9% and 13.4%, respectively. The reason is that the resources for both solar PV and wind turbine are not constantly available during a day like other systems.

As regards COE, this model would benefit for the community since its COE is even lower than Base model with only 0.109 $/kWh. However, due to more higher cost of renewable systems, the initial capital cost of this scenario reaches $7.63 billion, but it also receives more salvage value than Base model making its NPC is only $23 billion as demonstrated above in Table 16.

For power generation performance, this scenario achieves capacity shortage condition with 0.089 %/year, while excess electricity rises to 2.56 %/year, which is considered a small number for the 30.2% renewable fraction system. Thus, it seems that variation of NGCC plant and li-ion batteries work well to keep balance and compensate renewable resources with the system. In terms of CO_2 emissions, the level of emission drops from 8.052 billion kg/year to 5.615 billion kg/year or 30.26% reduction from Base model.

In Chapter 4.2.3 above, typical days in summer – 17th March and in Winter – 17th December are selected to show pattern and compare the characteristics of power generation systems in this scenario. Since hydrokinetic and biomass generate their power almost constantly in this system due to equally average monthly resources, these two systems are not included in these trends. In summer (Figure 26), solar PV can produce high power output from around 06:00 to 17:00 and reach to its peak around 2 GW of total generation at midday, which almost supply 100% for the demand at that time. Wind turbine also has the same peak time at noon, but in shorter period and less total power generation comp are to solar PV. When both solar PV and wind can produce high output, NGCC reduced its power generation to match up the electricity demand. However, the electricity demand is usually high at 18:00 to around 22:00 which both solar PV and wind cannot generate their power. Thus, NGCC would need to responsible for this period and li-ion battery could help to release its power as much as it can.

Figure 27 above shows power generation characteristics in winter which has quite a similar pattern to summer, but with lower electrical demand and solar PV output, which can reach approximately 1.4 GW of total power output. Nevertheless, the wind blows heavily in this season allowing wind turbine produce higher output than summer with around 400 MW of its generation.

4.3 Scenario 2

This scenario is set to reach at least 50% of renewable fraction by varying capacity of NGCC and renewable systems but fixed capacity of hydrokinetic. Similar to Scenario 1, configuration of Scenario 2 consists of both AC and DC sides connection. Power generations including NGCC, biomass, wind turbines, solar PV, and hydrokinetic are on the AC side which supply power to electricity load. However, lithium-ion battery is on the DC side where there is a converter that connects on both AC and DC sides to pass the power from both ways around. A schematic of Scenario 2 is shown below in Figure 28.

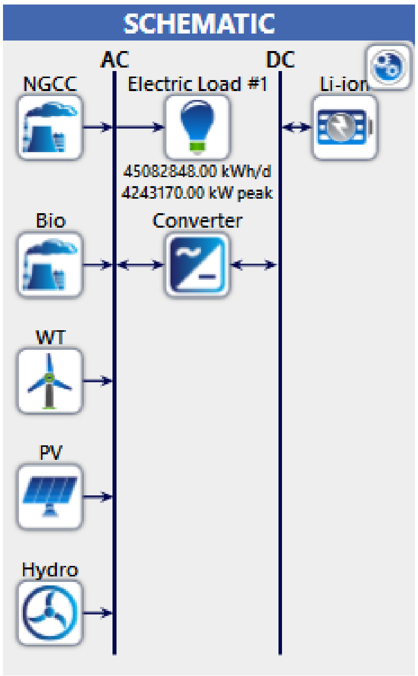


Figure 28: Schematic of Scenario 2

4.3.1 Scenario 2 Configuration Details

Components	Quantity	Production (%/year)	Capacity Factor (%)
NGCC (2.5 GW)	1	47.9	37.6
Biomass (200 MW)	1	7.66	75.1
Wind Turbine (95 kW)	14,188	9.19	13.4
Solar PV (1 kW)	2,934,185	23.9	15.9
Hydrokinetic (40 kW)	8,250	11.3	67.3
Li-ion Battery (1 MWh)	2,469	-	-
Converter (1 kW)	1,754,151	-	-

Table 17: Details of Scenario 2 configuration

4.3.2 Scenario 2 Results

Characteristic	Value
Renewable Fraction (%)	50
COE ($/kWh)	0.1181
Reduction of CO_2 emissions (%)	50
NPC ($)	24.8B
Initial capital cost ($)	11.4B
Capacity shortage (%/year)	0.0273
Excess electricity (%/year)	3.59

Table 18: The results of Scenario 2

4.3.3 Characteristic of Scenario 2 Power Systems in Summer and Winter

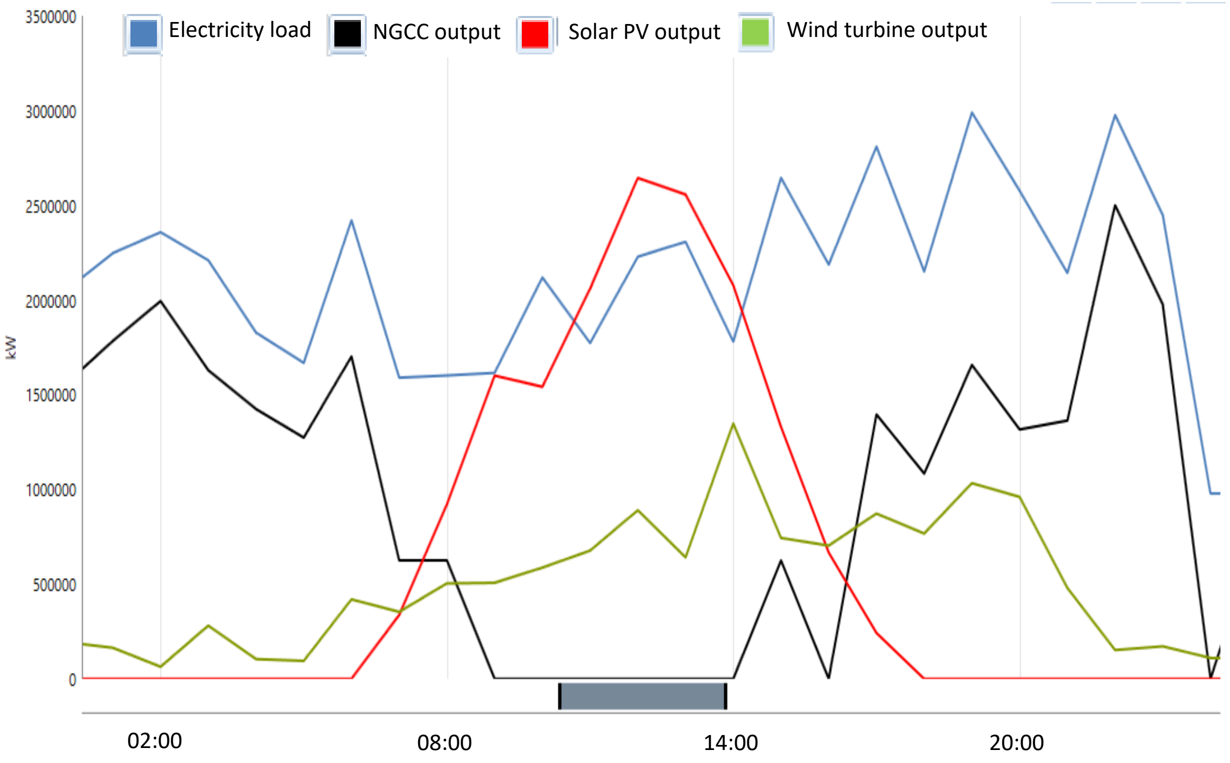


Figure 29: Characteristic of Scenario 2 power output in summer (17th March)

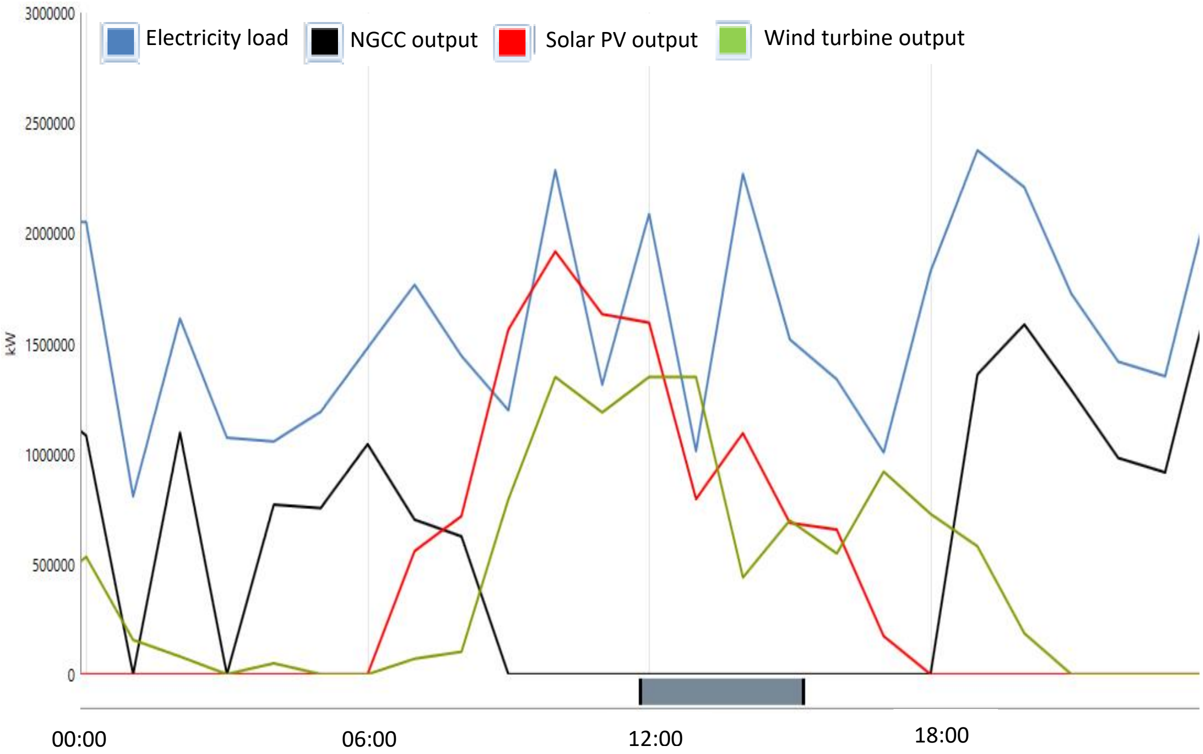


Figure 30: Characteristic of Scenario 2 power output in winter (17th December)

4.3.4 Scenario 2 Discussion

For the Scenario 2, the most optimal configuration to achieve renewable fraction of at least 50% are consisted of 2,934,185 panels of solar PV, 14,188 of wind turbines, 8,250 of hydrokinetic turbines, 2,469 of li-ion batteries, 1,754,151 of converters, a 2.5 GW NGCC plant and a 200 MW biomass power plant, which are shown above in Table 18. In this system, one half of total power generation comes from NGCC plant and another half from renewable systems. Solar PV is still the second place by generating power of 23.9% of total system following by hydrokinetic, wind energy and biomass but sharing proportion of each component is higher than in Scenario 1 since there is no component that generates power at less than 7.6% of total generation. Similar to Scenario 1, biomass still has the highest capacity factor with 75.1% following by hydrokinetic, while NGCC drop to third place with 37.6%. Solar PV, wind energy and hydrokinetic still have same value of capacity factor with in Scenario 1.

As regards COE, Scenario 2 has the COE price of 0.118 $/kWh which is slightly higher than Base model and this would not affect surrounding communities. Due to a larger number of power generation components, batteries and converters, the initial capital cost of this scenario reaches $11.4 billion, but it still receives much salvage value making its NPC at only $24.8 billion as demonstrated above in Table 18.

In terms of power generation performance, Scenario 2 completed capacity shortage condition with only 0.027 %/year, while excess electricity increases to 3.59 %/year, which is still considered as a small number for the 50% renewable fraction system. Therefore, it could say that the combination of NGCC plant, renewable components and li-ion batteries sufficiently optimize to keep balance and compensate electricity demand of the system. For of CO_2 emissions, the level of emission drops from 8.052 billion kg/year to 4.023 billion kg/year or 50% reduction from Base model.

According to Figure 29 and Figure 30, typical days from Scenario 1 in summer and winter are selected to show pattern and compare characteristic of power generation systems in this scenario. Similar with Scenario 1, hydrokinetic and biomass are not included in these graphs as they generate power almost constantly in this system due to equally average monthly resources. In summer (Figure 29), solar PV can produce power output from around 07:00 to 17:00 and reach to its peak around 2.7 GW at noon, which excess the electricity demand at that time. For wind turbines, there is a wider period of power generation than in Scenario 1 that they can produce power at least 500 MW from 06:00 to 20:00. NGCC still response to the period when renewable systems high power by reducing its power or even stop its generation when total production of alternative systems can cover electricity demand.

Winter, as shown above in Figure 30, still has similar pattern to summer, but solar PV can produce less power with around 1.9 GW of total power output. In contrast, wind turbine produces higher of its generation than in summer with around 1.4 GW that is almost equal to solar PV. Overall, Scenario 2 needs to rely on li-ion batteries more than Scenario 1 as there are periods that renewable output exceeds electricity demand.

4.4 Scenario 3

This scenario is set to reach at least 70% of renewable fraction by varying capacity of NGCC and renewable systems but fixed capacity of hydrokinetic. Similar to Scenario 1 and 2, configuration of Scenario 3 consists of both AC and DC sides connection. Power generations including NGCC, biomass, wind turbines, solar PV, and hydrokinetic are on the AC side which supply power to electricity load. However, lithium-ion battery is on the DC side where there is a converter that connects on both AC and DC sides to pass the power from both ways around. A schematic of Scenario 3 is shown below in Figure 31.

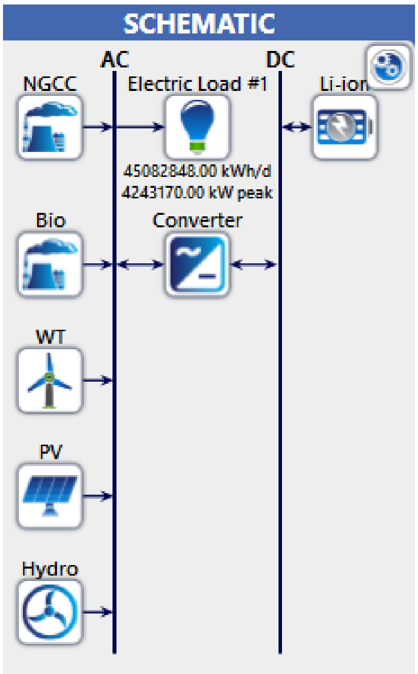


Figure 31: Schematic of Scenario 3

4.4.1 Scenario 3 Configuration Details

Components	Quantity	Production (%/year)	Capacity Factor (%)
NGCC (1.5 GW)	1	25.9	37.4
Biomass (500 MW)	1	16.3	70.6
Wind Turbine (95 kW)	17,510	10.3	13.4
Solar PV (1 kW)	5,056,830	37.2	15.9
Hydrokinetic (40 kW)	8,250	10.3	67.3
Li-ion Battery (1 MWh)	5,877	-	-
Converter (1 kW)	1,641,589	-	-

Table 19: Details of Scenario 3 configuration

4.4.2 Scenario 3 Results

Characteristic	Value
Renewable Fraction (%)	70.2
COE ($/kWh)	0.1345
Reduction of CO_2 emissions (%)	70.18
NPC ($)	28.3B
Initial capital cost ($)	16.5B
Capacity shortage (%/year)	0.0964
Excess electricity (%/year)	12.4

Table 20: The results of Scenario 3

4.4.3 Characteristic of Scenario 3 Power Systems in Summer and Winter

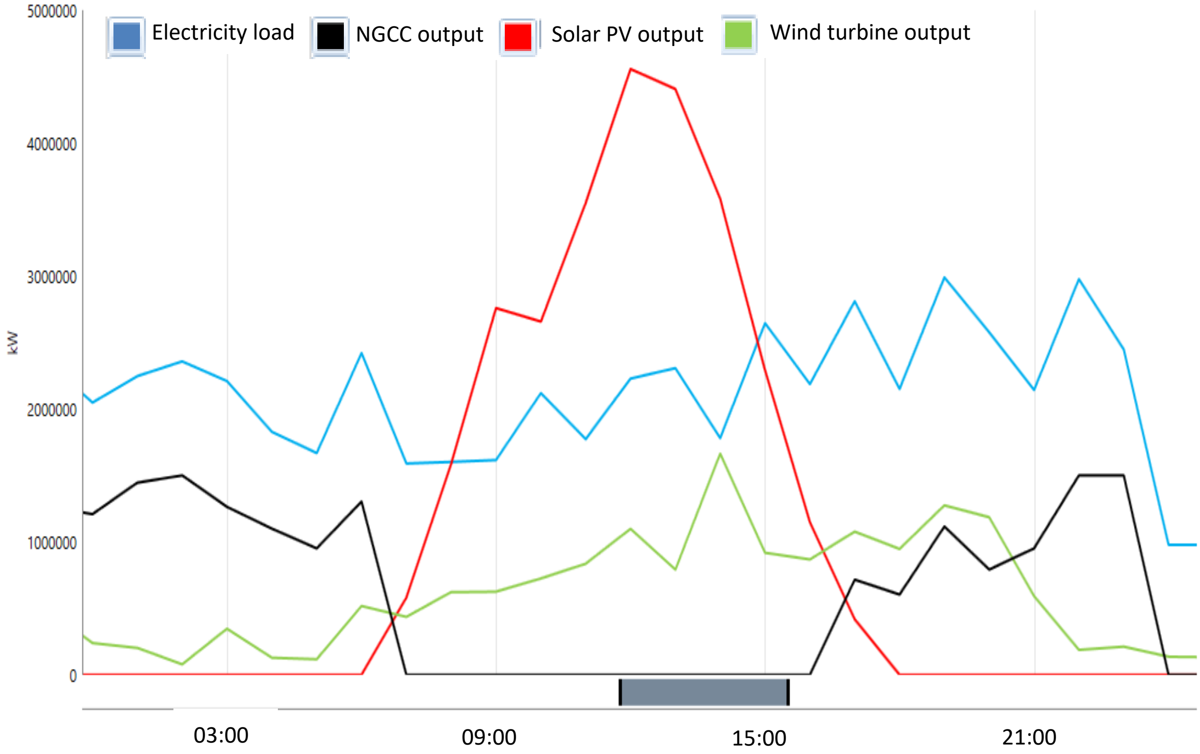


Figure 32: Characteristic of Scenario 3 power output in summer (17th March)

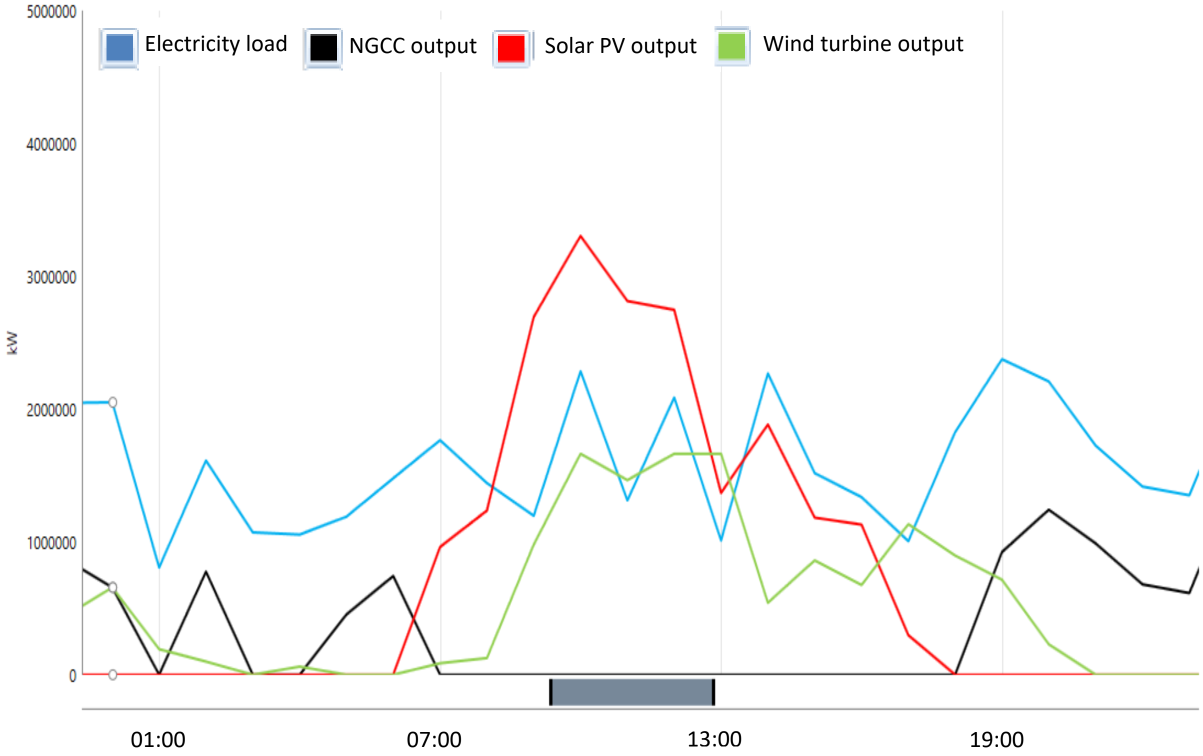


Figure 33: Characteristic of Scenario 3 power output in winter (17th December)

4.4.4 Scenario 3 Discussion

In the Scenario 3, the most optimal configuration to achieve renewable fraction of at least 70% are consisted of 5,056,830 panels of solar PV, 17,510 of wind turbines, 8,250 of hydrokinetic turbines, 5,877 of li-ion batteries, 1,641,589 of converters, a 1.5 GW NGCC plant and a 500 MW biomass power plant, which shown above in Table 19. In this system, the production share of NGCC plant drops to only 25.9% of total power production to allow alternative systems to become main supplier for the system. Solar PV is the first place by generating power of 37.2% of total system followed by biomass, whereas wind energy and hydrokinetic share the same proportion with 10.3% of total generation. Similar to Scenario 1 and 2, biomass still has the highest capacity factor with 70.6% following by hydrokinetic, while NGCC drop to third place with 37.4%. Solar PV, wind energy and hydrokinetic still have same value of capacity factor with in Scenario 1 and 2.

In terms of COE, Scenario 3 has the COE price of 0.134 $/kWh which is higher than Base model and this would have long-term effects on communities and industrial sector that require a large amount of energy consumption. Due to a larger number of power generation components, batteries, and converters than scenario 1 and 2, the initial capital cost of this scenario reaches $16.5 billion, but it still receives much salvage value making its NPC is $28.3 billion as demonstrated above in Table 20.

As regards power generation performance, Scenario 3 also achieved capacity shortage condition with 0.096 %/year, while excess electricity increases to 12.4 %/year, which is a bit high compared to other power generation systems. As a result, it seems that the level of stability of hybrid combination in this scenario is lower than Scenario 1 and 2 to keep balancing and compensate power for electricity demand. Nonetheless, the level of emission significantly drops from 8.052 billion kg/year to 2.401 billion kg/year or 70.18% reduction from Base model.

As stated in Figure 32 and Figure 33, typical days from Scenario 1 and 2 in summer and winter are selected to show pattern and compare the characteristics of power generation systems in this scenario. Similar to two previous scenarios, hydrokinetic and biomass are not included in these graphs as they generate power almost constantly in this system due to equally average monthly resources. In summer (Figure 32), solar PV can produce power output from around 07:00 to 17:00 and reach to its peak even higher than two previous scenarios with around 4.6 GW at noon, which excess is almost double of the electricity demand at that time. For wind turbines, the period of power generation is equal to Scenario 2, but they produce higher power with approximately peak at 1.6 GW. NGCC still response to the period when renewable systems high power by reducing its power or even stop its generation when total production of alternative systems can cover electricity demand, which non-operating period is longer than in first two scenarios.

In Figure 33, winter still has similar pattern to summer, but solar PV can produce less power with around 3.2 GW of total power output. However, wind turbine produces higher of its generation than in summer with around 1.7 GW. Overall, it seems that main problems of Scenario 3 are COE price and huge among of excess energy that even higher number of li-ion batteries cannot sufficiently store power produce from 70% of renewable production system.

4.5 Scenario 4

This scenario is set to reach exactly 100% of renewable fraction by varying capacity of renewable systems but fixed capacity of hydrokinetic. Configuration of Scenario 4 consists of both AC and DC sides connection. Different from Scenario 1, 2, and 3, power generations this scenario is not include NGCC, which is non-renewable resource, but other alternative systems such as biomass, wind turbines, solar PV, and hydrokinetic remain the same on the AC side which supply power to electricity load. For lithium-ion battery, it is on the DC side where there is a converter that connects on both AC and DC sides to pass the power from both ways around. A schematic of Scenario 4 is displayed below in Figure 34.

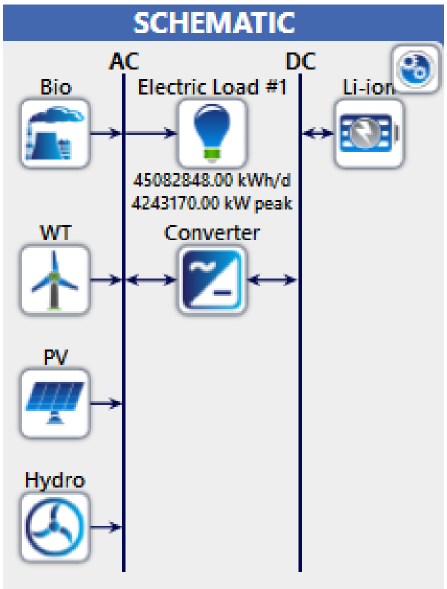


Figure 34: Schematic of Scenario 4

4.5.1 Scenario 4 Configuration Details

Components	Quantity	Production (%/year)	Capacity Factor (%)
Biomass (500 MW)	1	8.72	60.3
Wind Turbine (95 kW)	52,076	19.1	13.4
Solar PV (1 kW)	14,257,840	65.7	15.9
Hydrokinetic (40 kW)	8,250	6.43	67.3
Li-ion Battery (1 MWh)	44,295	-	-
Converter (1 kW)	3,674,064	-	-

Table 21: Details of Scenario 4 configuration

4.5.2 Scenario 4 Results

Characteristic	Value
Renewable Fraction (%)	100
COE ($/kWh)	0.366
Reduction of CO_2 emissions (%)	99.4
NPC ($)	76.9B
Initial capital cost ($)	58.3B
Capacity shortage (%/year)	0.0994
Excess electricity (%/year)	41.9

Table 22: The results of Scenarios 4

4.5.3 Characteristic of Scenario 4 Power Systems in Summer and Winter

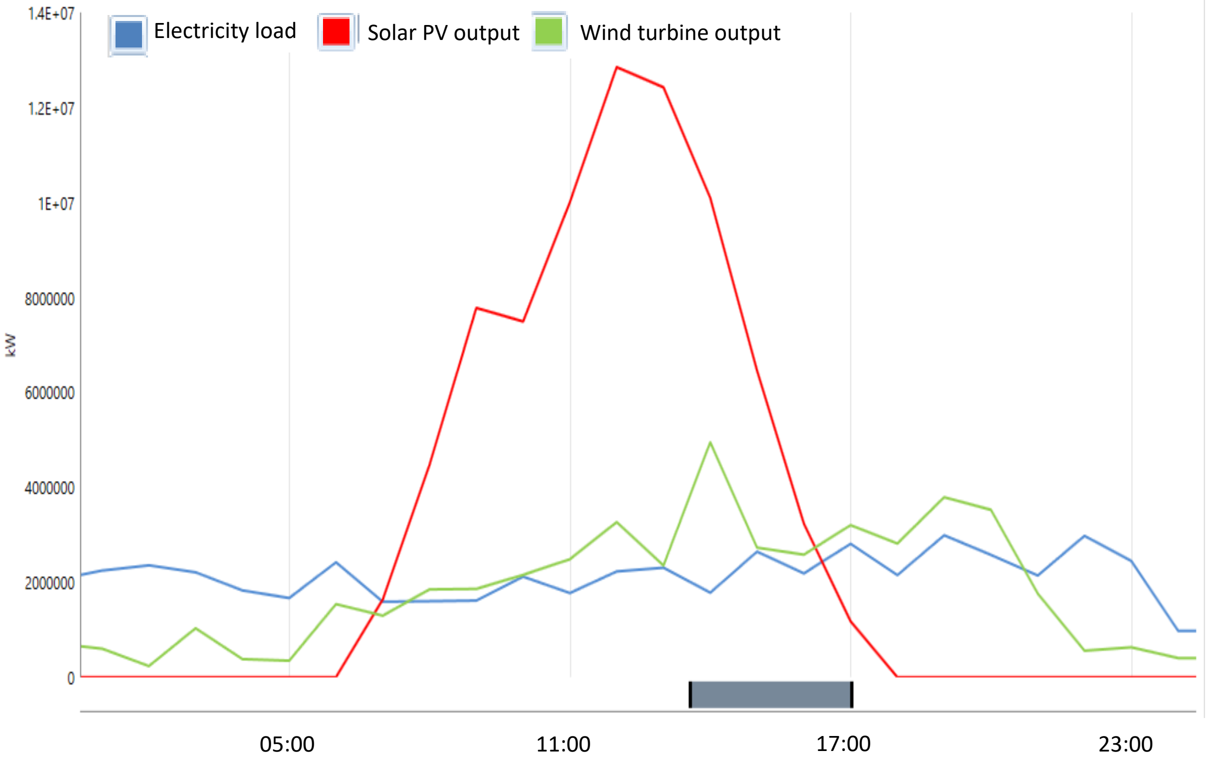


Figure 35: Characteristic of Scenario 4 power output in summer (17th March)

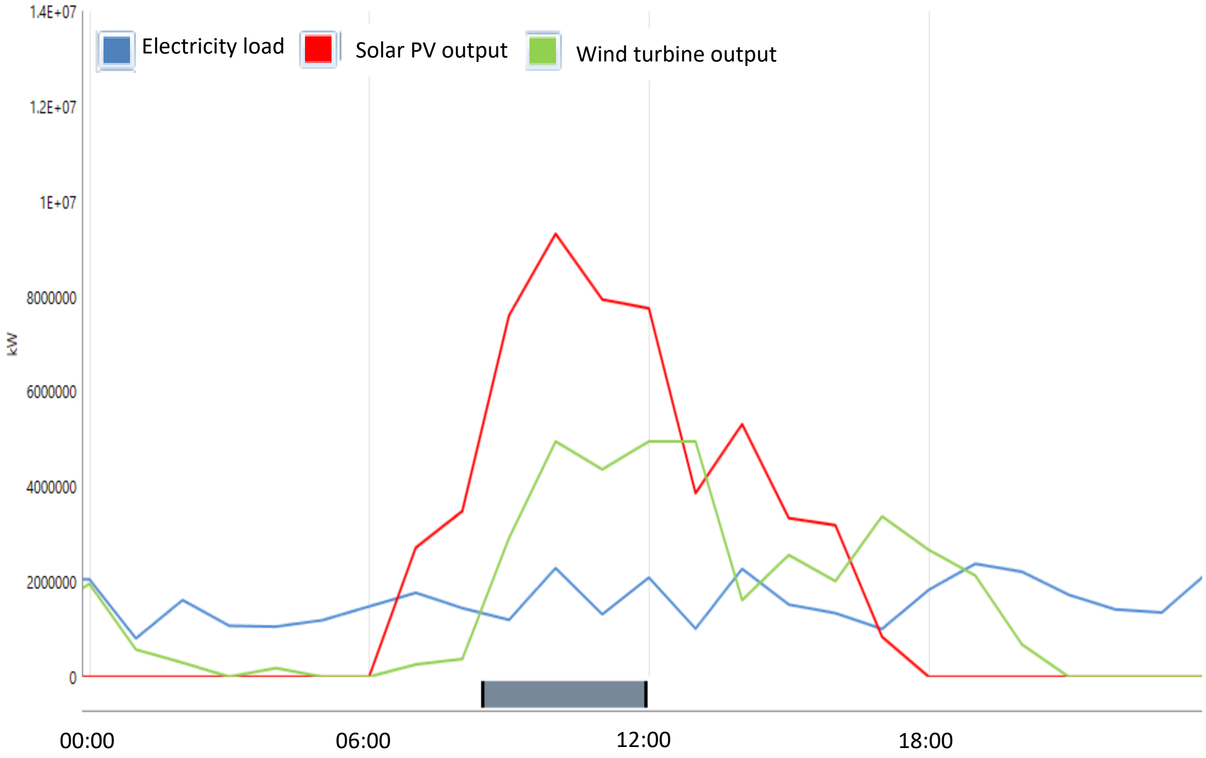


Figure 36: Characteristic of Scenario 4 power output in winter (17th December)

4.5.4 Scenario 4 Discussion

In the Scenario 4, the most optimal configuration to achieve renewable fraction of exactly 100% consists of 14,257,840 panels of solar PV, 52,076 of wind turbines, 8,250 of hydrokinetic turbines, 44,295 of li-ion batteries, 3,674,064 of converters, and a 500 MW biomass power plant, which are shown above in Table 22. In this system, there is no NGCC plant since alternative systems take control of all power production for the system. Solar PV is the major source by generating power of 65.7% of total system following by wind turbines, biomass and hydrokinetic. For capacity factor, solar PV, wind energy and hydrokinetic still have same value of capacity factor with in Scenario 1,2 and 3, while capacity factor of biomass rises to 60.3%.

COE of this scenario would have significant effects on any sectors and users as it is more than 3 times higher than Base model. Because of extremely large number of power generation components, batteries, and converters than scenario 1,2 and 3, the initial capital cost of this scenario reach to $58.3 billion and even it receives huge salvage, NPC is still a large number of $76.9 billion as demonstrated above in Table 22.

In terms of power generation performance, Scenario 4 can still achieve capacity shortage condition with 0.099 %/year, but excess electricity reaches 41.9 %/year, which is extremely high compared to other power generation systems. As a result, this also emphasizes that the higher renewable fraction of hybrid combination causing the lower stability of the system. Nonetheless, the biggest advantage of this scenario would be the reduction of CO_2 emissions that drops from 8.052 billion kg/year to 1.43 million kg/year or 99.4% reduction from Base model.

As stated in Figure 35 and Figure 36, typical days from three previous scenarios summer and winter are selected to show pattern and compare the characteristics of power generation systems in this scenario. Similar to three previous scenarios, hydrokinetic and biomass are not included in these graphs as they generate their power almost constantly in this system due to equally average monthly resources, while NGCC is no longer use in this system. In summer (Figure 35), solar PV can produce power output from around 07:00 to 18:00 hrs. and reach its peak even higher than three previous scenarios with around 13.5 GW at noon, which excess is almost 6 times higher than the electricity demand at that time. For wind turbines, the period of power generation is equal with Scenario 2 and 3, but they produce higher power with approximately peak at 5.8 GW.

In Figure 36, winter still has similar pattern to Summer, but solar PV can produce lower power with around 10 GW of total power output. However, wind turbine produces higher of its generation than in summer with around 5 GW. Overall, it could say that this scenario is an ideal system that could not be done since COE is extremely high as well as quantity of power generation components, batteries, and converters. In addition, this scenario along with Scenario 3 proves that larger renewable systems will cause a problem to stability and electricity excess even higher batteries have been added.

5. Scenario 1-4 Comparison and Discussion

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Renew Fraction (%)	30.2	50	70.2	100
COE ($/kWh)	0.109	0.118	0.134	0.366
CO_2 reduction (%)	30.26	50	70.18	99.4
Capital cost ($)	7.63B	11.4B	16.5B	58.3B
NGCC plant (GW)	2.5	2.5	1.5	-
Biomass plant (MW)	20	200	500	500
Hydrokinetic turbine 40 kW (#)	8,250	8,250	8,250	8,250
Solar PV 1 kW (#)	2,118,060	2,934,185	5,056,830	14,257,840
Wind turbine 95 kW (#)	3,322	14,188	17,510	52,076
Li-ion battery 1 MWh (#)	1,424	2,469	5,877	44,295
Converter 1 kW (#)	1,043,894	1,754,151	1,641,589	3,674,064

Table 23: Summary results of scenario 1-4

Table 23 shows summary results of scenario 1-4 in order to compare and justify the most appropriate scenario to locate in Southern Thailand. For scenario 3 and 4, it seems that these two have totally small opportunity to apply further, especially scenario 4. Technically, the result revealed that 100% renewable power generation system can be achieved even in large-scale of region, but in reality, it seems that this scenario is impossible due to a large number of components and extremely expensive capital cost and COE.

Although Scenario 3 result has huge different from Scenario 4 in almost every aspect, it is likely that this scenario is still difficult to build. The main challenge for Scenario 3 would be the quantity of wind turbine and li-ion battery. Since a suitable location for wind turbine is near coastal areas, which receive higher wind speed than inner areas of the South, to add 17,510 wind turbines would bring a huge impact on tourism business and villagers across the areas. In the same way, to place 5,877 of 1 MWh li-ion battery, which has a size of a container, would require large areas as well as workers to take care of them. However, COE and capital cost of this scenario should not be huge problem if government allocate more subsidy or draw up policy for pathway in the future. Additionally, cost of renewable technologies could continuously decrease according to high competition in this field making COE and capital cost lower than current situation. Therefore, Scenario 3 could possibly be a choice in the future when technical and social aspects of green energy match up together.

Since the conditions of Scenario 3 and Scenario 4 are not suitable to use, the last two models, Scenario 1 and Scenario 2, will be justified to find the most appropriate hybrid combination system. The results and components of both scenarios are slightly close together. COE and capital cost of Scenario 2 that are a bit higher than Scenario 1 should not be a problem since its COE is almost equal to the average price of Thailand which will not have an impact on public sector. Thus, the majority of people in the area would prefer to live with scenario that produces less harmful impacts on the environment and would encourage the government and investors to build hybrid combination with higher renewable fraction. However, geology would be the biggest challenge for Scenario 2 as a quantity of wind turbine is about 4 times higher than in Scenario 1. As already mentioned above that suitable location of wind turbine is around coastal area of the region, which would affect villagers and tourism business, the possibility to build hybrid combination of Scenario 2 would be generally lesser than Scenario 1. All it all, the feasibility to located Scenario 1 or Scenario 2 in the South of Thailand can be possible depending on which priority to focus on. If the first priority is the reduction of CO_2 emissions, Scenario 2 will be a better choice. If the priority is geology and financial aspect, then Scenario 1 will be an option for that.

Overall, since the criteria of hybrid combination in this project are at least 30% renewable fraction, financial, environmental and social impacts, Scenario 1 can complete 3 out of 4 conditions, while Scenario 2 achieves 2 out of 4 criteria. Therefore, Scenario 1 will be selected to be the most suitable hybrid combination of this project.

5.1 Suggesting Suitable Location for the Most Feasible Scenario

Figure 37: Map of 14 provinces in Southern Thailand (Pookpunt & Ongsakul, 2016)

This section will suggest possible locations in Southern Thailand in order to locate hybrid combination of Scenario 1, which is selected to be the most feasible scenario of this project. The following list will classify each main component of Scenario 1:

- **NGCC plant** – as a main power supply for the demand, this plant should be located in large cities with large population such as Nakhon Si Thammarat and Songkhla. In addition, these two provinces are on the same side of the Gulf of Thailand, where most of natural gas comes from. Thus, this would be beneficial for fuel transportation to power plants.

- **Biomass plant –** according to a study from Chamamahattana et al. (2005), plantations of oil palms, which are the main fuel for biomass, exist mainly in Surat Thani, Krabi, and Trang. Hence, biomass plant should be located in these provinces to reduce difficulties in transportation.

- **Wind turbine –** Suitable location for wind turbine is around coastal areas, which can gain higher wind speed than inner areas of the South, However, many coastal areas such as Trang, Krabi, Phuket**,** Phang-nga, Nakhon Si Thammarat and Songkhla are the main point for tourism. Therefore, coastal areas of Yala and Chumphon should be appropriate locations to share around 1,600 wind turbines together.

- **Solar PV –** location of solar PV can be more flexible than other systems since it can be installed on rooftop of any house according to the residents' requirements. It is estimated that there are around 3 million households in the southern region and assumed that average PV panel per household is 8 panels. Only about 8.7% of total household in this region would require to install solar PV of this system. Optional, solar farm can be located in this region to reduce the reliance on households.

- **Hydrokinetic –** hydrokinetic turbines have a fixed location, which is in the Pattani River. The 214 km long from the Gulf of Thailand through Pattani to Yala would be the place for 8,250 hydrokinetic turbines.

- **Li-ion Battery –** according to a research from Hutchison (2017), the average size of 1 MWh of li-ion battery is a 20 feet container (long 6 meters, wide 2.4 meters and height 2.6 meters). Generally, this battery will be placed near renewable power plant. Thus, in this case, location near solar farm or wind farm would be expected.

6. Conclusion

According to the current status of power generation system in Southern Thailand, this area has high possibility to face energy shortage in the near future due to rapid growth of industrial sector and electricity demand. The government drew up a plan to tackle this problem by suggesting to add 3 coal-fired power plants, which have total capacity of 2,800 MW, to accommodate the increasing demand in the near future. However, there are many negative public opinions since the villagers have claimed that this plan would create huge social and environmental impacts. For this reason, this project is aimed at carrying out a suitable model that consists of renewable systems at least 30% under criteria of financial, social and environmental aspects. As a result, HOMER is selected to be the software for the simulations.

However, HOMER can provide the results related to technical, financial, environment aspects, but not covering social impact. The software also has a limitation on type of power generation component. For instance, there is no model of coal-fired power plant, NGCC plant, and a small number of hydrokinetic turbines. In addition, some input parameters for simulation are in lack of certain necessary information, such as monthly water speed and biomass fuel resources. Consequently, assumptions based on study in common areas were made to achieve the most precise results as much as possible. Furthermore, suitable locations for hybrid combination were suggested under social impact concern and fuel availability.

As regards the results of this project, there are 4 scenarios that were carried out using HOMER to be feasible in terms of technical aspect. These scenarios are classified by renewable fraction, wherein Scenario 1-4 would represent hybrid combination with renewable fraction of 30%, 50%, 70%, and 100%, respectively. Each scenario consists of non-renewable NGCC plant as a base load, except Scenario 4, and 4 renewable systems, such as solar PV, wind turbine, biomass and hydrokinetic. From the results, Scenario with significant renewable production systems would benefit the environment as it had higher percentage of CO_2 emissions reduction. In contrast, it seems that major barriers of scenarios with significant renewable fraction model would be financial and social impacts. The following list will conclude the main points from the results and analysis.

- Solar PV would play an important role of hybrid combination since it has the largest proportion of power production and its installation might be less complicated than other renewable systems.

- For daily power production, both solar PV and wind turbine can produce power from around 06:00 to 18:00 hrs. and reach their peak at midday. Solar PV can generate higher output in summer, and wind turbine in winter.

- Due to intermittent outputs of renewable power, battery is significantly important to keep balance of the system. However, a larger number of batteries cannot enhance the stability of high renewable fraction model, especially all alternative power system, according to optimal hybrid combination.

- Although high renewable fraction system can reduce higher CO_2 emissions, COE is more expensive and the requirement for construction area is greater due to a larger number of components.

- Only Scenario 1 and 2 seem to be viable for the southern region. Nevertheless, Scenario 1 was selected to be the most feasible model with regard to financial and social impacts.

Overall, this case study of Southern Thailand can be concluded that hybrid combination with renewable fraction of 30% (Scenario 1) is the most feasible and appropriate model according to criteria of the project. In the future, this model could be more efficient due to improvements of technology and government support for renewable systems. Finally, this project may have some drawback due to limitations mentioned above or others. Thus, the following chapter will identify future work that could be an improvement for the project.

7. Future Work

Due to limitation of timeframe, software and lack of some data inputs for simulation, the result might not be totally accurate and this project may not satisfy literature in some aspects. Thus, the following will identify some methods that could be further improvement for this project.

- **Location of hybrid combination** – as mentioned in Chapter 5.1, suggested locations are only considered under the distance from the available resources and social impacts conditions. For further improvement, power network system in the region should be studied to be able to locate the hybrid combination accordingly.

- **Sensitivity analysis –** the simulation of this project includes many fixed input data such as solar resource, wind speed, water speed and price of fuel. Therefore, sensitivity analysis of these parameters would illustrate of the configuration and result of hybrid combination.

- **Accurate parameters** – since there are many assumptions in the simulation as stated in Chapter 3.2, these should be carried out as real data for a more precise result.

- **Demand side management –** to study about cooling demand systems in residential sector and identify methods to reduce its demand, which will lower electricity demand and then reduce the size of hybrid combination.

- **Pump hydro storage –** the potential of pump hydro storage in the region should be studied. This technology can reduce the need of li-ion battery and could improve the result of hybrid combination.

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