Chapter 2

Clean Electricity Supply

February 2021

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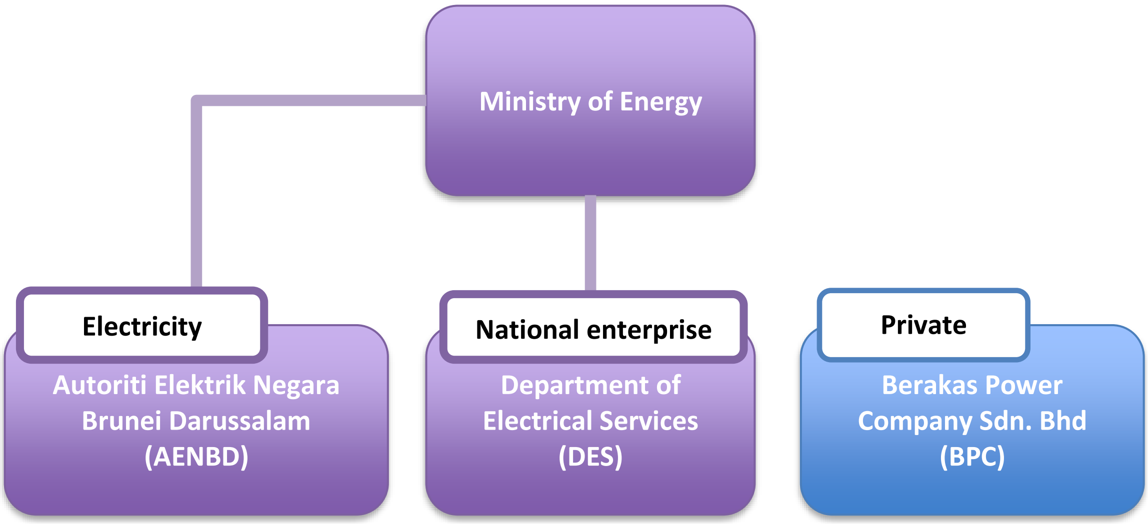
Chapter 2

Clean Electricity Supply

1. Organisation of the Electricity Sector

There are two electric utilities in Brunei Darussalam: the Department of Electrical Services (DES), which is a state enterprise, and the Berakas Power Company Sdn Bhd (BPC), which is a private enterprise. Figure 2.1 shows the organisational structure of Brunei's electricity sector.

Figure 2.1: Organisational Structure of the Electricity Sector, Brunei Darussalam



Source: Authors.

1) Ministry of Energy

The Ministry of Energy (MOE) was initially formed in 2005 as an energy division under the Prime Minister's Office. The division regulates and oversees the development of the petroleum industry in Brunei Darussalam. It was later upgraded into the Energy and Industry Department at the Prime Minister's Office (EIDPMO) in 2011. Effective April 2018, the department was upgraded to the Ministry of Energy, Manpower and Industry to focus on energy affairs fully. Then it was restructured to the current MOE in November 2019.

The MOE (i) is responsible for prudent exploitation of hydrocarbon resources; (ii) grows and diversifies the downstream industry; (iii) strengthens sustainable energy efforts through the implementation of renewable, alternative, and energy efficiency initiatives; and (iv) ensures the supply of reliable, safe, efficient, and affordable energy to the nation.

2) Department of Electrical Services (DES)

The DES was established in 1921. As a national enterprise in Brunei under the MOE, the DES is responsible for the electricity sector's operation and development. As a utility, the DES operates the generation, transmission, and distribution network to the end users throughout the country and supplies about 60% of the national electric power demand.

3) Berakas Power Company Sdn Bhd (BPC)

The BPC was established as a private enterprise in 1999. It operates the generation, transmission, and distribution network to the end users in Brunei's central area, where Bandar Seri Begawan (BSB) is located and supplies approximately 40% of the national electric power demand. The BPC is also responsible for implementing government power infrastructure projects in the country.

4) Autoriti Elektrik Negara Brunei Darussalam (AENBD)

The EIDPMO introduced the new 'Electricity Order 2017', which repealed the Electricity Act. Electricity Order 2017 aimed at strengthening the legal and safety aspects relating to the generation, transmission, and distribution of electricity in Brunei Darussalam. These objectives would be achieved through changes and additions to the order, including the introduction of a licensing scheme for the generation, transmission, and distribution of electricity; certification requirement for electrical workers; and regulations on installation and modification of electrical works.

To enforce and supervise the implementation of Electricity Order 2017, AENBD was formed as an electricity authority of Brunei Darussalam in June 2017 (https://borneobulletin.com.bn/new-electricity-order-2017-introduced/).

2. Current Situation of Power System in Brunei Darussalam

2.1. Overview of the power system in Brunei Darussalam

There are two power systems in Brunei Darussalam, as mentioned. The DES power system covers the whole country, supervises Temburong district, and comprises four power stations and transmission lines at 275 kV, 132 kV, and 66 kV. However, the current maximum operating voltage is 66 kV. Since some transmission lines were designed at 275 kV and 132 kV, DES is considering operating the transmission network at 132 kV when the power demand grows.

DES also operates four power stations: Gadong 1 and 2, Bukit Panggal, Lumut, and Belingus. Gadong 1 and 2, Bukit Panggal, and Lumut power stations use gas thermal power plants and are connected to the main grid. The Belingus power station is located in Temburong district and uses a diesel power plant. The total generation capacity is approximately 600 MW.

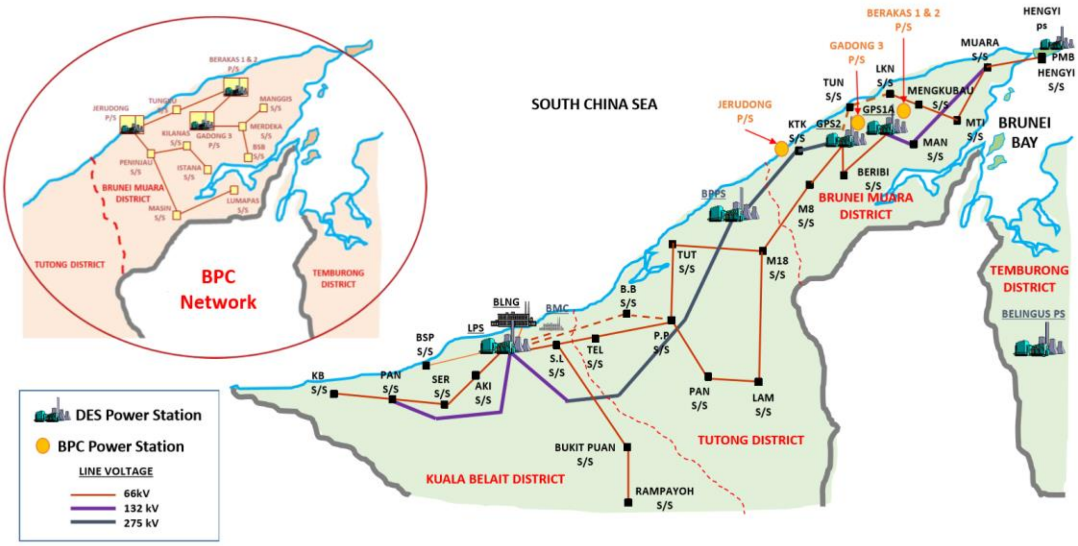
Temburong district is currently an off-grid system, and one diesel power station is operational. There is a plan to synchronise the main grid and the Temburong grid in the future. The interconnection plan with Temburong district will be described later.

The other power system is that of the BPC that covers Brunei Muara district, including BSB, which is a load centre. The BPC power system comprises three power stations and transmission lines at 66 kV.

The BPC also operates three power stations: Berakas 1 and 2, Jurudong, and Gaddong 3 power stations. These power stations use gas thermal power plants whose total generation capacity is about 320 MW.

The DES and BPC power systems are synchronised with a 66 kV transmission line (Figure 2.2).

Figure 2.2: Transmission Network of DES and BPC



DES = Department of Electrical Services, BPC = Berakas Power Company Sdn Bhd.
Source: DES.

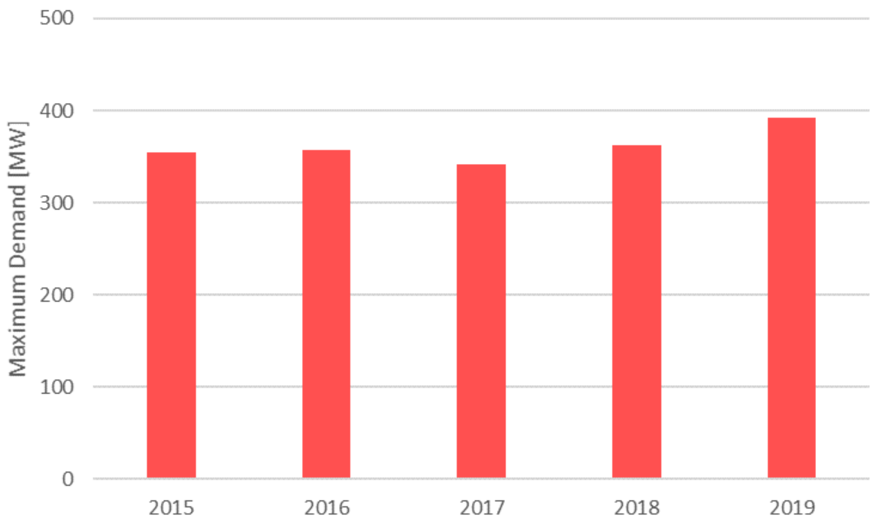
2.2. Power demand

2.2.1. Power Demand in Main Grid of Brunei Darussalam

Actual power demand data was obtained from DES and BPC. Figures 2.2 and 2.3 show the changes in DES maximum demand, including Temburong, and of BPC. The maximum power demand of DES in 2015 was 355 MW. It steadily increased from 2015 except for a small dip in 2017 and reached 392 MW in 2019. The demand growth rate from 2015 to 2019 was approximately 10.4%. On the other hand, the maximum power demand of BPC in 2015 was 230 MW. Although its power demand reached 240 MW in 2016, it slowed down after that and settled at 239 MW in 2019. The demand growth rate from 2015 to 2019 was approximately 4.5%. Figure 2.4 shows the monthly maximum daily load curve in the main grid of Brunei Darussalam in 2019. Power demand seemed to be highest in April and September and lowest in October. The increase in power demand could be largely due to the dry season in April and September. Also, as will be described later, since the average temperature was the highest in August 2019, it is thought that the power demand would increase. The decrease in power demand from October to December could be due to the rainy season.

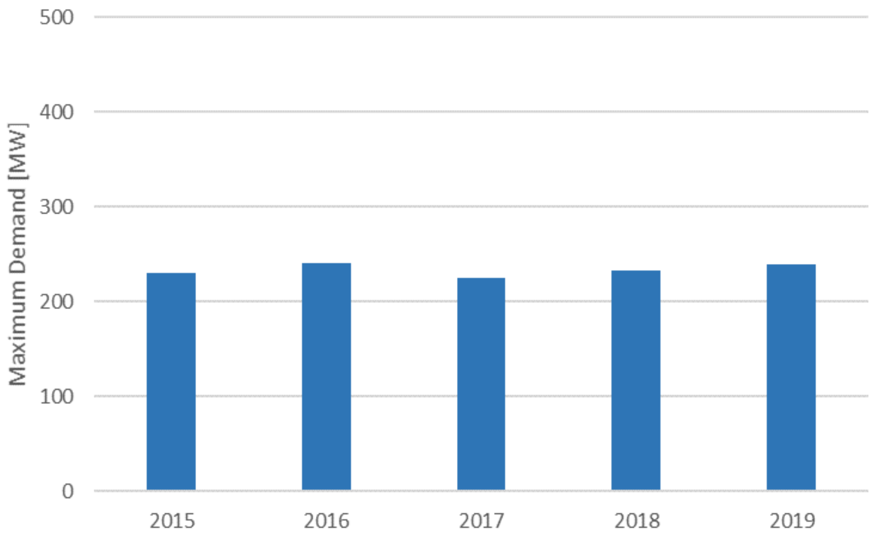
The demand curve in Brunei Darussalam starts to increase gradually in the morning with the start of industries and offices and reaches the daytime peak around 14:00 to 15:00 due to air conditioning. Then it dips around 17:00 with the end of work in some industries and offices and increases again. The day peak of power demand is basically around 19:00 to 20:00 due to light and household demand. After that, it gradually decreases and reaches a minimum demand around 6:00.

Figure 2.3: Changes in Maximum Demand of DES (Including Temburong)



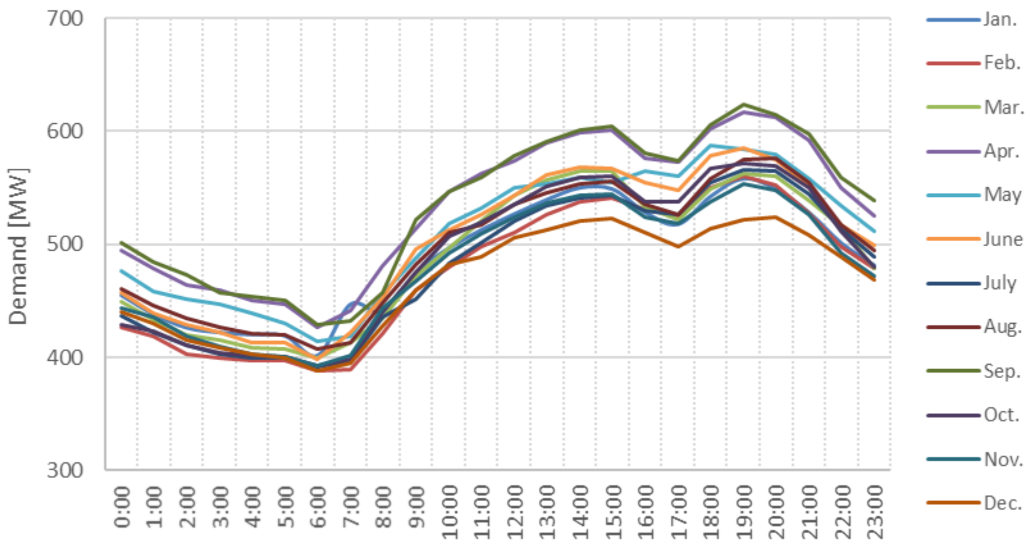
Source: DES data, modified by the author.

Figure 2.4: Changes in Maximum Demand of BPC



Source: BPC data, modified by the author.

Figure 2.5: Monthly Maximum Daily Load Curve in Main Grid of Brunei Darussalam (as of 2019)

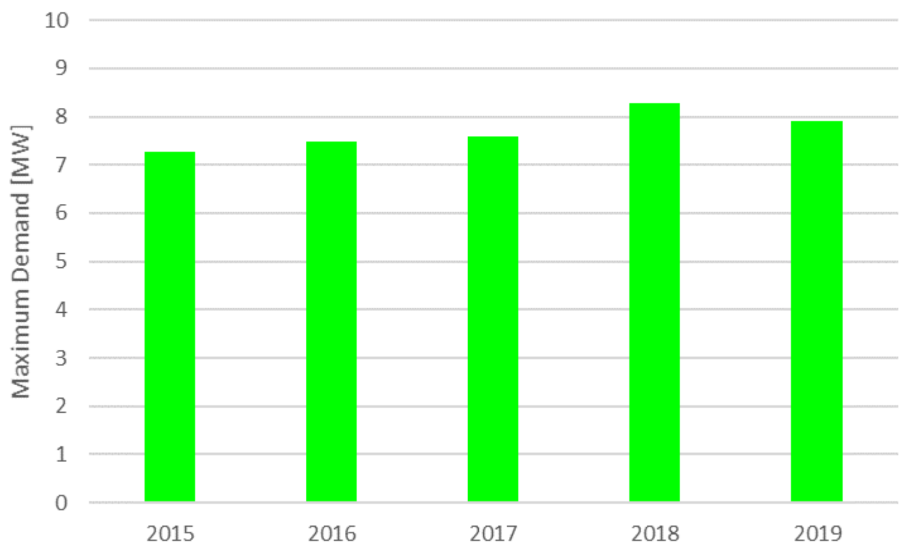


Source: DES and BPC data, modified by the author.

2.2.2. Power Demand in Temburong District

Power demand data in Temburong district was also obtained from DES. Figure 2.6 shows the changes in maximum demand in Temburong district, reaching approximately 7.3 MW in 2015. It gradually increased from 2015, peaked at approximately 8.3 MW in 2018, and decreased to about 7.9 MW in 2019. The demand growth rate from 2015 to 2019 was about 13.7%.

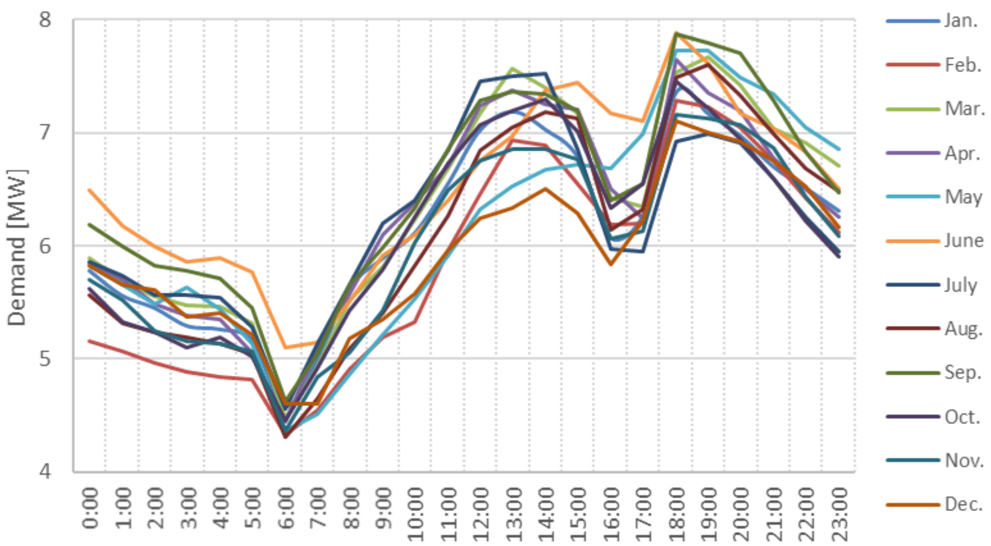
Figure 2.6: Changes in Maximum Demand in Temburong District



Source: DES data, modified by the author.

Figure 2.7 shows the monthly maximum daily load curve in Temburong district in 2019. Power demand seemed to be highest in June and August. As will be described later, since the average temperature was the highest in August and the second in June, and the rainfall in June and August was relatively low, power demand was expected to increase. The decrease in power demand in November and February could be due to the rainy season. The demand curve in Temburong district is almost the same as that of Brunei.

Figure 2.7: Monthly Maximum Daily Load Curve in Temburong District (as of 2019)



Source: DES data, modified by the author.

2.3. Temburong transmission line plan

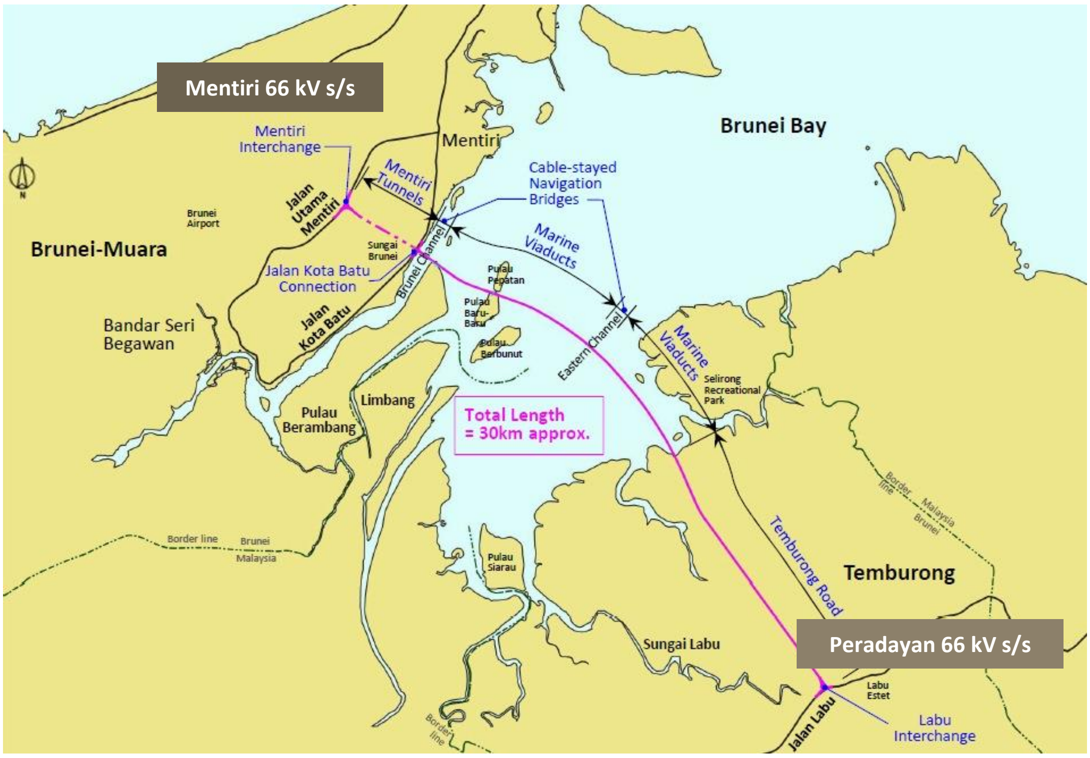
Temburong district is an off-grid system. Electricity is supplied to customers by diesel generators at the Belingus power station. In 2020, the completion of the Temburong Bridge connecting Muara and Temburong districts made it possible to travel between the mainland and Temburong by land.

DES plans to develop a transmission line connecting the main grid and Temburong district using the Temburong Bridge.

Figure 2.8 shows the Temburong transmission line plan. This transmission line will be designed at 66 kV and two circuits. A transmission capacity has not been fixed but DES considers 30–50 MVA in the initial design. The Temburong transmission line will be connected between Mentiri 66 kV substation and Peradayan 66 kV substation.

DES will disconnect the diesel generator because Temburong district will be connected to the main grid after the transmission line is constructed. Also, Temburong district is always synchronised with the main grid, therefore, power system reliability is expected to improve.

Figure 2.8: Temburong Transmission Line Plan 2023/2024



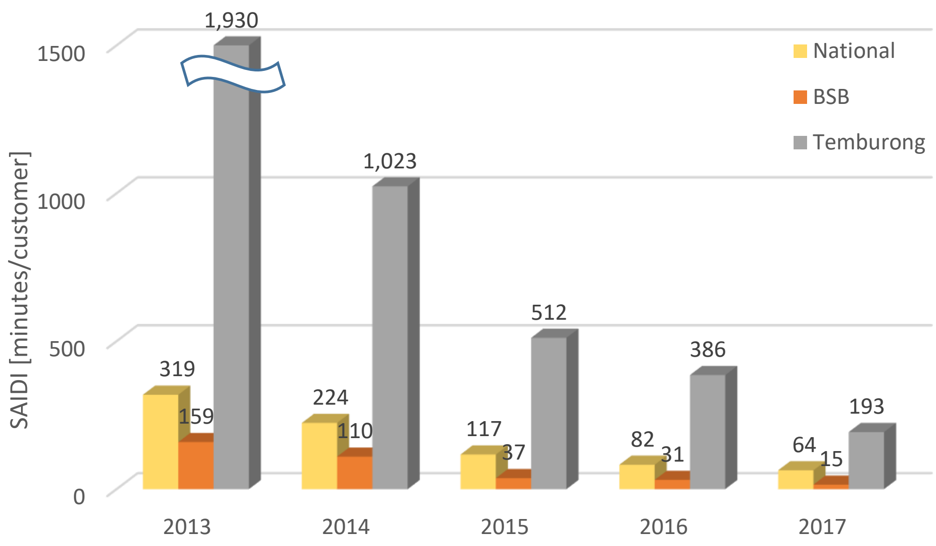
Source: DES.

2.4. Power system reliability

The System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) are generally used as international standards to monitor the distribution systems' reliability. SAIDI is a system index of average duration of interruption in the power supply indicated in minutes per customer. SAIFI is a system index of the average frequency of interruptions in the power supply. These indices serve as valuable tools for comparing the power system reliability of electrical utilities.

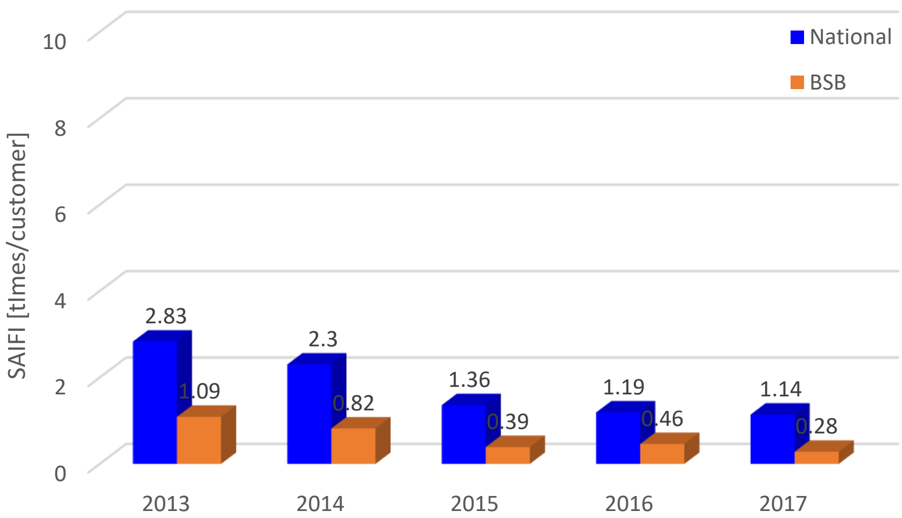
Figures 2.9 and 2.10 show SAIDI in Brunei Darussalam. Table 2.1 shows the power outage over 1 hour in Temburong district instead of its SAIFI. The national, BSB, and Temburong SAIDIs decreased from 2015 to 2019. The national SAIDI improved to about one fifth and that of BSB and Temburong dramatically improved to one tenth. During the same period, the national and BSB SAIFI decreased. The national SAIFI improved to approximately one third and that of BSB improved to about one quarter. The number of power outage over 1 hour in Temburong district also dramatically decreased from 38 times in 2013 to 5 times in 2017.

Figure 2.9: SAIDI in Brunei Darussalam



Source: DES data, modified by the author.

Figure 2.10: SAIFI in Brunei Darussalam



Source: DES data, modified by the author.

Table 2.1: Power Outage over 1 Hour in Temburong District

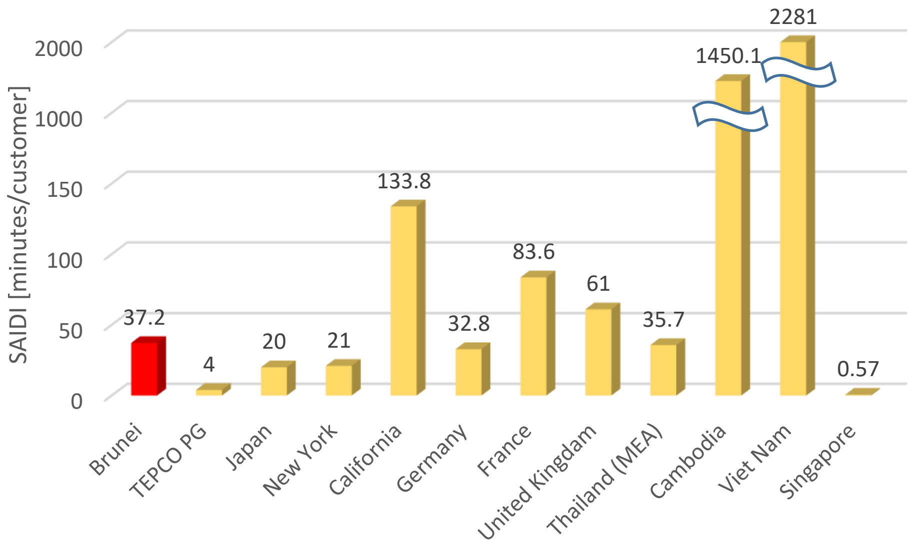
	2013	2014	2015	2016	2017
Temburong district power outage > 1 hour	38	19	17	8	5

Source: DES data, modified by the author.

Figures 2.11 and 2.12 show the international comparison of SAIDI and SAIFI in 2015, respectively. Although Brunei's SAIDI and SAIFI are low compared to high-level countries, such as Japan and Singapore, they are at the same level as developed countries such as European countries and the USA. Brunei's SAIDI and SAIFI are also at a sufficiently high level compared to other ASEAN countries.

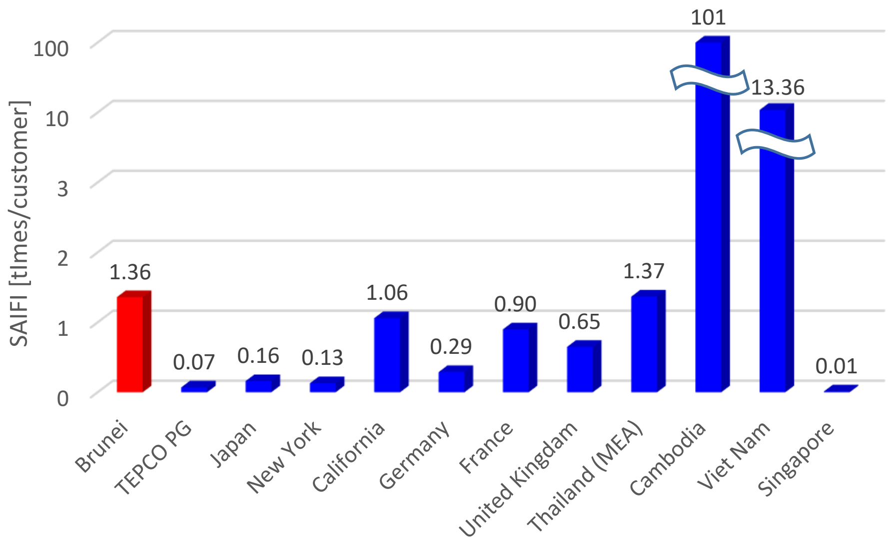
However, the power system reliability of the Temburong district is still low. Therefore, as mentioned, the Temburong transmission line plan is expected to improve further the power system reliability of the Temburong district.

Figure 2.11: International Comparison of SAIDI (as of 2015)



Source: Authors.

Figure 2.12: International Comparison of SAIFI (as of 2015)



Source: Authors.

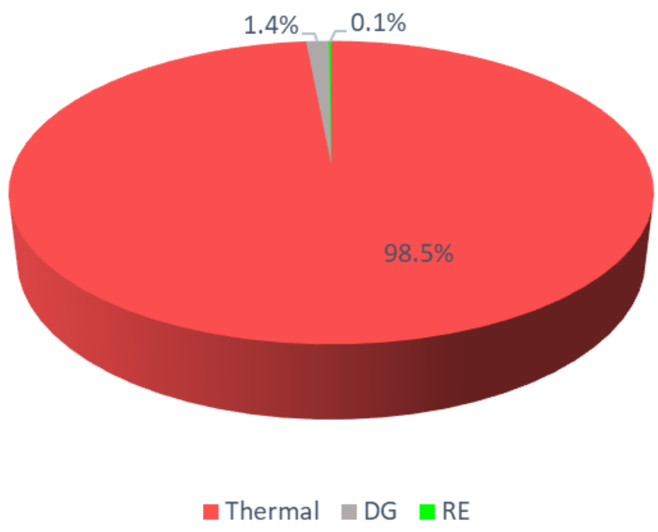
3. Renewable Energy

3.1. Current situation of renewable energy in Brunei Darussalam

Brunei Darussalam has about 867 MW of installed capacity in power generation, including variable renewable energy (vRE) power stations. Currently, the only vRE power station is Tenaga Suria Brunei (TSB) Power Station with an installed capacity of 1.2 MW. The installed capacity portfolio in Brunei is shown in Figure 2.13. The ratio of vRE is approximately 0.1% only and gas-fired thermal power accounts for most of the total installed capacity.

The TSB power station is an on-grid 1.2 MW solar PV power plant in Seria, Belait district, developed through a collaboration between Brunei and Mitsubishi Corporation of Japan. The TSB was installed in 2011 and, after a 2-year evaluation period, went into commercial operation. The TSB is one of Brunei's initiatives to develop and promote renewable energy, in line with its target of generating about 10% of the total power generation mix from renewable energy (DES et al., 2016).

Figure 2.13: Installed Capacity Portfolio in Brunei Darussalam



DG = diesel generation , RE = renewable energy.
Source: DES data, modified by the author.

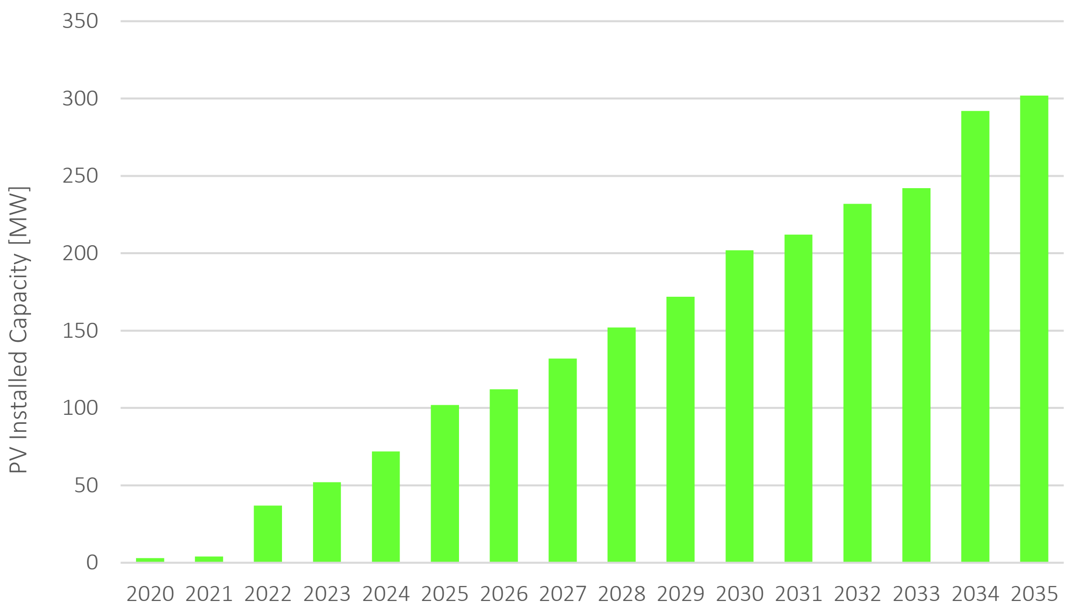
3.2. Renewable energy installation target

In October 2015, ASEAN announced a region-wide aspirational target to achieve 23% renewable energy in total primary energy supply by 2025, significantly increasing from just less than 10% in 2014. The goal is part of ASEAN's Plan of Action for Energy Cooperation 2016–2025, adopted by its member states at the 33rd ASEAN Ministers on Energy Meeting in September 2015 in Kuala Lumpur, Malaysia. ASEAN member states must make an immediate and concerted effort to realise the 23% aspirational target by 2025 (IRENA and ACE, 2016).

Brunei also plans to promote renewable energy. The country supports implementing three strategic goals set out in the Brunei Darussalam's Energy White Paper launched in March 2014 to drive the economy into a sustainable future. The White Paper (EDPMO, 2014) sets out strategic goal 2 specifically for supply and demand: to ensure a safe, secure, reliable, and efficient supply of energy in Brunei Darussalam. Strategic goal 1 focuses on strengthening oil and gas upstream and downstream activities whilst goal 3 focuses on maximising economic spin-off from the energy sector (Kimura and Han, 2019). Strategic goal 2 targets to achieve 10% renewable energy in total primary energy by 2035.

Figure 2.14 shows the PV installation plan in Brunei Darussalam, which was provided by the MOE. The amount of PV installed capacity was 1.2 MW as of 2019, but Brunei plans to gradually increase the installed capacity of PV to about 100 MW by 2025, about 200 MW by 2030, and about 300 MW by 2035. Since the current total installed power generation capacity is approximately 867 MW, if 300 MW of PV will be introduced as planned by 2035, it will account for about 25% of the total installed power generation capacity in 2035.

Figure 2.14: PV Installation Plan in Brunei Darussalam



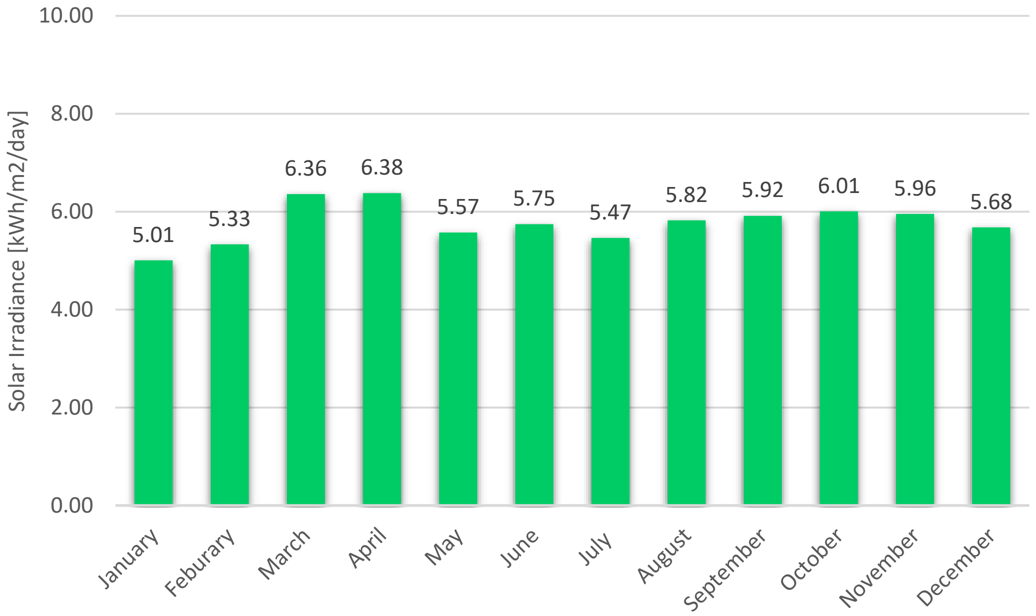
Source: MOE data, modified by the author.

3.3. Climate and weather of Brunei Darussalam

3.3.1. Solar Radiation

Figure 2.15 shows the monthly average daily solar irradiance at the TSB Power Station in 2018. It ranged from 5.01 kilowatt-hours per square metre per day (kWh/m^2/day) in January to 6.38 kWh/m^2/day in April. The country had a relatively high solar radiation in March and April, which could be due to the dry season. On the other hand, Brunei had relatively low solar radiation in January and February, which could be due to clouds or rain. However, the monthly difference in the amount of solar radiation is not significant.

Figure 2.15: Monthly Average Daily Solar Irradiance at Tenaga Suria Brunei Power Station

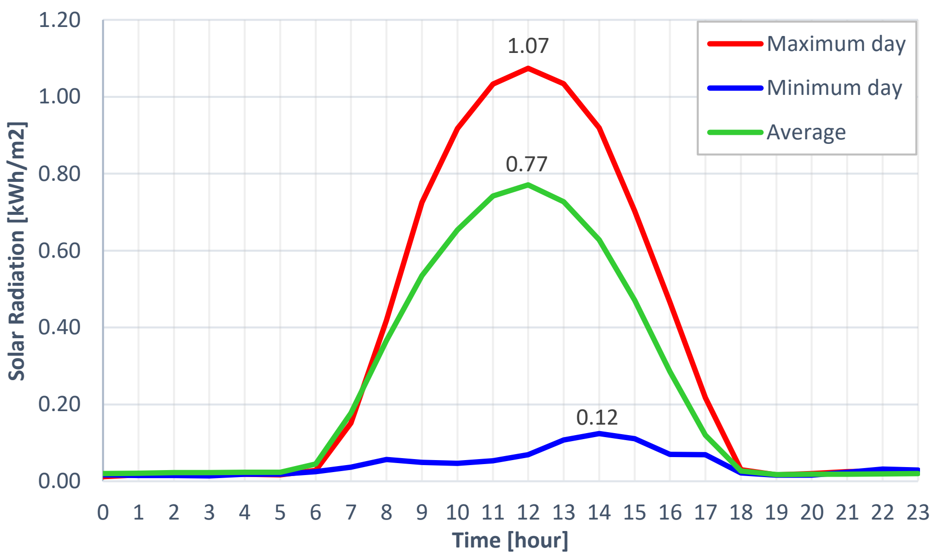


Source: MOE data, modified by the author.

Figure 2.16 shows the hourly solar irradiance for 2018. The maximum day and average curves exhibit an approximate symmetrical shape at noon, which has the highest radiation at 1.07 kWh/m^2 of maximum and 0.77 kWh/m^2 of average irradiance.

The solar irradiance data cited above was measured only within the Belait district where the TSB power station is situated. However, since the districts' latitudes and longitudes are close to each other, these solar radiation values can be assumed to be similar (Malik and Abdullah, 1996).

Figure 2.16: Hourly Solar Irradiance for 2018 at Tenaga Suria Brunei Power Station

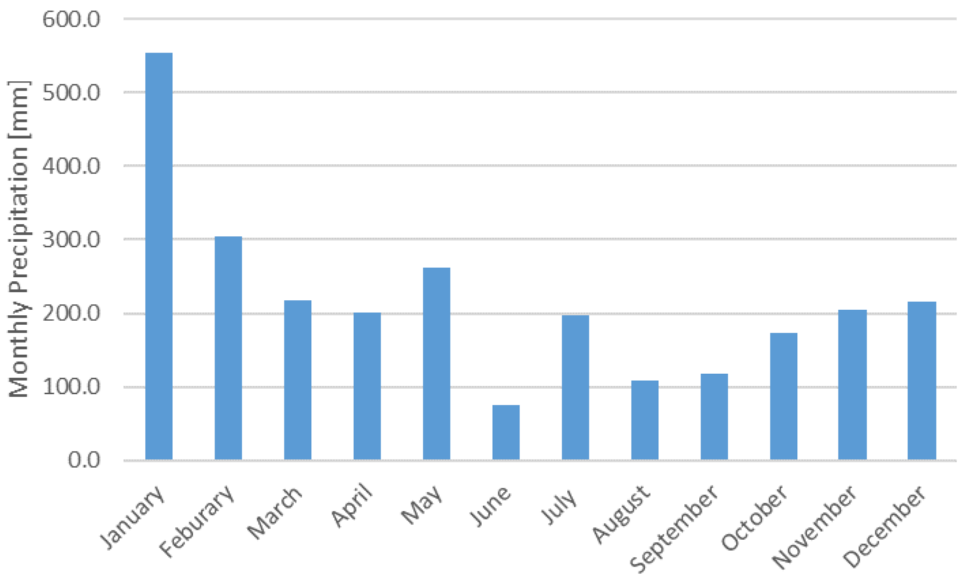


Source: MOE data, modified by the author.

3.3.2. Precipitation and Temperature

Between 1984 and 2013, Brunei's average precipitation amounted to about 2,976 millimetres (mm), with an increase of 26.16 mm per year (Hasan et al., 2015). January 2018 had the highest precipitation amount of 554 mm, coinciding with the wet season, usually between October and February. On the other hand, precipitation was relatively low from March to September 2018, coinciding with the dry season (Figure 2.17). The annual rainfall in 2018 was about 2,632 mm, which was about 90% of the average from 1984 to 2013. Monthly fluctuations in precipitation were relatively small.

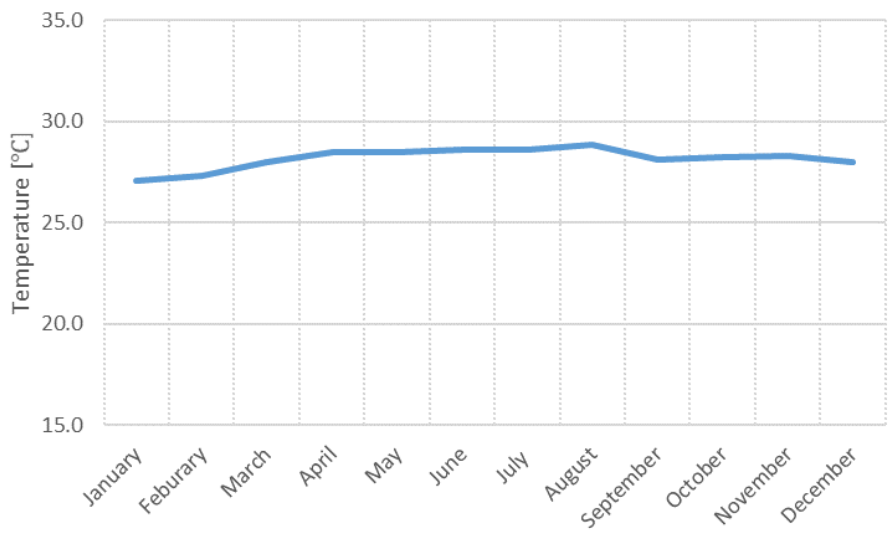
Figure 2.17: Precipitation at Tenaga Suria Brunei Power Station in 2018



Source: MOE data, modified by the author.

The average temperature at the TSB power station in 2018 ranged from 27.0°C in January 2018 to 28.8°C in August (Figure 2.18). Between 1979 and 2008, 2013, and 2016, August had the highest monthly average of maximum temperature (BDMD, 2017). Therefore, since the temperature tends to rise in August, power demand tends to increase due to air conditioners. Monthly fluctuations in average temperature are also minimal.

Figure 2.18: Average Temperature at Tenaga Suria Brunei Power Station in 2018

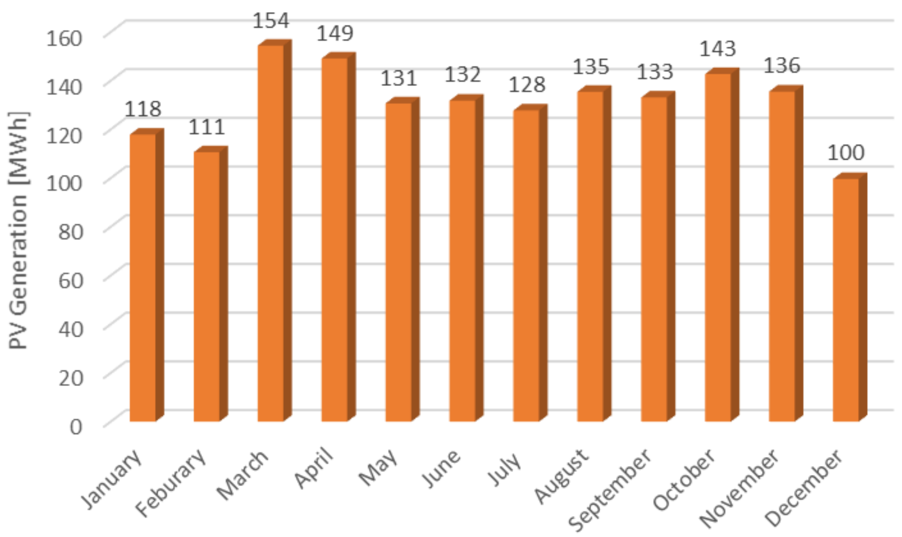


Source: MOE data, modified by the author.

3.4. PV generation at TSB power station

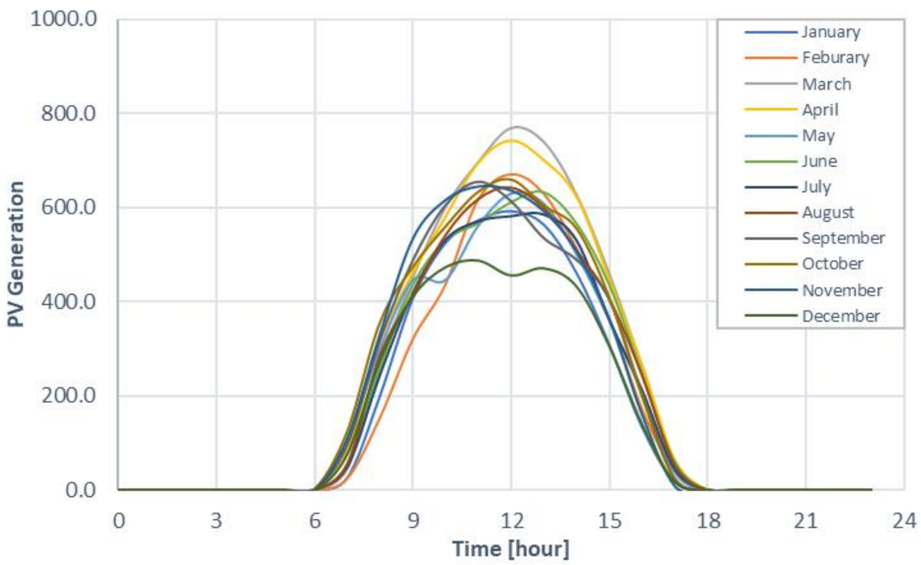
The MOE provides the PV generation data. Figures 2.19 and 2.20 show the monthly PV generation and monthly average hourly PV generation at the TSB power station in 2018, respectively. PV generation was highest in March and April, at 154 MWh and 149 MWh, respectively. The increase in PV generation could be large in March and April due to the dry season. On the other hand, PV generation was lowest in December at 100 MWh. Since the TSB power station did not operate for 3 days in December, the actual power generation in December was about the same as January or February. The decrease in PV generation from December to February could be due to the rainy season.

Figure 2.19: Monthly PV Generation at Tenaga Suria Brunei Power Station in 2018



Source: MOE data, modified by the author.

Figure 2.20: Monthly Average Hourly PV Generation at Tenaga Suria Brunei Power Station



Source: MOE data, modified by the author.

3.5. Capacity factor of TSB power station

An index called the 'capacity factor' generally shows the performance of the generators. The capacity factor is the unitless ratio of actual electrical energy output over a given period to the maximum possible electrical energy output over that period. This index is also often used to show the performance of renewable energy generation. The capacity factor is given by the following formula.

$$Capacity\ Factor = \frac{Annual\ energy\ generation\ [MWh]}{Rated\ capacity\ of\ generator\ [MW] \times 8{,}760\ [h]} \times 100\ [\%]$$

The capacity factor of the TSB power station in 2018 was calculated using the following formula:

Annual energy generation	1,569	MWh
Rated capacity	1.2	MW
Time	8,760	hours
Capacity factor	14.9	%

The capacity factor of the TSB power station in 2018 was about 14.9%. When this PV was installed in 2011, this power plant's capacity factor was expected to be 15% to 16% (DES, EIDPMO, and BNERI, 2016). Seven years have passed since PV installation, and the equipment has deteriorated over the years. Nevertheless, a capacity factor of about 15% was achieved, not to mention the facility performance. However, the climate in Brunei is also suitable for PV power generation.

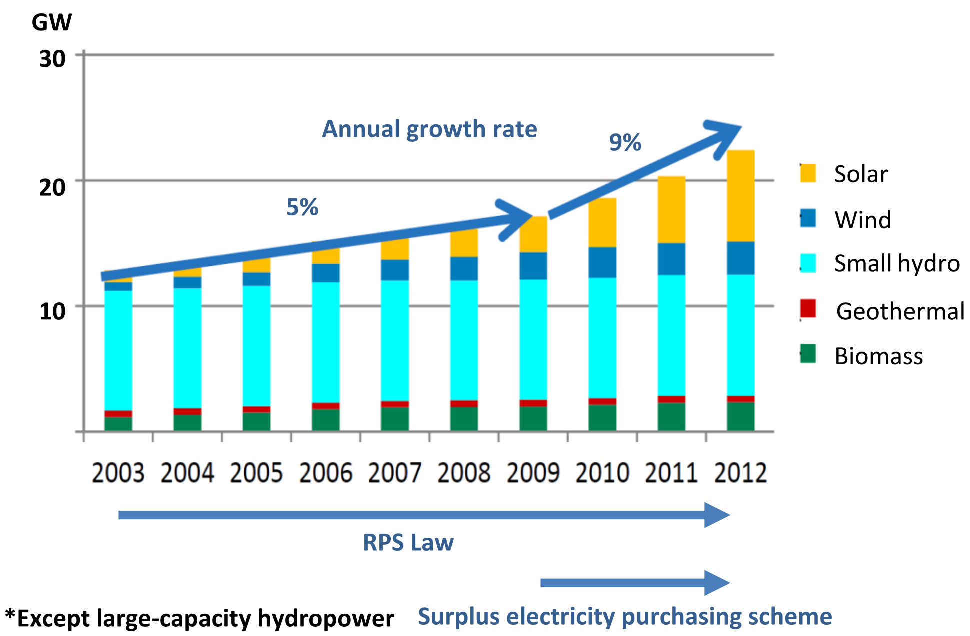
3.6. Promotion of the introduction of renewable energy in Japan

3.6.1. Feed-in-Tariff Law in Japan

Japan implemented its Renewable Portfolio Standard (RPS) Law in 2003 to 2012. The RPS is a regulation that requires increased power generation from vRE sources, such as wind, solar, biomass, and geothermal. The RPS obliges electric power utilities to use electricity generated from vRE at a certain percentage or more according to the amount of electricity sales. Figure 2.21 shows changes in installed capacity of vRE except large-capacity hydropower under the RPS in Japan. After the enforcement of RPS, electric power utilities fulfilled the government's directive to generate electricity from renewable energy. Then the vRE capacity gradually increased at the annual growth rate of about 5% from 2003 to 2009. After the Excess Electricity Purchasing Scheme[6] came into effect, the annual growth rate was about 9% from 2009 to 2012.

Nevertheless, as of 2012, 10 years after the start of the RPS, the installed capacity rate of vRE was approximately 9% of the total installed capacity, which was not so large. Electric power utilities have achieved the government's target of introducing vRE, but the target was set low. As a result, once the electric power utility reached the power generation target of vRE, there was no incentive to introduce more vRE capacity.

Figure 2.21: Changes in Installed Capacity of vRE under RPS in Japan



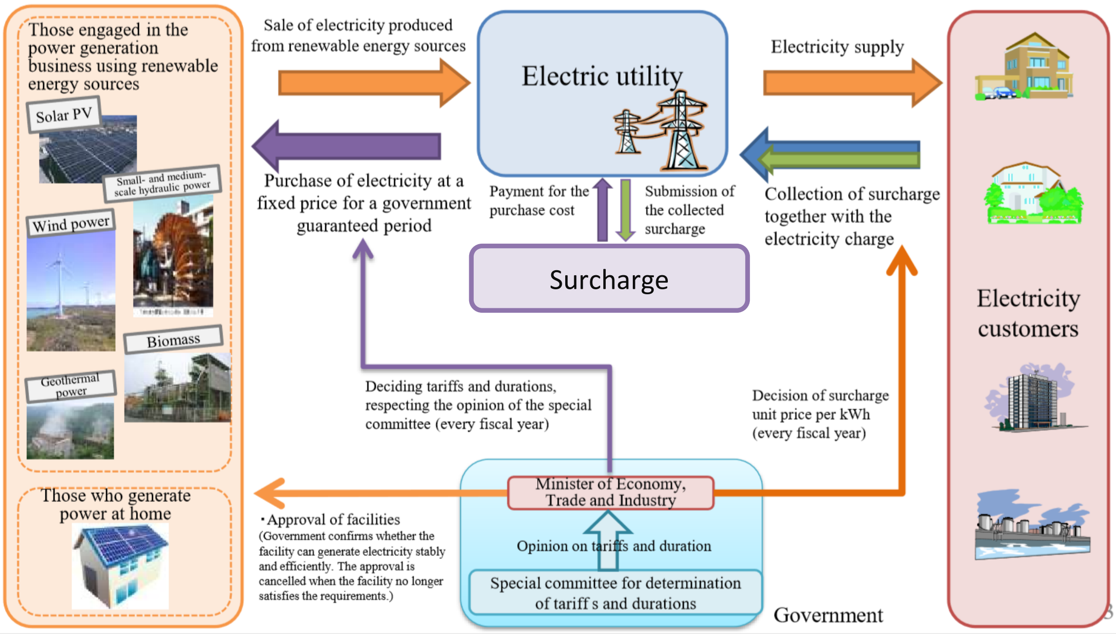
Source: METI (2011).

[6] The Excess Electricity Purchasing Scheme was implemented in Japan from 1 November 2009 to 1 July 2012. Under this scheme, electric utilities were obliged to purchase surplus electricity from PV generation at homes and businesses at a fixed price. This scheme changed to the FIT scheme in 2012.

To further promote vRE, the government introduced the Feed-in-Tariff (FIT) Law in 2012. Figure 2.22 shows the basic mechanism of FIT.

The RPS mandates the vRE generation targets for electric power utilities. FIT mandates them to connect vRE generation, unless there are no grid constraints, and purchase electricity from vRE generation before other generations, except nuclear power, at a fixed price for a long-term period guaranteed by the government. This has forced electric power utilities to accept grid connections as long as there are renewable energy producers, including households, to generate vRE. Figure 2.23 shows the changes in FITs in Japan.

Figure 2.22: Basic Mechanism of Feed-In-Tariff



Source: METI (2011).

Figure 2.23: Changes in Feed-In-Tariff Price in Japan

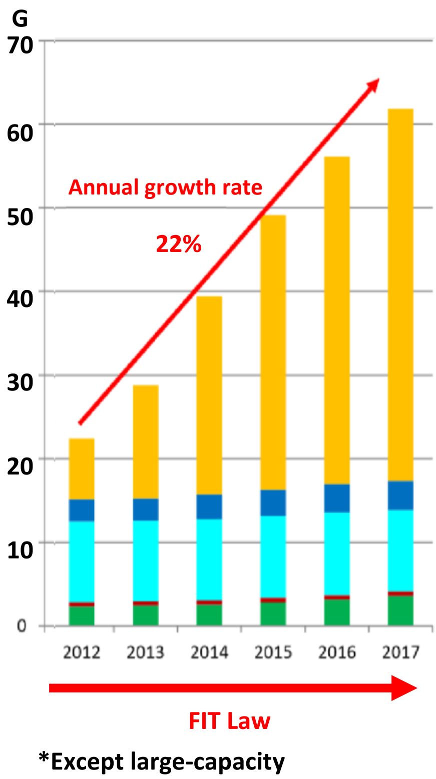
	2012	2013	2014	2015	2016	2017	2018	2019	2020
Industrial solar (more than 10kW)	¥40	¥36	¥32	¥29	¥24	Transfer to bid (2000 kW~)			Future discussion
				¥27 ※7/1~	¥21	~2000 kW			
House solar (less than 10kW)	¥42	¥38	¥37	¥33	¥31	¥28	¥26	¥24	Controlling power
				¥35	¥33	¥30	¥28	¥26	
Wind	¥22(20 kW~)						¥20	¥19	
	¥55 JPY(~20 kW)								
			¥36(off shore wind)						
Geothermal	¥26(15,000 kW~)								
	¥40(~15,000 kW)								
Hydro	¥24(1,000 kW~30,000 kW)						¥20(5,000kW~30,000kW)		
	¥29(200 kW~1,000 kW)					¥27(1,000kW~5,000kW)			
	¥34(~200 kW)								
Biomass	¥39(methane gas)								
	¥32(wood biomass)			¥32(2,000 kW~) ¥40(~2,000 kW) (wood biomass)					
	¥24(general wood biomass)						¥21(20,000kW~) ¥24(~20,000kW)		
	¥13(construction material waste)								
	¥17(general waste and other biomass)								

Source: METI (2017).

The FIT price of PV was ¥40/kWh for industrial (more than 10 kW) and ¥42/kWh for household (less than 10 kW) at the start of FIT. The prices gradually decreased year by year until the household PV price was ¥24/kWh in 2019. The industrial PV price for 10 kW–500 kW was ¥14/kWh, and 500 kW or more was decided by bidding. It has decreased to less than half the price at the start of FIT. The FIT price was set higher than the production cost and was calculated based on the system setup cost.

Figure 2.24 shows the changes in installed capacity of vRE except large-capacity hydropower under the RPS in Japan. After FIT's enforcement, the installed capacity of vRE skyrocketed at the annual growth rate of about 22% from 2012 to 2017. The annual growth rate under FIT is higher than that under the RPS. Thus, the implementation of FIT can be said to be very effective in introducing vRE, especially PV in Japan.

Figure 2.24: Changes in Installed Capacity of vRE under FIT in Japan



FIT = feed-in tariff, vRE = variable renewable energy.
Source: METI (2020).

3.6.2. Current Situation of Renewable Energy in Japan

After FIT came into effect, vRE spread in Japan. As of March 2019, the total installed capacity of vRE, except for large hydropower stations, was 91.6 GW (Table 2.2), of which PV accounted for 58 GW. Japan targets introducing approximately 95 GW of renewable energy by 2030, of which PV accounts for 64 GW.

Table 2.2: Installed Capacity Portfolio of vRE in Japan

	Before FIT (June 2012)	After FIT [A] (as of September 2019)	Target [B] (FY2030)	Progress [A]/[B]
Geothermal	0.5 GW	0.6 GW	1.4 – 1.6 GW	40%
Bioenergy	2.3 GW	4.3 GW	6.0 – 7.3 GW	64%
Wind	2.6 GW	3.9 GW	10 GW	39%
Solar PV	5.6 GW	52.4 GW	64 GW	82%
Hydro (middle or small)	9.6 GW	9.8 GW	10.9 – 11.7 GW	86%

Source: METI (2020).

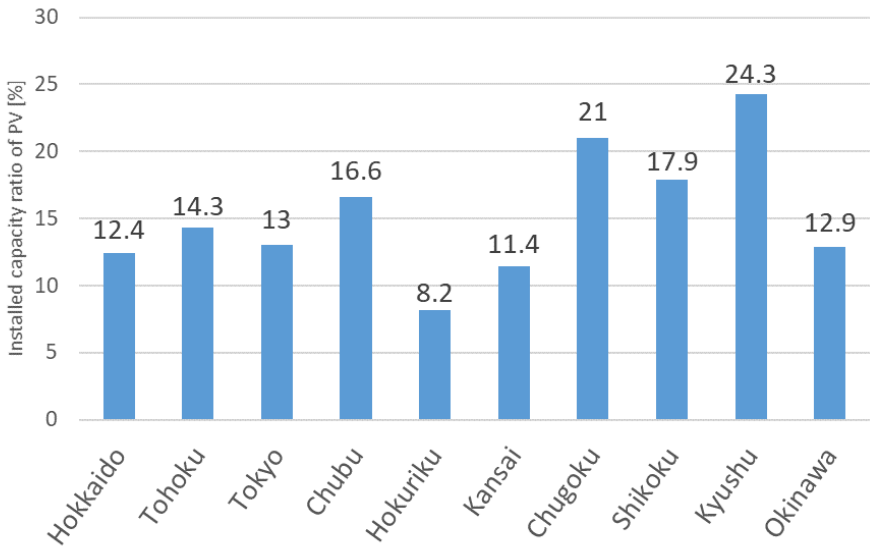
Figure 2.25 shows that the installed capacity ratio of PV in the Kyushu and Chugoku regions has already exceeded 20% of the total power generation capacity. With a large amount of PV introduced, surplus PV power generation has been more serious, especially in the Kyushu region.

On 13 October 2018, the Kyushu region was instructed to suppress PV generation. This suppression order was the first time in Japan. The Kyushu Electric Power Company required PV generation producers to suppress the PV output based on the estimation that the reserve margin for decrease would be insufficient. Generally, electric utilities have to secure the reserve margin to meet increasing power demand. However, in the situations where a lot of PV is generated, electric utilities have to secure the reserve margin for decease to meet increasing PV generation, because PV output depends on solar radiation. Figure 2.26 shows the overview of PV generation suppression in the Kyushu region on 28 October 2019. To secure the reserve margin, firstly, the electric utility companies decrease the outputs of thermal generators. Next, they operate pumped storage hydropower with pumping up mode to absorb the output from PV generation.

Nevertheless, if the surplus output cannot be absorbed, they export the power using the interconnection with the neighbouring electric power company as much as possible. If the output surplus cannot be absorbed even after implementing the above measures, they issue the PV suppression order as a last resort. Electric utilities suppressed PV generation in the Kyushu region 26 times in FY2018 and 51 times in FY2019 (December 2019).

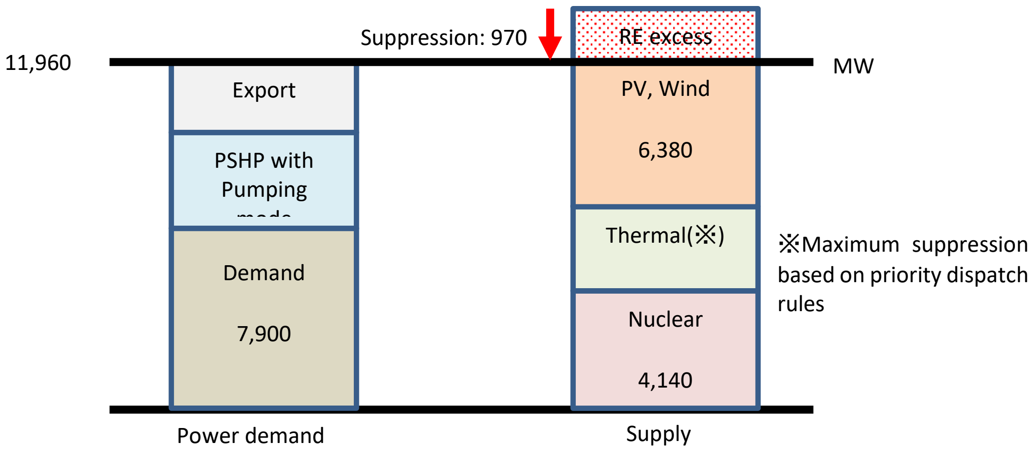
In addition to the Kyushu region are an increasing number of regions where PV generation must be suppressed. To overcome this problem, each electric power utility calculates an appropriate amount of vRE capacity that can be connected to each area under the initiative of the Ministry of Economy, Trade and Industry (METI) every year. This report defines this amount as ‘connectable capacity’. This effort is significant in promoting the introduction of renewable energy. Therefore, ERIA analysed a vRE capacity that can be connected to Brunei's power grid and Temburong district. The next chapter describes the details of the analysis.

Figure 2.25: Installed Capacity Ratio of PV in Each Region



PV = photovoltaic.
Source: Authors.

Figure 2.26: Overview of PV Generation Suppression in Kyushu Region on 28 October 2019



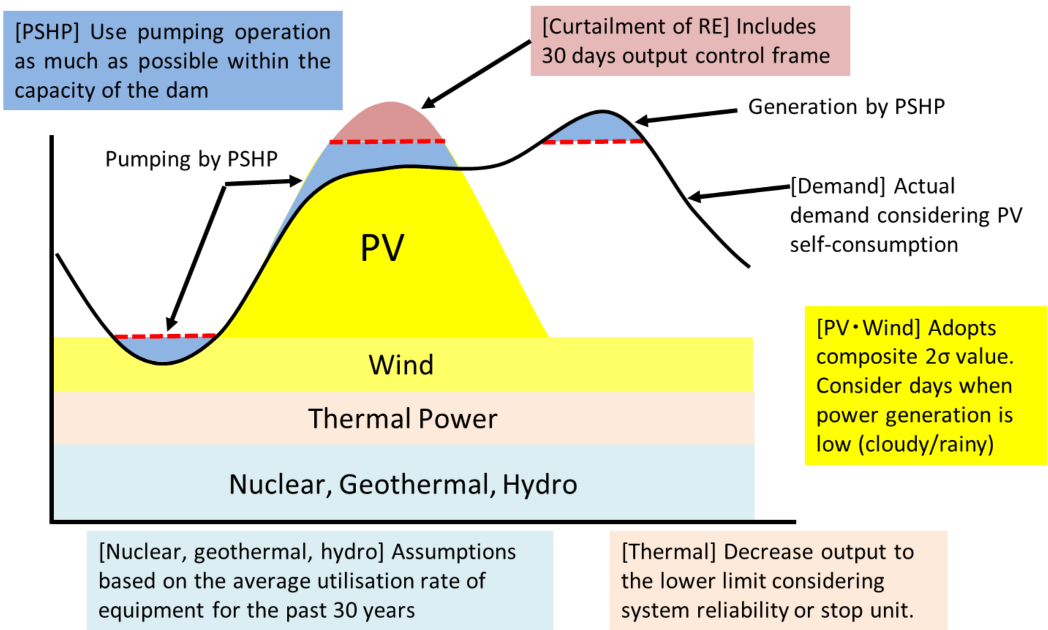
PSHP = pumped storage hydropower, PV = photovoltaic.
Source: Authors.

4. Best Mix of Power Generation System for Brunei Darussalam's Power Network

4.1. Concept of simulation analysis

To analyse a connectable capacity of vRE that can be connected to Brunei Darussalam's power grid, we simulated using the calculation method used in Japan. Figure 2.27 shows the conceptual figure of the calculation condition for vRE connectable capacity in Japan. Nuclear power, geothermal power, and hydropower (except pumped storage hydropower) are assumed based on the average utilisation rate of equipment for the past 30 years. Thermal power decreases the output to a lower limit, considering the power system's reliability or unit commitment. Pumped storage hydropower operates with pumping mode as much as possible, considering the dam's capacity to absorb the output from vRE generation. Also, suppose the surplus output of vRE cannot be absorbed, the transmission system operator (TSO) exports the power using the interconnections with the neighbouring electric power companies as much as possible. Nevertheless, suppose the output surplus cannot be absorbed even after implementing the above measures. The TSO can curtail the vRE output under the 30-day output control scheme as a last resort.

Figure 2.27: Conceptual Figure of Calculation Condition for Connectable Capacity of vRE in Japan

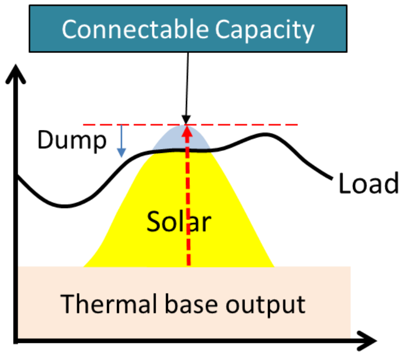


PSHP = pumped storage hydropower, PV = photovoltaic, vRE = variable renewable energy.
Source: Authors.

Figure 2.28 shows the conceptual model of connectable capacity. The TSOs can instruct the dump (output curtailment) to the PV generation producers within 30 days per year. Under this scheme, the connectable capacity can be increased compared to when the dump is not allowed.

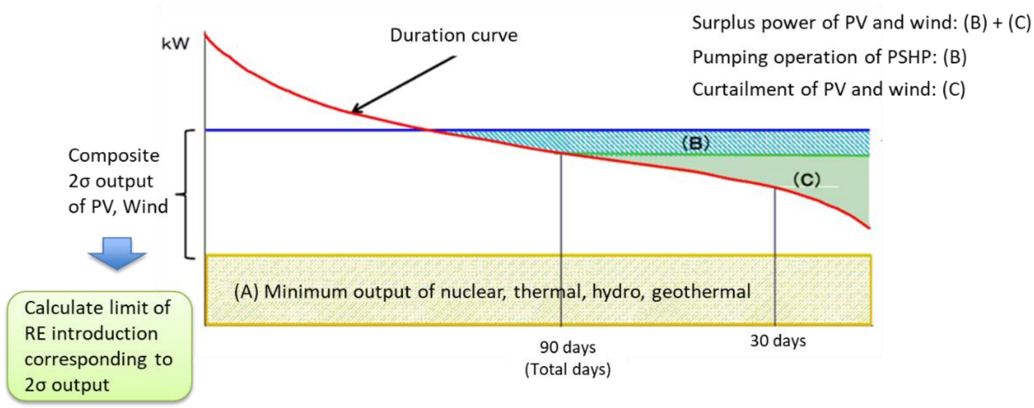
Figure 2.28: Definition of Connectable Capacity

Output-curtailment–acceptable type



Source: Authors.

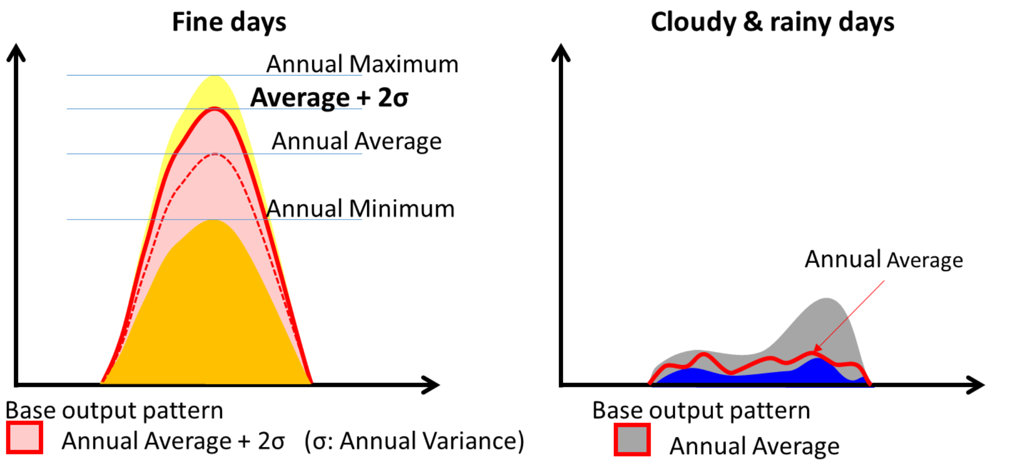
Figure 2.29: Conceptual Figure of Calculation Method for Connectable Capacity of vRE in Japan



PSHP = pumped storage hydropower, PV = photovoltaic, vRE = variable renewable energy.
Source: Authors.

Under the above assumptions, the connectable capacity is calculated as in Figure 2.29. The 8,760 hours of actual demand data for the previous year is used for the duration curve. The output of renewable energy is assumed to be based on the PV output and wind power output of the previous year, which are combined on monthly and hourly bases. The TSOs calculate an 'annual average + 2σ curve' and 'average curve' of vRE output for 8,760 hours from the combined output of PV and wind power. The conceptual figures of the output pattern of vRE for connectable capacity calculation are shown in Figure 2.30. The annual average + 2σ curve is applied to fine days and the average curve applies to cloudy and rainy days. As a result, it is possible to calculate a more severe result of connectable capacity than using the actual output curve of vRE.

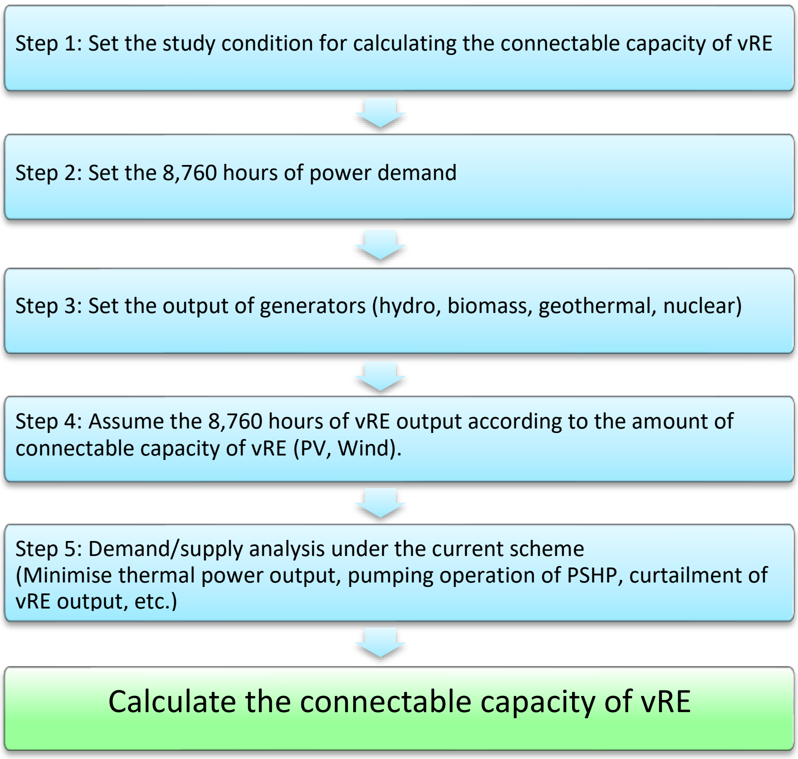
Figure 2.30: Conceptual Figures of Output Pattern of vRE for Connectable Capacity Calculation



Source: Authors.

Figure 2.31 shows the flowchart of the connectable capacity calculation method in Japan. Each TSO in Japan estimates the connectable vRE capacity every year based on this calculation method.

Figure 2.31: Flowchart of Connectable Capacity Calculation Method in Japan



PSHP = pumped storage hydropower, PV = photovoltaic, vRE = variable renewable energy.
Source: Authors.

4.2. Assumptions of simulation analysis for Brunei's power grid

This study simulated the connectable capacity of vRE in Brunei Darussalam based on the above-mentioned Japanese calculation method. In carrying out the simulation, we assumed the following conditions of the country's power grid.

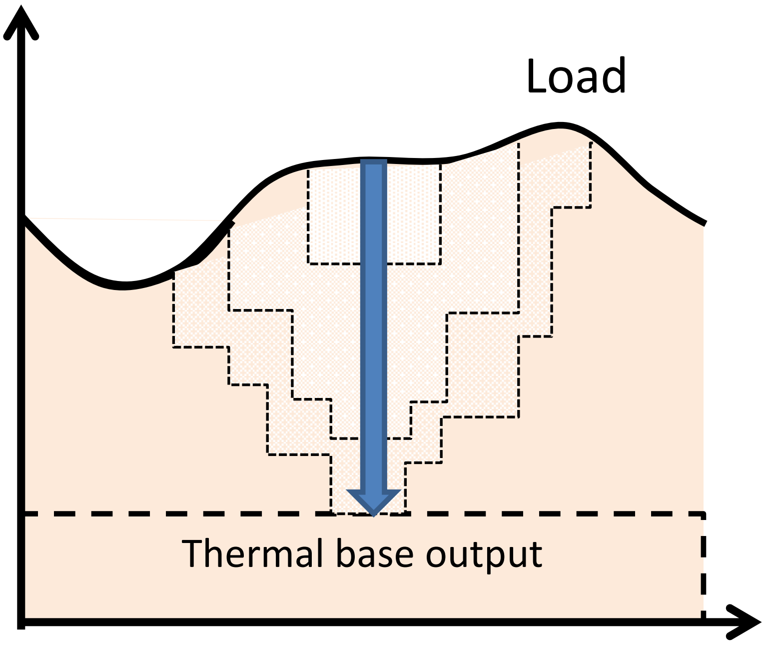
a) Power demand

- ❖ The 8,760 hours of actual power demand data obtained from DES and the BPC were used as inputs of the simulation.
- ❖ The BPC power demand was set to a constant value because the growth of the maximum power demand from 2015 to 2019 was small and the reserve ratio at the time of maximum demand was low.
- ❖ The DES power demand was set to four patterns: actual demand, 1.2 times, 1.3 times, and 1.4 times the actual power demand. The maximum demand had increased from 2015 to 2019, and the reserve ratio at the maximum power demand was large.
- ❖ The power demand of Temburong district was also set to four patterns as the DES area.

b) Thermal power plant

- ❖ The thermal power plant data obtained from DES and BPC were used as inputs of the simulation.
  - Rated capacity [MW]
  - Minimum output [MW]
  - Minimum output under load frequency control operation [MW]
  - Thermal efficiency [%]
  - Operational constraint
- ❖ The output of thermal power had been lowered to the minimum output level to maximise the vRE output.
- ❖ In this study, this minimum output level of thermal power plants is defined as 'thermal base output'. The thermal base output is determined by considering a unit commitment of generators, minimum rated output, must-run units, and frequency sensitive units (free governor mode operation, load frequency control, etc.).

Figure 2.32: Definition of Thermal Base Output



Source: Authors.

c) Interconnections between DES and BPC areas and between DES mainland and Temburong district

- ❖ The DES and BPC power systems are synchronised with 66 kV interconnection.
- ❖ The BPC controls this interconnection's power flow to zero (hereinafter referred to as 'zero-control operation').
- ❖ We studied two cases: (i) current zero-control operation and (ii) that where the power flow of interconnection is not zero.
- ❖ Temburong district will be synchronised to the DES main grid with 66 kV interconnection.
- ❖ We assumed that 2 cct of transmission line with a capacity of 50 MW per 1 cct would be constructed based on the information provided by DES.

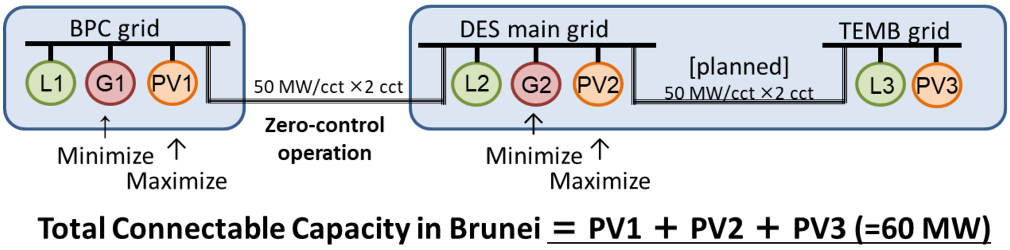
d) Connectable capacity of PV

- ❖ Since Brunei has not considered promoting the introduction of vRE other than PV, we considered only PV in this study.
- ❖ The PV outputs in DES, BPC, and Temburong district were estimated based on the TSB power station's actual output curve connected to the DES power grid.
- ❖ The total connectable capacity of Brunei is the sum of connectable capacities of DES (PV1), BPC (PV2), and Temburong district (PV3).

e) Connectable capacity of PV into Temburong district

- Since this study's main objective is to make the Temburong district an ecotown, we assumed that PV will be introduced preferentially in said district. However, environmental issues, such as land use for PV introduction, were not considered.
- It is necessary to set the connectable capacity of Temburong district considering N-1 fault (1 cct interconnection trip). The power flow of interconnection should always be kept within 50 MW.
- Assuming that the connectable capacity of Temburong district is 60 MW, the maximum output is 48 MW based on the generation output record of the TSB power station.
- Therefore, we assumed that the connectable capacity of Temburong district is fixed at 60 MW.

Figure 2.33: Conceptual Figure of the Brunei Darussalam's Power Grid for Simulation



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, PV = photovoltaic
Source: Authors.

f) Secured amount of reserve for load frequency control (LFC)

- A reserve for LFC was set to secure more than 2% of the demand at that time in the BPC and DES.

Table 2.3: Summary of Simulation Assumptions

<table>
<tr><th colspan="2">3</th><th>Details</th></tr>
<tr><td rowspan="2">Demand</td><td>Base curve</td><td>▪ Actual records (8,760 points in 2019) in DES, BPC, and TEMBURONG</td></tr>
<tr><td>How to increase</td><td>▪ In DES & TEMBURONG: Base curve x Increase rate
▪ In BPC: fixed to the Base curve</td></tr>
<tr><td rowspan="7">Thermal Power Generators</td><td colspan="2">Set the 34 units' status to the 'Thermal base output'</td></tr>
<tr><td>Rated output</td><td rowspan="5">▪ DES (20 units)
Bukit Panggal: 3 units
Gadong 1: 3 units
Gadong 2: 4 units
Lumut: 10 units
▪ BPC (14 units)
Barakas: 7 units
Gadong 3: 3 units
Jerdong: 4 units</td></tr>
<tr><td>Minimum output</td></tr>
<tr><td>Minimum output under LFC</td></tr>
<tr><td>Secured reserves for LFC</td></tr>
<tr><td>Efficiency</td></tr>
<tr><td>Must-run p/s</td><td>▪ Select the power plants considering the constraints of power stations</td></tr>
<tr><td rowspan="2">PVs</td><td>Base output pattern</td><td>▪ Actual records (8,760 points in 2019) of existing mega-solar farm</td></tr>
<tr><td>How to increase</td><td>▪ In DES & BPC: Base Output Pattern + 1 MW x n (n = 0, 1, 2,)
▪ In TEMBRONG: fixed to 60 MW [Max. output to the grid: 48 MW]</td></tr>
<tr><td colspan="2">Capacity of tie-line</td><td>▪ 50 MW, considering N-1 constraint (1-circuit trip)</td></tr>
<tr><td colspan="2">Reserves for LFC</td><td>▪ 2% of electricity demand in each area</td></tr>
</table>

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, LFC = load frequency control, PV = photovoltaic.
Source: Authors.

Table 2.4: Simulation Cases in this Study

Case	Zero Control Operation b/w DES & BPC	Electricity Demand in DES including TEMBURONG			Electricity Demand in BPC		
		Annual Max. Demand [MW]	Max. Demand/Gen. Capacity	Demand Increase Rate	Annual Max. Demand [MW]	Max. Demand/Gen. Capacity	Demand Increase Rate
1-1	**Yes** (= Not interconnected)	392	66%	×1.0	239	90%	×1.0 (Fixed)
1-2		450	75%	×1.2			
1-3		500	84%	×1.3			
1-4		550	92%	×1.4			
2-1	**No** (= Can exchange within 50 MW)	392	66%	×1.0	239	90%	×1.0 (Fixed)
2-2		450	75%	×1.2			
2-3		500	84%	×1.3			
2-4		550	92%	×1.4			

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

4.3. Calculation method for case 1

Since the power flow operation between DES and the BPC is a zero-control operation in case 1, the connectable capacities of DES and the BPC were calculated individually. Figure 2.34 shows the flow of the calculation method for case 1.

Figure 2.34: Flow of the Calculation Method for Case 1

Step 1: Set the study condition for calculating the connectable capacity of vRE in BPC

↓

Step 2: Set the 8,760 hours of power demand in BPC

↓

Step 3: Assume the 8,760 hours of PV output according to the amount of connectable capacity of PV in BPC

↓

Step 4: Minimise thermal power output in BPC

↓

Step 5: Calculate the connectable capacity of vRE in BPC

↓

Step 6: Set the study condition for calculating the connectable capacity of vRE in DES

↓

Step 7: Set the 8,760 hours of power demand in DES

↓

Step 8: Set the connectable capacity in Temburong district [60 MW]

↓

Step 9: Assume the 8,760 hours of PV output according to the amount of connectable capacity of PV in DES

↓

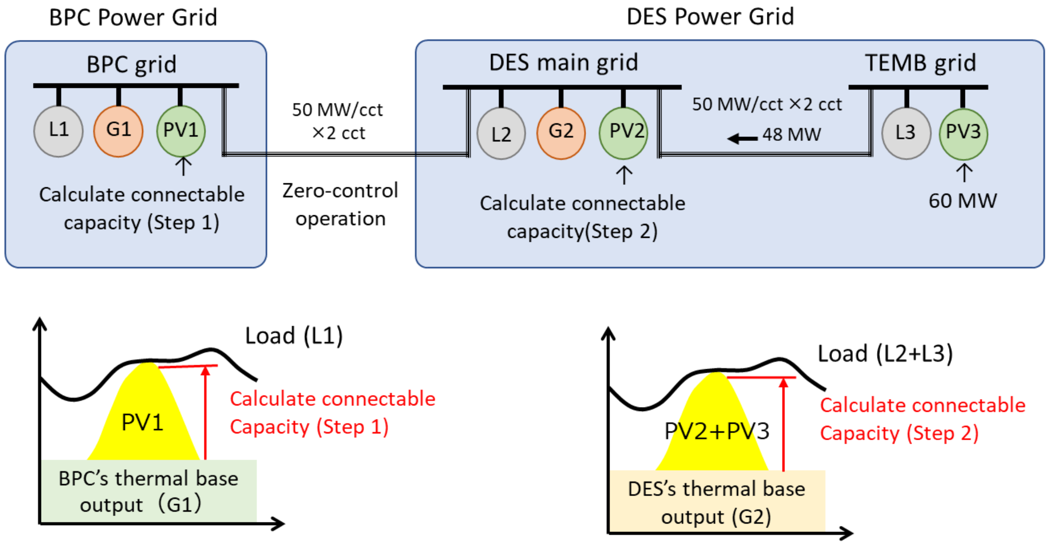
Step 10: Minimize thermal power output in DES

↓

Step 11: Calculate the connectable capacity of vRE in DES (Note: Total connectable capacity of DES includes the connectable capacity of Temburong district [60 MW]

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, PV = photovoltaic, vRE = variable renewable energy.
Source: Authors.

Figure 2.35: Conceptual Figure of the Calculation Method for Case 1



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, PV = photovoltaic.
Source: Authors.

4.4. Calculation result of Case 1

Table 2.5 shows the calculation result of case 1.

Table 2.5: Calculation Result of Case 1

Case	Conditions		Connectable Capacity for vRE [MW]				
	Zero Control	Annual Max. Demand in DES [MW]	DES	BPC	TEMB	TOTAL	PVs/Total Capacity
1-1	Yes	392	127	132	60	**334**	28%
1-2		450	177			**369**	30%
1-3		500	220			**412**	32%
1-4		550	263			**455**	35%

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, TEMB = Temburong, vRE = variable renewable energy.
Source: Authors.

4.4.1. Calculation Result of Connectable Capacity of DES

The connectable capacity of DES under the current demand level (case 1-1) was calculated at 127 MW. The total connectable capacity of DES was 187 MW, including 60 MW of Temburong district. This result was approximately 24% of the total generation capacity of DES. The connectable capacity increased as the demand level of DES increased. In case 1-4, where the demand was 550 MW, the connectable capacity of DES was calculated at 263 MW, and the total connectable capacity was estimated at 323 MW, including the Temburong district. The capacity ratio in case 1-4 was about 35% of the total generation capacity.

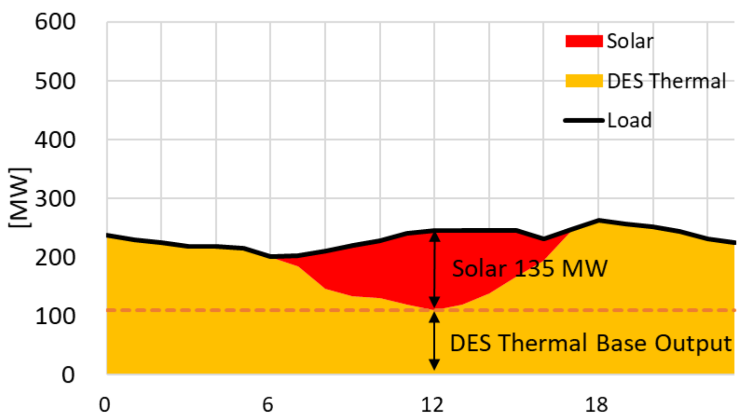
As a result of analysing the connectable capacity of 8,760 hours using the provided data, the point where DES's connectable capacity became the minimum during the year was 12:00 p.m. on 9 November. The demand–supply balance in each case on 9 November is shown in Tables 2.6, 2.7, 2.8, 2.9, and Figures 2.36, 2.37, 2.38, and 2.39, respectively.

Table 2.6: Demand–Supply Balance of DES in Case 1-1 on 9 November

Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
245	135	None	110

Source: Authors.

Figure 2.36: Demand–Supply Balance of DES in Case 1-1 on 9 November



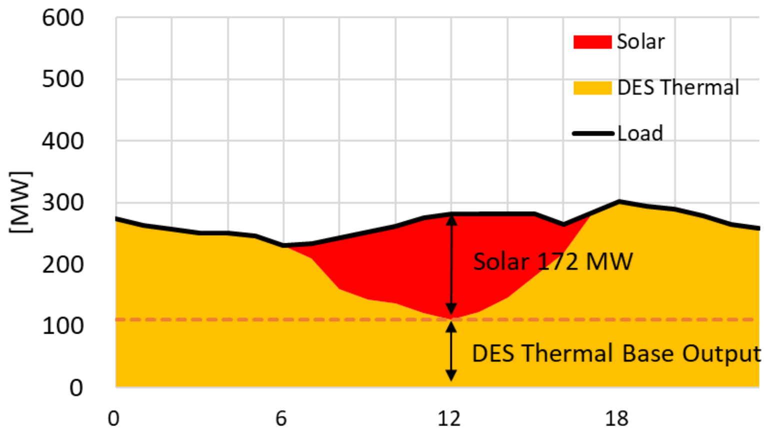
DES = Department of Electrical Services.
Source: Authors.

Table 2.7: Demand–Supply Balance of DES in Case 1-2 on 9 November

Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
282	172	None	110

DES = Department of Electrical Services.
Source: Authors.

Figure 2.37: Demand–Supply Balance of DES in Case 1-2 on 9 November



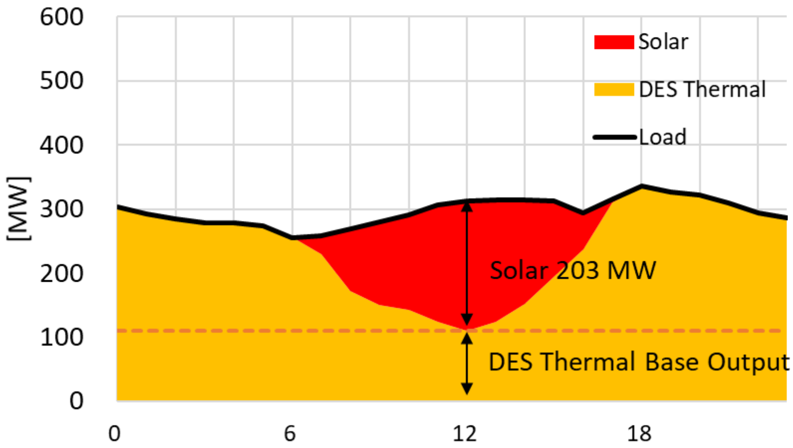
DES = Department of Electrical Services.
Source: Authors.

Table 2.8: Demand–Supply Balance of DES in Case 1-3 on 9 November

Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
313	203	None	110

DES = Department of Electrical Services.
Source: Authors.

Figure 2.38: Demand–Supply Balance in Case 1-3 on 9 November



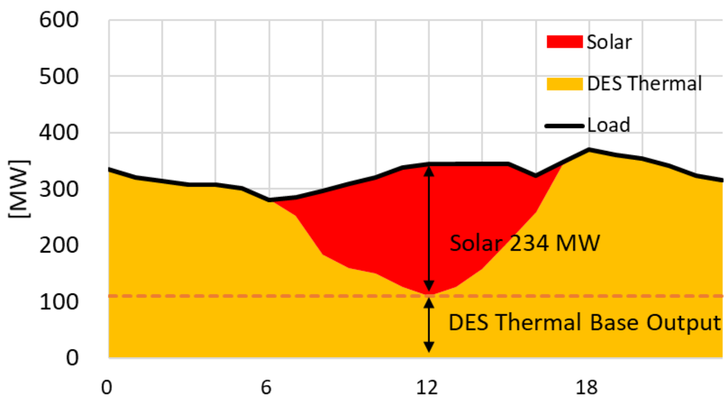
DES = Department of Electrical Services.
Source: Authors.

Table 2.9: Demand–Supply Balance of DES in Case 1-4 on 9 November

Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
344	234	None	110

DES = Department of Electrical Services.
Source: Authors.

Figure 2.39: Demand–Supply Balance of DES in Case 1-4 on 9 November



DES = Department of Electrical Services.
Source: Authors.

4.4.2. Calculation Result of Connectable Capacity of BPC

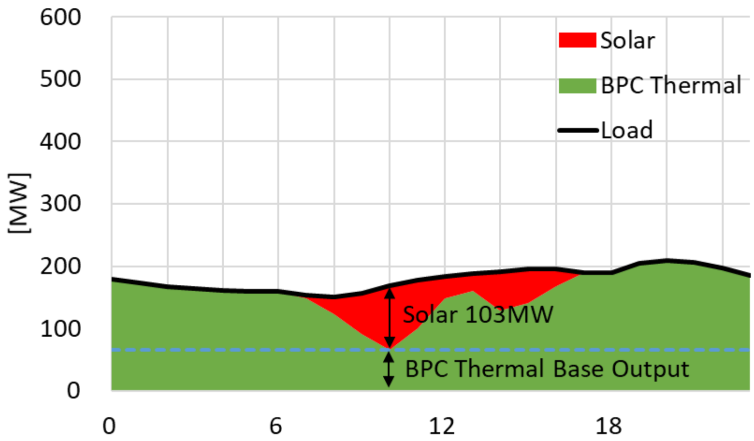
BPC's connectable capacity under the current demand level (case 1-1) was calculated at 132 MW. This result was about 33% of the total generation capacity of BPC. As a result of analysing the connectable capacity of 8,760 hours using the provided data, the point where BPC's connectable capacity became the minimum in the year was 10:00 on 24 March. The demand–supply balance in each case on 24 March is shown in Table 2.10 and Figure 2.40, respectively. Please note that BPC demand was constant between cases 1-1 and 1-4, as mentioned.

Table 2.10: Demand–Supply Balance of BPC on 24 March

Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
168	103	None	65

BPC = Berakas Power Company Sdn Bhd.
Source: Authors.

Figure 2.40: Demand–Supply Balance of BPC on 24 March



BPC = Berakas Power Company Sdn Bhd.
Source: Authors.

4.4.3. Calculation Result of Connectable Capacity of Brunei Darussalam

From the results in sections 2.4.4.1 and 2.4.4.2, Brunei's connectable capacity at the current demand level was estimated at 334 MW. This result was about 28% of the total generation capacity of Brunei. Furthermore, in case 1-4, where the demand is 789 MW, the connectable capacity of Brunei was calculated as 455 MW, and the capacity ratio in case 1-4 was approximately 35% of the total generation capacity.

4.4.4. Benefits of Introducing a Large Amount of PV into the Brunei Power Grid

Per the previous section, Brunei's connectable capacity was estimated at 334 MW at the current power demand level. Based on these results, the yearly electricity consumption and the annual PV generation in case 1 are shown in Table 2.11. When the connectable capacity is 344 MW, the country's annual PV generation is 417 GWh, accounting for about 10% of the yearly electricity consumption. This result shows that about 10% of existing thermal power generation can be reduced, and fuel cost can be saved annually at the current power demand level. Furthermore, the current electricity consumption of the Temburong district is 49 GWh. Suppose 60 MW of PV, which is the connectable capacity, is introduced in Temburong district. The yearly PV generation is 78 GWh, the amount of PV generation exceeding the annual electricity consumption in Temburong district.

Table 2.11: Yearly Electricity Consumption and PV Generation in Case 1

Case	Yearly Energy Consumption [GWh]				Yearly Energy Output from PVs [GWh]			
	DES	BPC	TEMB	TOTAL	DES	BPC	TEMB	TOTAL
1-1	2,399	1,608	49	4,056	166	173	78	417
1-2	2,755		56	4,419	231			482
1-3	3,061		63	4,732	288			539
1-4	3,367		69	5,044	344			595

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, TEMB = Temburong.
Source: Authors.

4.5. Calculation method for Case 2

Since the zero-control operation between DES and the BPC was not adopted in case 2, the connectable capacities of DES and the BPC were calculated as one value. Figure 2.41 shows the flow of the calculation method for case 2.

Figure 2.41: Flow of the Calculation Method for Case 2

Step 1: Set the study condition for calculating the connectable capacity of vRE in Brunei Darussalam (DES + BPC)

Step 2: Set the 8,760 hours of power demand in Brunei Darussalam (DES + BPC)

Step 3: Set the connectable capacity in Temburong district (60 MW)

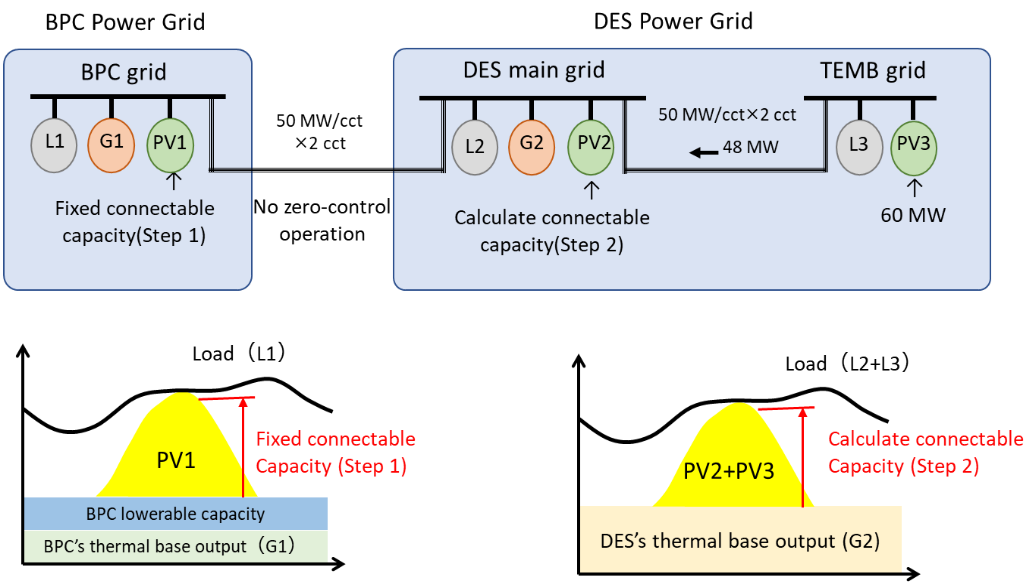
Step 4: Assume the 8,760 hours of PV output according to the amount of connectable capacity of PV in Brunei Darussalam (DES + BPC)

Step 5: Minimise thermal power output in Brunei Darussalam (DES + BPC)

Step 6: Calculate the connectable capacity of vRE in Brunei Darussalam (DES + BPC)

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, vRE = variable renewable energy.
Source: Authors.

Figure 2.42: Conceptual Figure of the Calculation Method for Case 2



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, PV = photovoltaic.
Source: Authors.

4.6. Calculation result of Case 2

The calculation result of cases 1 and 2 is shown in Table 2.12 (Case 1 is aforementioned).

Table 2.12: Calculation Result of Cases 1 and 2

Case	Conditions		Connectable Capacity for vRE [MW]				
	Zero Control	Demand in DES [MW]	DES	BPC	TEMB	TOTAL	PVs/Total Capacity
1-1	Yes	392	127	132	60	**334**	28%
1-2		450	177			**369**	30%
1-3		500	220			**412**	32%
1-4		550	263			**455**	35%
2-1	None (Free)	392	128	132	60	**335**	28%
2-2		450	178			**370**	30%
2-3		500	221			**413**	32%
2-4		550	264			**456**	35%

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services, PV = photovoltaic, TEMB = Temburong, vRE = variable renewable energy.
Source: Authors.

4.6.1. Calculation for Connectable Capacity of vRE using Interconnection between DES and BPC

DES and the BPC can share the reserves since the power flow of interconnection between them is not zero. Therefore, their connectable capacities, using the interconnection between them, were calculated as one value. Their connectable capacity under the current demand level (case 2-1) was estimated at 335 MW. As a result of analysing the connectable capacity of 8,760 hours using the provided data, the point where the connectable capacity of DES + BPC also became the minimum in the year was 12:00 p.m. on 9 November. Compared with the connectable capacity of 334 MW in case 1-1, the additional connectable capacity was only 1 MW.

The comparisons of the demand–supply balance between cases 1 and 2 on 9 November are shown in Tables 2.13 to 2.16 and Figures 2.43 to 2.46. Since the differences between cases 1 and 2 have the same trend in all figures, we focused on Table 2.13 and Figure 2.43.

The left side of Figure 2.43 shows the demand–supply balance that combines DES and BPC in case 1. The lowerable capacity of DES thermal power was 0 MW, and that of the BPC was 1 MW only at 12:00 p.m. on 9 November. By using this reserve to reduce 1 MW through the interconnection between DES and BPC, the connectable capacity of PV into the DES power grid can be increased.

On the other hand, the right side of Figure 2.43 shows the demand–supply balance that combines DES and BPC in case 2. At 12:00 p.m. on 9 November, by utilising the interconnection, the reserve for reduction of the BPC thermal power became 0 MW. The PV output increased from 135 MW to 136 MW.

Table 2.13: Comparison of Demand–Supply Balance between Cases 1-1 and 2-1 on 9 November

Without Zero-control Operation

	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	245	135	None	110
BPC	162	96	1	65
	407	231	1	175

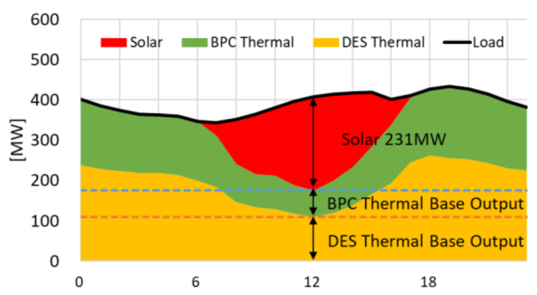
With Zero-control Operation

	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	245	136	None	110
BPC	162	96	None	65
	407	232	None	175

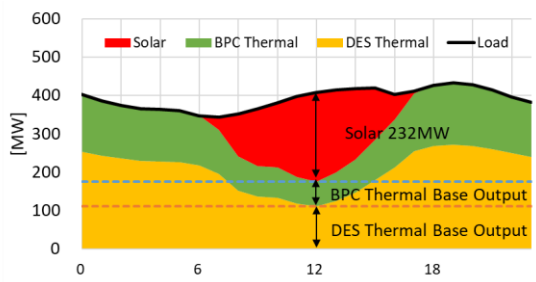
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Figure 2.43: Comparison of Demand–Supply Balance between Cases 1-1 and 2-1 on 9 November

Without Zero-control Operation



With Zero-control Operation



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Table 2.14: Comparison of Demand–Supply Balance between Cases 1-2 and 2-2 on 9 November

Without Zero-control Operation

	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	282	172	None	110
BPC	162	96	1	65
	444	268	1	175

With Zero-control Operation

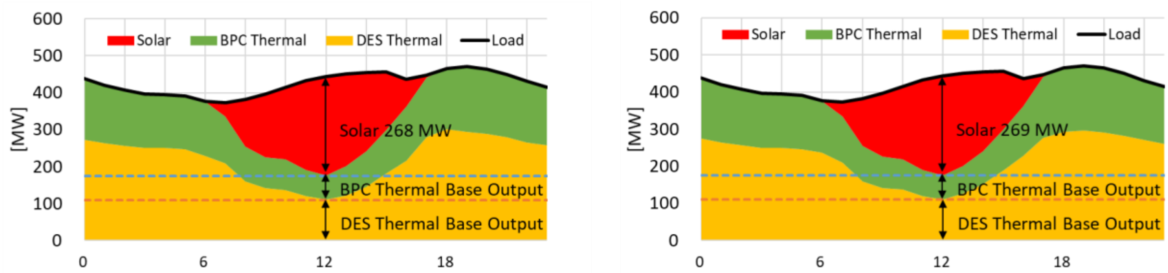
	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	282	173	None	110
BPC	162	96	None	65
	444	269	None	175

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Figure 2.44: Comparison of Demand–Supply Balance between Cases 1-2 and 2-2 on 9 November

Without Zero-control Operation

With Zero-control Operation



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Table 2.15: Comparison of Demand–Supply Balance between Cases 1-3 and 2-3 on 9 November

Without Zero-control Operation

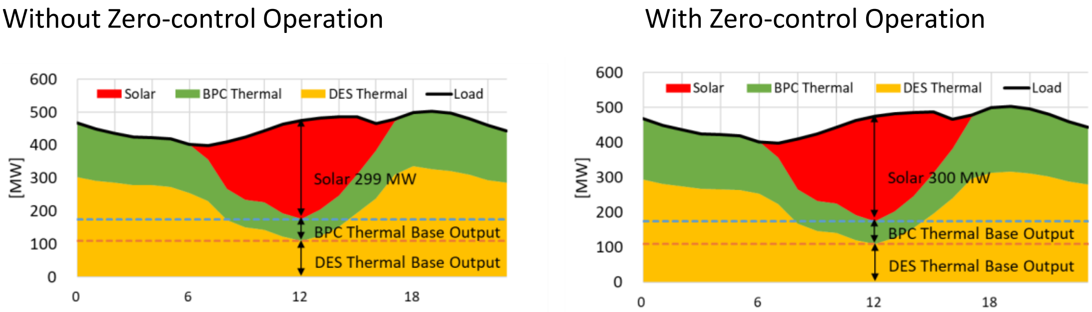
	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	313	203	None	110
BPC	162	96	1	65
	475	299	1	175

With Zero-control Operation

	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	313	204	None	110
BPC	162	96	None	65
	475	300	None	175

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services
Source: Authors.

Figure 2.45: Comparison of Demand–Supply Balance between Cases 1-3 and 2-3 on 9 November



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Table 2.16: Comparison of Demand–Supply Balance between Cases 1-4 and 2-4 on 9 November

Without Zero-control Operation

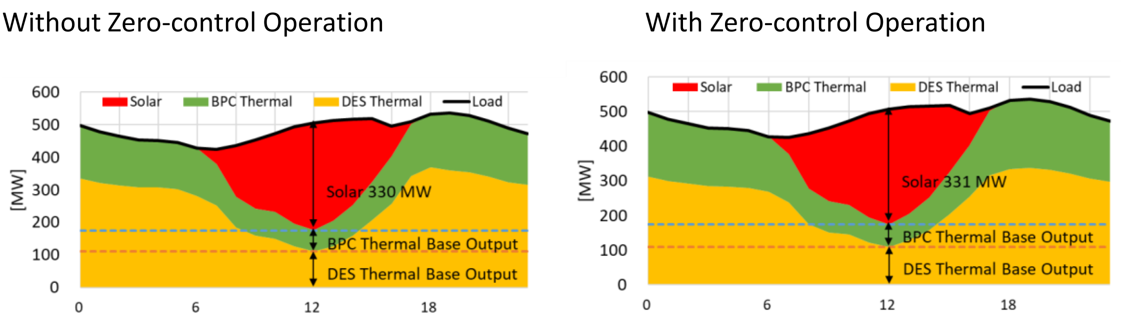
	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	344	234	None	110
BPC	162	96	1	65
	506	330	1	175

With Zero-control Operation

	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	344	235	None	110
BPC	162	96	None	65
	506	331	None	175

BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

Figure 2.46: Comparison of Demand–Supply Balance between Cases 1-4 and 2-4 on 9 November



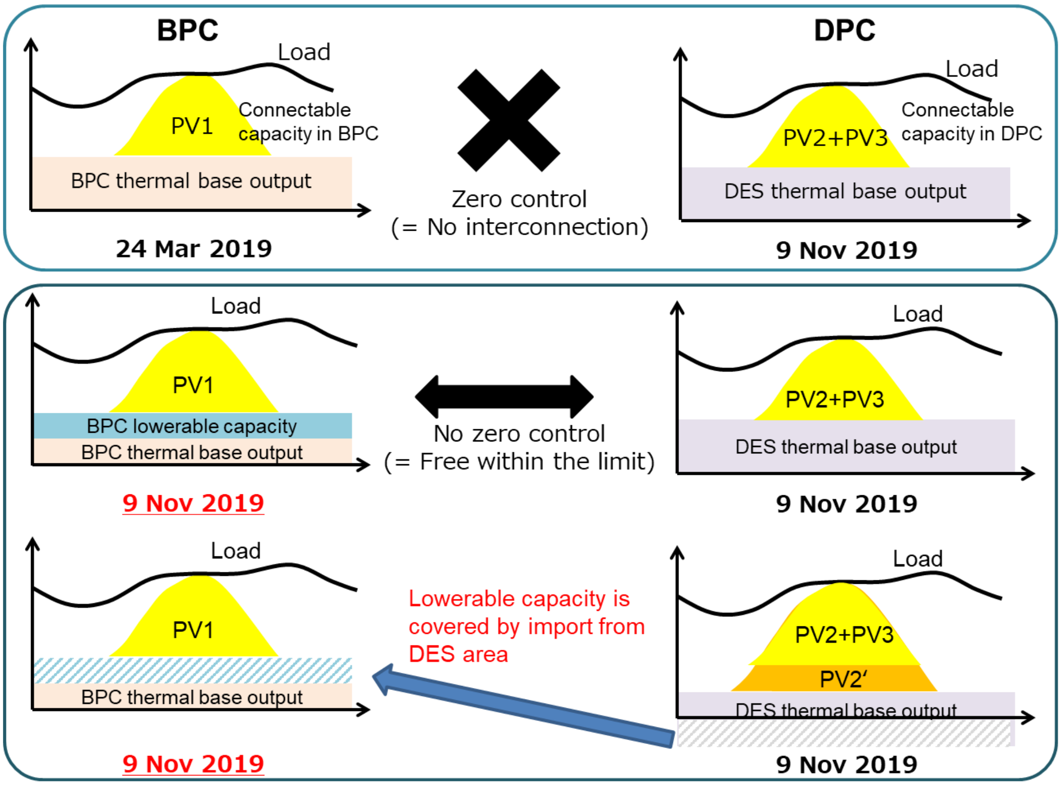
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

4.6.2. Effects of Utilising Interconnection

Figure 2.47 shows the conceptual figure of using interconnection. The upper figure shows the simulation result in case 1. When the operation is zero control, the DES and BPC connectable capacities are minimum at 12:00 p.m. on 9 November and 10:00 a.m. on 24 March, respectively (as referred to in Clause 2.4).

In case 2, Brunei's connectable capacity was minimum at 12:00 p.m. on 9 November as a result of DES in case 1. As mentioned, BPC's connectable capacity with zero control is 132 MW on 24 March. If BPC's lowerable capacity remains (per middle figure in Figure 2.47), DES can use BPC's additional lowerable capacity. As a result, the amount of DES connections can be increased compared to case 1 by utilising the interconnection (PV2). If the BPC has no lowerable capacity, DES cannot introduce additional PV by using interconnection.

Figure 2.47: Conceptual Figure of Utilising Interconnection



BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

4.7. Summary of simulation analysis

We simulated the calculation of the connectable capacity of Brunei's power network, depending on whether the interconnection between DES and BPC is used or not. The connectable capacity of Temburong district was set to 60 MW in consideration of the N-1 constraint and the actual output of PV generation. Brunei's connectable capacity is 334 MW, which accounts for 28% of the total generation capacity when the interconnection is not used in the current power demand and grid. Figure 2.14 shows Brunei will introduce about 300

MW of PV generation by 2035. Thus, this study result fully covers the capacity of Brunei's PV development plan in 2035. Also, the connectable capacity will increase as the power demand level increases.

When the connectable capacity is 344 MW, the country's yearly PV generation is 417 GWh, accounting for approximately 10% of the annual electricity consumption. This result shows that about 10% of the existing thermal power generation can be reduced, and fuel cost can be saved annually at the current power demand level. Furthermore, the current electricity consumption of Temburong district is 49 GWh. If 60 MW of PV is introduced in Temburong district, the yearly PV generation is 78 GWh, which exceeds the annual electricity consumption in Temburong district.

On the other hand, when the interconnection is used to supply the surplus reserve, Brunei's connectable capacity is 335 MW, accounting for 28% of the total generation capacity. In this simulation, the increase in connectable capacity when using the interconnection is only 1 MW.

5. Optimal Generation Control in Brunei's Power Network Using the Energy Management System

5.1. Overview of frequency control in Brunei's power network

The power system frequency of Brunei Darussalam is 50 Hz and both DES and BPC are responsible for frequency control.

As of February 2020, when we interviewed DES and BPC, the BPC's control centre had the Energy Management System (EMS)/Supervisory Control and Data Acquisition (SCADA) manufactured by PSI. This EMS has the automatic generation control (AGC) function, which automatically controls the power output of multiple generators at different power stations in response to changes in the load. Since a power grid requires that generation and load closely balance moment by moment, frequent controls to the generator output are necessary. The BPC supervises its area frequency and the power flow of interconnection between DES and the BPC. The BPC control centre manages the generator outputs to keep the power flow of interconnection at zero, like the tie-line bias control (TBC), one of the frequency control methods. The TBC detects the amount of change in frequency and the amount of change in power flow of interconnection simultaneously and controls the generator output only when it determines that a load change has occurred in its system.

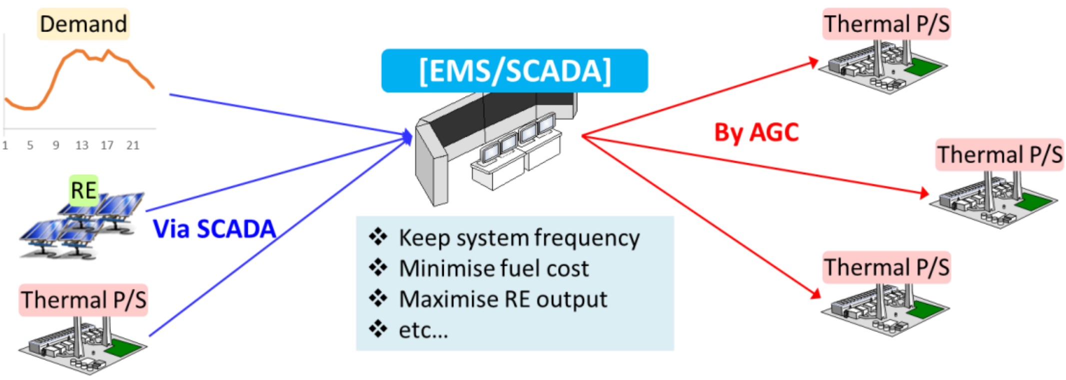
On the other hand, the DES control centre has the SCADA system only. Therefore, the DES power stations supervise their system frequency and manually control the generator outputs to keep their frequency at 50 Hz. However, according to interviews with DES, its control centre plans to install an EMS system, including the AGC function, in 2020. After installating the EMS, DES's control centre can also automatically instruct the outputs of generators to keep the frequency.

5.2. Optimal generation control to maximise vRE generation

Figure 2.48 shows the conceptual figure of optimal generation control to maximise vRE generation in Brunei Darussalam. SCADA gathers information on system frequency, generator outputs, including vRE output, power demand, etc. Using this information, the AGC calculates a necessary amount of generator output to meet demand in real time, considering maximising vRE output and minimising fuel costs. Then the AGC instructs new output to the generators.

We calculated the connectable capacity in Brunei Darussalam, considering the frequency conditions. The BPC already has an EMS system with an AGC function, and the BPC will install it in 2020. Therefore, if the vRE generators will be introduced up to the connectable capacity we have calculated, Brunei can already realise optimal generation control whilst maximising vRE output.

Figure 2.48: Conceptual Figure of Optimal Generation Control for Maximising vRE Generation in Brunei Darussalam



AGC = automatic generation control, RE = renewable energy, SCADA = Supervisory Control and Data Acquisition.
Source: Authors.

6. Estimation of Required Land Scale and Installation Cost for vRE Introduction

6.1. Estimation of required land scale for vRE introduction

In Section 2.4, we calculated the connectable capacity of vRE in Brunei Darussalam and found that the country has considerable potential for vRE generation. However, more than half of Brunei is covered with forest. Much of Temburong district is also covered with forest, and 40% of the district is designated as a national park. Thus, it is necessary to consider the natural environment in introducing a large PV amount.

According to the Solar Energy Industries Association, a utility-scale solar power plant may require 5 and 10 acres/MW of generating capacity. Table 2.17 shows the required land use for PV introduction in Brunei Darussalam.

Table 2.17: Required Land Use for PV Introduction in Brunei Darussalam

Case	Connectable Capacity for vRE [MW]		Required Land Use [acre]	
	Brunei Total*[a]	Temburong	Brunei Total*[a]	Temburong
1-1	**334**	60	**1670 ~ 3340**	300 ~ 600
1-2	**369**		**1845 ~ 3690**	
1-3	**412**		**2060 ~ 4120**	
1-4	**455**		**2275 ~ 4550**	

[a] Brunei Total includes Temburong district.
Source: Authors.

If the PV generations were introduced to the connectable capacity under the current power demand condition, 300–600 acres of land use would be required in Temburong district, and 1,670–3,340 acres of land use would be required in Brunei Darussalam. This result could significantly impact nature in Temburong district. However, the connectable capacity calculated in this study only shows the maximum value that can be technically introduced.

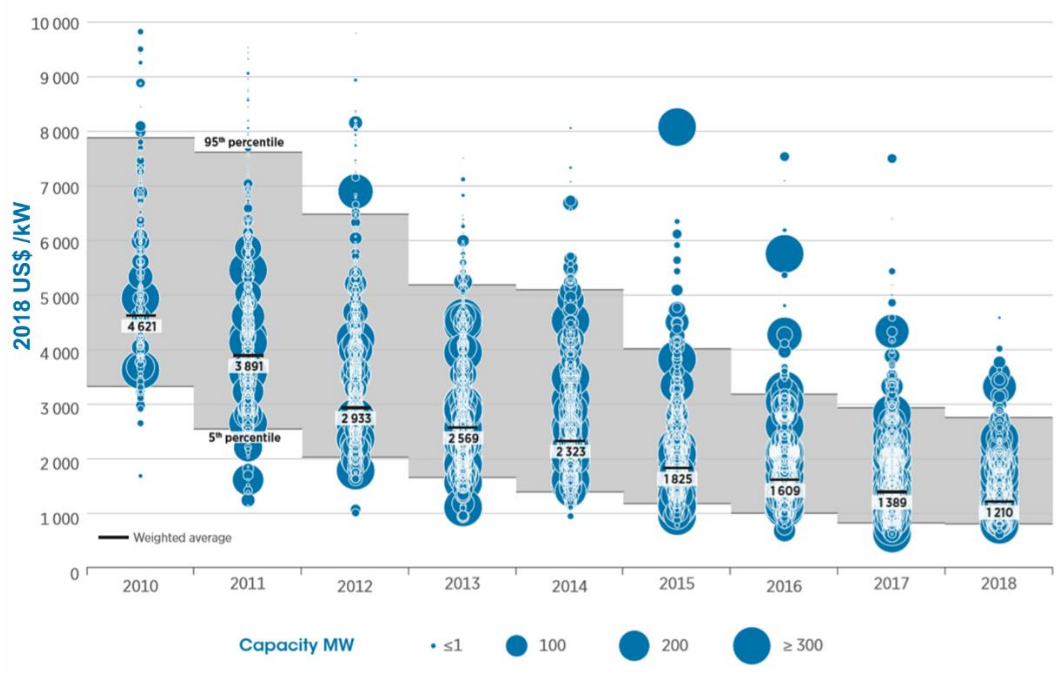
When we asked the MOE experts about this result during the Third Working Group meeting, we obtained the following answers. The experts thought they could unlikely get 300–600 acres of the land use for Temburong district. Furthermore, the MOE has made it clear not to cut down trees. At present, they have identified around 10 MW of land potentially available for the PV development in Temburong district by 2025. However, this amount of land potential is far from connectable capacity. Thus, the amount of PV introduced should be in harmony with the natural environment of Temburong district. The rooftop-type PV should be initiallyintroduced in office buildings and shopping malls, etc. through the Temburong Ecotown Plan. Furthermore, Brunei should consider placing the floating-type PV somewhere, such as along the Temburong Bridge.

6.2. Estimation of the installation cost for vRE introduction

Brunei's PV installation plan is up to 2035. The country will install approximately 300 MW of PV generation by 2035. In this section, we calculated an installation cost and operations and maintenance (O&M) cost based on Brunei's PV installation plan.

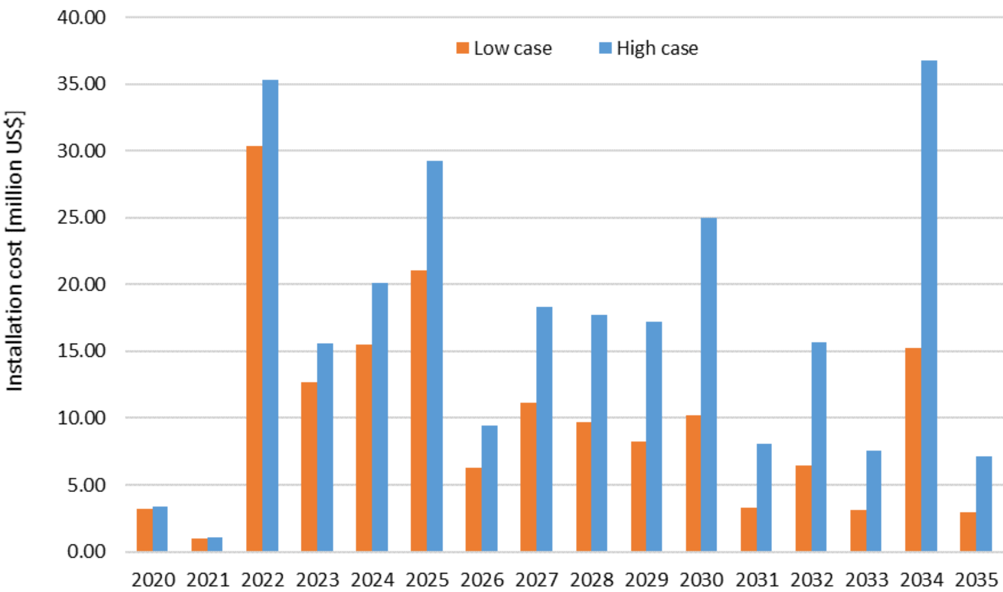
According to IRENA (2019a), the global weighted average total installed cost of utility-scale solar PV has fallen by 74% between 2010 and 2018. Installed costs also converged closer to the average, with the 5th and 95th percentile ranges dropping from the US$3,300–US$7,900/kW range in 2010 to US$800–US$2,700/kW in 2018. Utility-scale solar PV project investment costs have fallen from US$4,621/kW in 2010 to US$1,210/kW in 2018 (Figure 2.49). Furthermore, IRENA (2019b) had assumed that the total installation cost of PV projects would continue to decline globally in the next 3 decades. This would make PV highly competitive in many markets, with the average falling in the range of US$340/kW–US$834/kW by 2030 and US$165–US$481/kW by 2050. The annual installation cost estimate of PV in Brunei, using this installation cost range, is shown in Figure 2.50.

Figure 2.49: Total Installed Cost for Utility-Scale Solar PV Projects and the Global Weighted Average, 2010–2018



Source: IRENA (2019a).

Figure 2.50: Annual Installation Cost of PV in Brunei Darussalam

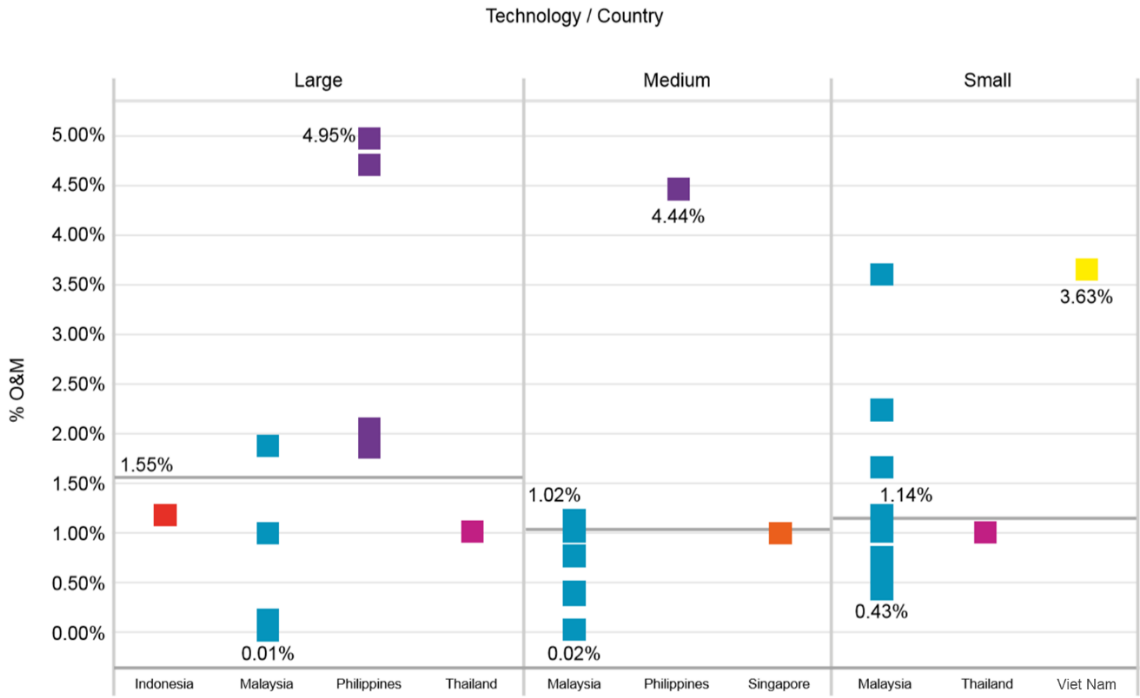


Source: Authors.

Figure 2.14 shows the installed capacity of PV increases by 10–20 MW each year. However, the annual costs are smaller in the later years. Brunei plans to add 50 MW in 2034, but the cost is about US$40 million at most. The total installation cost by 2035 ranges from about US$160 million to US$268 million.

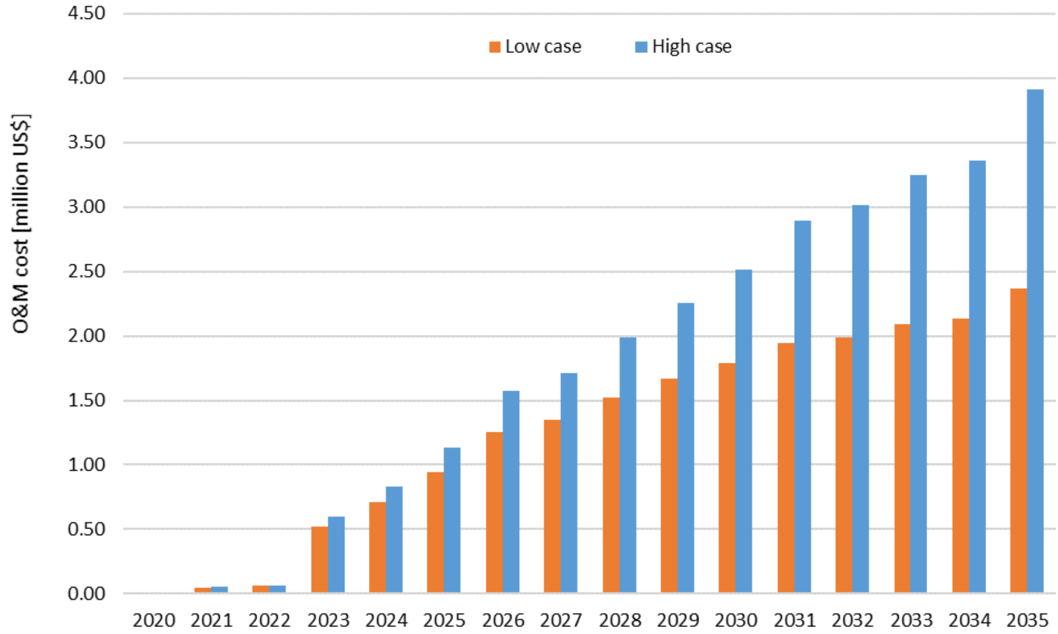
O&M costs are major costs incurred in the operation of power plants. According to ACE (2019), the O&M costs ranged from about 0.23% to 3.63%, 0.02% to 4.44%, and 0.01% to 4.95% of capital expenses (CAPEX) for the small (less than 100 kW)- , medium (100–1,000 kW)-, and large-scale (1,000 kW or more) projects, respectively, in ASEAN member states. On average, for all scales, the O&M costs were approximately 1%–1.6% of CAPEX and were not significantly different according to system size (Figure 2.51). Therefore, 1.5% of CAPEX was considered in the O&M costs in this study based on the data in Figure 2.51. Figure 2.52 shows the annual O&M cost estimate of PV in Brunei Darussalam.

Figure 2.51: O&M Costs for PV Projects in ASEAN Member States



Source: ACE (2019).

Figure 2.52: Annual O&M Cost Estimation of PV in Brunei Darussalam



O&M = operation and maintenance, PV = photovoltaic.
Source: Authors.

The O&M costs will increase as the installed capacity increases and will range from approximately US$0.9 million to US$1.1 million in 2025, US$1.8 million to US$2.5 million in 2030, and US$2.4 million to US$3.9 million in 2035. The total O&M cost by 2035 will range from about US$20 million to US$29 million.

7. Conclusions

This research study calculated the connectable capacity of vRE in Brunei's power network, depending on whether the interconnection between DES and the BPC is used or not. This study also changed the power demand level in DES and calculated the connectable capacity in eight cases. The connectable capacity of Temburong district was set to 60 MW in consideration of the N-1 constraint and the actual output of PV generation. Based on these assumptions, the connectable capacity of Brunei Darussalam is 334 MW, which accounts for 28% of the total generation capacity when the interconnection is not used in the current power demand and power grid. Furthermore, in increasing the demand of DES to 550 MW, the connectable capacity also increased to 455 MW, which accounts for 35% of the total generation capacity. This study result fully covers the capacity of Brunei's PV development plan in 2035.

When the connectable capacity is 344 MW, the yearly PV generation is 417 GWh, accounting for about 10% of the annual electricity consumption. This result shows that about 10% of existing thermal power generation can be reduced, and fuel cost can be saved annually at the current power demand level. Furthermore, the current electricity consumption of Temburong district is 49 GWh. Suppose the 60 MW of PV is introduced in Temburong district.

The yearly PV generation is 78 GWh, which is the amount of PV generated exceeding the annual electricity consumption in Temburong district.

On the other hand, when the interconnection is used to supply the surplus reserve, the connectable capacity of Brunei Darussalam is 335 MW, which also accounts for 28% of the total generation capacity. In this simulation, the increase in connectable capacity when using the interconnection is only 1 MW.

This study calculated the connectable capacity, considering the frequency conditions. If a large amount of vRE is introduced to the power grid, the generator output should be appropriately adjusted to achieve optimal control. Many electric power companies worldwide have introduced the EMS system with AGC function to control the generator output automatically. The BPC has already introduced EMS with AGC function, and DES will introduce it in 2020. Therefore, if the vRE generators will be introduced up to the connectable capacity this study calculated, Brunei can already realise optimal generation control whilst maximising the vRE output. However, this study did not consider other power grid issues, such as short circuit current, voltage stability, and transient stability, caused by the introduction of a large vRE amount. Whilst the results of the analysis in this study may lead to further discussion and decisions, we must acknowledge that this study had insufficiently addressed several issues. In the future, it will therefore be necessary to study these issues at each point where vRE is introduced.

This study also estimated the required land use for introducing PV generation up to the connectable capacity. Around 300–600 acres of land use would be required in Temburong district and 1,670–3,340 acres of land use would be needed in Brunei Darussalam under current power demand conditions. This result could significantly impact nature in Temburong district. However, the Minister of Energy has made it clear that cutting down trees is not allowed. Also, there is a small potential of land use to introduce PV generation in Temburong district. Thus, the amount of PV introduced should be in harmony with the natural environment of the Temburong district. The rooftop-type PV should be initiatively introduced to, for instance, office buildings and shopping malls through the Temburong Ecotown Plan. Furthermore, Brunei should consider the floating-type PV placed somewhere, such as along the Temburong bridge.

According to IRENA (2019b), PV projects' total installation cost would continue to decline. Based on this assumption, this study calculated the installation and O&M costs. As a result, the total installation cost would range from about US$160 million to US$268 million, and the O&M cost by 2035 would range from about US$20 million to US$29 million.

ASEAN member states aspire to realise 23% of vRE by 2025. Brunei Darussalam also plans to promote renewable energy. To do this, Brunei should proceed with various institutional designs. It is gratifying that this study could contribute to the development of vRE in Brunei Darussalam and Temburong district.