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Simulation Study on Energy Mix for Power Generation in Temburong Eco Town

edited by
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Foreword

In 2015–2016, the Economic Research Institute for ASEAN and East Asia (ERIA) conducted a study on current and future available technologies of energy efficiency and conservation applying to buildings and road transport, as well as smart grid technologies to maximise penetration of renewable energy such as solar photovoltaic (PV) and wind (Phase 1 study). This year, ERIA applies the major outputs from the Phase 1 study to a specific area in the ASEAN region. It has selected Temburong District as an eco town, which is an ongoing project in Brunei Darussalam (Phase 2 study).

Under the Temburong district development plan, several types of building will be constructed in the district – office, mall, hotel, hospital, university, and residential apartment. Thus, ERIA assumed to apply two types of building technology: (i) ordinary technology and (ii) green technology or eco technology. Referring to the Malaysian building standard code, including the Green Building Index (GBI), ERIA estimated two electricity demands of the buildings: (i) normal township applying ordinary building energy intensity (BEI) and (ii) green township applying green BEI.

There is a diesel power station in Temburong that installs 4 units x 3 megawatts (MW) power generation system, which provides electricity to subscribers in the area. In addition, about 6MW solar PV system will be installed soon. After installation of the system, electricity generation by the diesel station will be reduced. However, once new buildings are constructed according to the Temburong district development plan, more solar PV will be needed. In 2015 and 2016, ERIA collected climate data – solar radiation and rainfall data – in Brunei Darussalam to check intermittency caused by PV system installation. In this regard, ERIA applied a dynamic simulation approach to check the intermittency under the combination of diesel power generation, solar PV system, and electricity storage. After the simulation, ERIA extracted the best capacity mix of diesel power, solar PV, and storage at minimum cost.

Eco town or smart city is an important concept for promoting energy efficiency and renewable energy in residential and commercial sectors, and there are many similar plans for this across the ASEAN region. ERIA will start the Phase 3 study to prepare a master plan for Temburong Eco Town using an engineering design company to be presented in a blueprint of the eco town, which includes clean electricity supply.

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Abbreviations and Acronyms

PV	photovoltaic
BIA	Brunei International Airport
BDMD	Brunei Darussalam Meteorological Department
BEI	building energy intensity
DEPD	Department of Economic Planning and Development
GBI	Green Building Index
ha	hectare
kWh	kilowatt-hour
LCOE	levelised cost of energy
m^2	square metre
mm	millimetre
MW	megawatt
MWh	megawatt hour
MOD	Ministry of Development

Executive Summary

There is an eco town development plan in Temburong District, Brunei Darussalam. The eco town concept is about applying energy efficiency technologies to achieve lower energy demand, especially electricity, to be used by buildings, and renewable energy such as solar photovoltaic (PV). At the request of the Ministry of Energy and Industry (MEI), Brunei Darussalam, ERIA conducted a research study. The study measured the impact of the application of energy efficiency technologies for buildings and installation of solar PV with electricity storage as power supply system based on the Temburong district development plan prepared by Town and City Planning Department under the Ministry of Development (MOD).

For energy efficiency technologies for buildings, ERIA applied two types of building energy intensity (BEI): (i) normal township (ordinary BEI) and (ii) eco township (green BEI, like Green Building Index in Malaysia). In Temburong District, several types of buildings – office, hotel, shopping mall, hospital, and others – will be constructed based on the Temburong district plan. If MOD could apply the eco township (GBI), electricity demand would be reduced by 30% from the normal township, which is a significant effect. In general, if buildings could apply the eco township (GBI), construction cost would be higher than that of the normal township, but power generation cost could be saved due to lower electricity demand. Focusing on initial cost of solar PV and storage, the eco township (GBI) will contribute a reduction of about US$ 100 million compared with the normal township.

Based on hourly electricity demand (normal and eco) and solar radiation data, ERIA conducted simulation studies on hourly-basis power supply using diesel power, solar PV, and electricity storage. Three scenarios were examined: (i) Case 1: diesel (12 megawatts [MW]), solar PV, storage; (ii) Case 2: diesel (6MW), solar PV, storage; and (iii) Case 3: only solar PV and storage. All scenarios showed feasible solutions, although Case 3 did not involve diesel power. However, power generation cost will be high at a levelised cost of energy (LCOE) of US$ .40. The study recommends to use diesel power initially, and to gradually shift the power generation mix to greater use of solar PV with storage system, leading to a decrease in cost of both solar PV and storage.

According to the hourly solar radiation data in 2016, it was rainy and cloudy during the summer months from March to May, and consequently the operation rate of solar PV was 9%–13%. Data on the solar radiation status in Brunei Darussalam is harder to obtain than for the Middle East and California.

Chapter 1
Data Collection

1. Climate of Brunei Darussalam and Temburong District

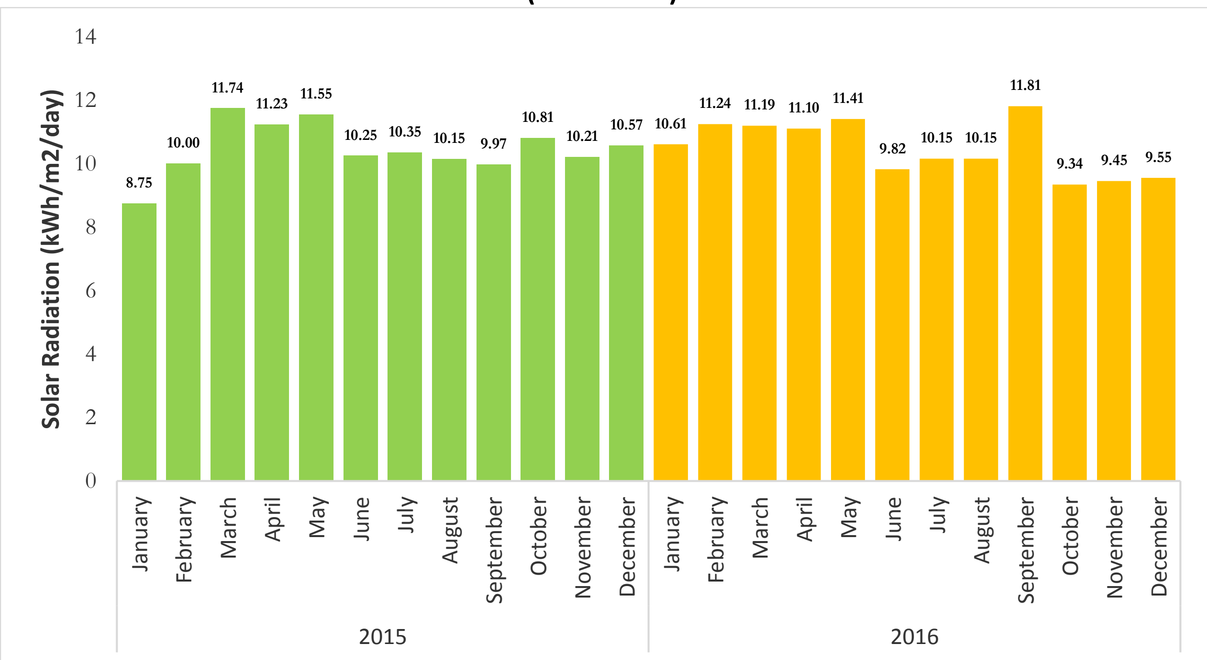
Situated at around four degrees north of the Equator, Brunei Darussalam enjoys an equatorial climate with an abundance of sunshine, high temperatures, and rainfall all year round. These parameters influence the development of the solar research programme, which may include solar photovoltaic (PV) modelling. In Brunei Darussalam, only three meteorological stations are available, the Brunei International Airport (BIA) meteorological station being the main one. In this chapter, data on solar radiation and rainfall will be examined and analysed.

1.1. Climate and Weather of Brunei Darussalam

1.1.1. Solar Radiation

Solar radiation data for years 2015 and 2016 were obtained from the Brunei Darussalam Meteorological Department (BDMD), a government agency under the Ministry of Communications. BDMD records the solar radiation data at the BIA meteorological station, which is the only station that has the capability to measure solar radiation and bright sunshine hours. The station utilises an Eppley black and white pyranometer and a Campbell–Stokes recorder, and is fully automatic.

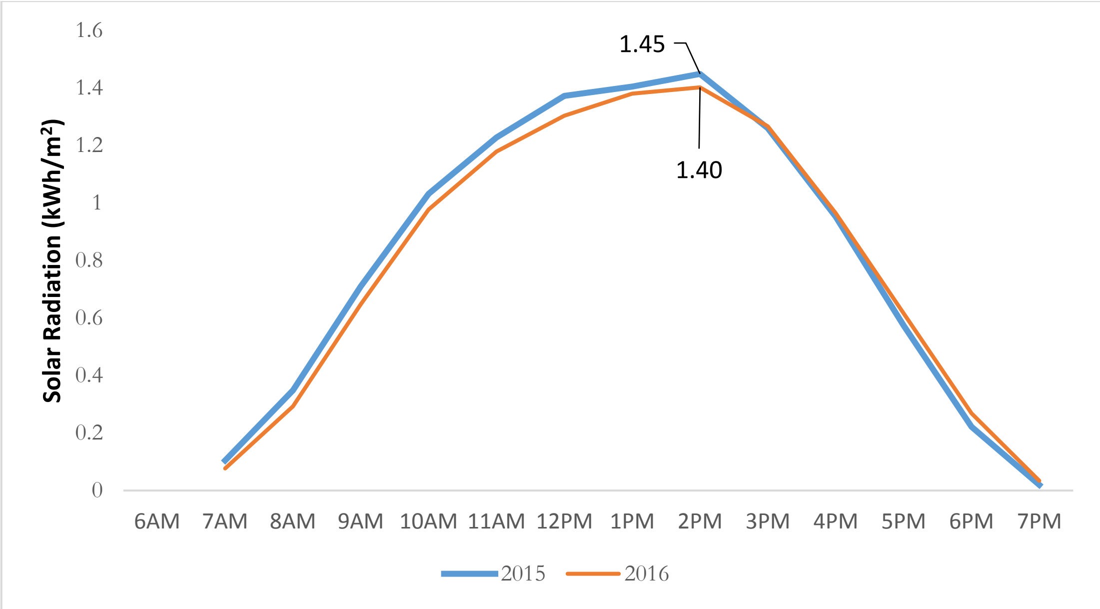
Figure 1.1. Monthly Average Daily Solar Radiation in Brunei Darussalam (2015–2016)



kWh = kilowatt-hour, m^2 = square metre.
Source: Brunei Darussalam Meteorological Department (2017).

Figure 1.1 shows that the monthly average daily solar radiation ranged from 8.75 kilowatt- hours per square metre per day (kWh/m^2/day) in January 2015 to 11.81 kWh/m^2/day in September 2016. The country received relatively low solar radiation in January 2015, October 2016, November 2016, and December 2016, which could be due to the presence of clouds or the occurrence of rain.

Figure 1.2. Annual Average Hourly Solar Radiation for 2015 and 2016



kWh = kilowatt-hour, m^2 = square metre.
Source: Brunei Darussalam Meteorological Department (2017).

Figure 1.2 shows the average hourly solar radiation for 2015 and 2016. The curves follow each other closely and exhibit an approximate symmetrical shape at noon (between 12:00 noon and 2:00 p.m.), with the radiation being highest at around 2:00 p.m. at 1.45 kWh/m^2 in 2015 and 1.40 kWh/m^2 in 2016.

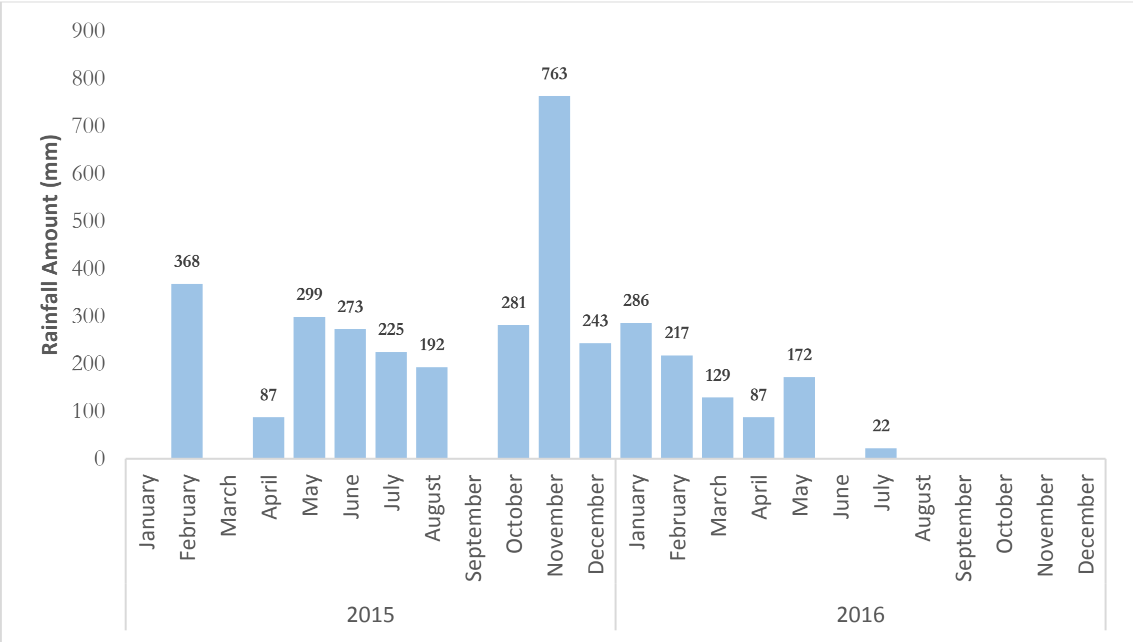
It should be noted that the solar radiation data cited above were measured only within the Brunei Muara District where the BIA meteorological station is situated. However, since the latitudes and longitudes of all the districts are close to each other, these solar radiation values can be assumed to be similar (Malik and Abdullah, 1996).

1.1.2. Rainfall

BDMD also provided the rainfall data but based in Bangar area, Temburong District, unlike data on solar radiation that was not measured locally in the district. Between 1984 and 2013, the country's average rainfall amounted to about 2,976 millimetres (mm), with an increase of 26.16 mm per year (Pg. Ali Hasan, Ratnayake, and Shams, 2015).

Figure 1.3 shows that November 2015 had the highest rainfall amount of about 763 mm, coinciding with the wet season, which usually occurs between October and February. July 2016 had the lowest with 22 mm. Missing data in most of the months are attributed to technical problems in measurements at Bangar station, according to BDMD. This makes it difficult to properly understand rainfall trends in the area.

Figure 1.3. Rainfall Data in Bangar, Temburong District
(2015 and 2016)



mm = millimetre.
Source: Brunei Darussalam Meteorological Department (2017).

1.2. Temburong District

1.2.1. Overview

Temburong District is located at the eastern edge of Brunei but is separated from the remainder of the country by the Malaysian state of Sarawak and the South China Sea to the north. The district is home to the country's most extensive forest area, of which 500 square kilometres in the south is still pristine (Hadi et al., 2011). The district comprises five provinces: Bangar, Bokok, Amo, Batu Apoi, and Labu. Bangar is the urban centre within the district as it contains Bangar town, which is the capital town with the most significant development. Temburong is largely underdeveloped, especially in certain areas in the central and southern parts, which are characterised by mountainous terrain and river catchments. The northern region is mostly low-lying, which makes it prone to tidal flooding. The district's development has therefore concentrated around central Temburong, which has access to river valleys and the main road system.

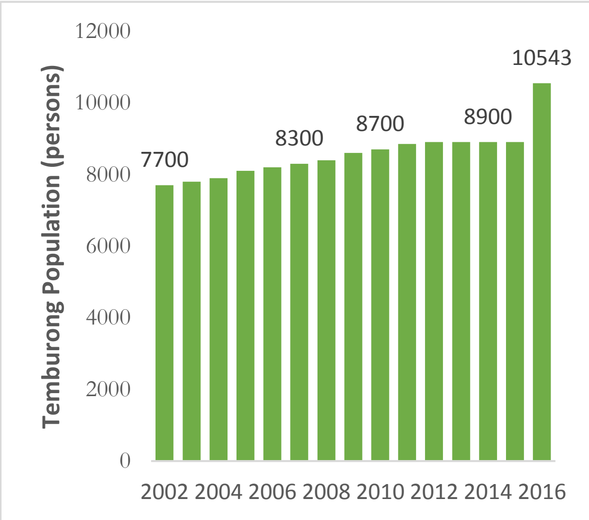
1.2.2. Temburong District Plan 2006–2025

In August 2010, Town and Country Planning Department, Ministry of Development established the Temburong District Plan 2006–2025, with the purpose of guiding and managing potential developments to meet key environmental, social, economic, and rural and urban land use objectives up to 2025. Sustaining the district's community is one of the core strategies in the district plan through providing adequate community facilities while preserving the richness of its forestry, biodiversity, and other natural resources.

1.2.3. Population

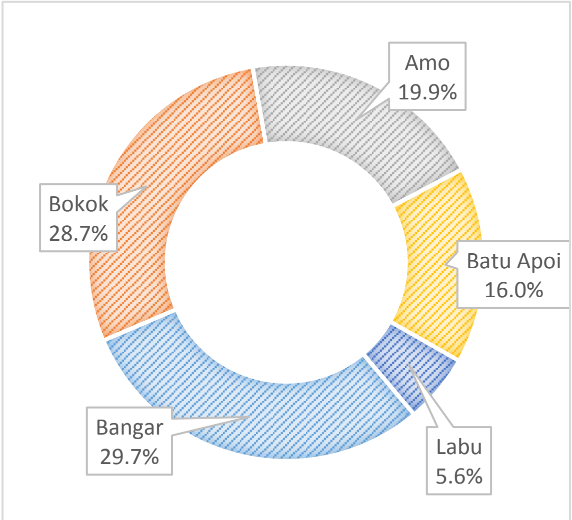
Although Temburong is the second largest district within Brunei Darussalam, it is sparsely populated with only 10,543 inhabitants in 2016, which is about 2.5% of the whole population of Brunei Darussalam (Department of Economic Planning and Development, 2016). Figure 1.4 illustrates that population had been growing at an annual rate of 1.12% from 2002 to 2015, with the population peaking at 8,900 between 2012 and 2015. However, there was a significant rise in population in 2016 at 10,543, with an increase of 18.5%. This may be due to the settlement of new residents through the Rataie National Housing Scheme.

Figure 1.4. Overall Population in Temburong (2002–2016)



Source: Department of Economic Planning and Development (2016).

Figure 1.5. Share of Population in Temburong by Mukim



Source: Department of Economic Planning and Development (2001).

Based on the 2001 Report on the Population Census, the majority of the Temburong population lives within Mukim[1] Bangar, corresponding to approximately 29.7%. This is evident since Bangar town is located within the mukim. About 28.7% reside in Mukim Bokok, followed by Mukim Amo at 19.9%, Mukim Batu Apoi at 16%, and Mukim Labu at 5.6% (Figure 1.5).

The population in Temburong is forecast to grow rapidly since a 30-kilometre-long mega bridge connecting Bandar Seri Begawan and Temburong is due to be completed in 2019. Since more economic activities are expected to bloom in the district, demand for housing lands will increase. Although the demand for energy in Temburong is the least among all the districts, the energy demand's annual growth will double from the current 3% rate, hence the importance of maintaining energy security, as well as its usage, in a sustainable manner within the district.

[1] County, ward, or parish are the closest English translations for *mukim*.

1.2.4. Bangar Urban Growth Expansion

As shown in Figure 1.6, Bangar is the only town and main service centre within the district. The current infrastructure and development within the town is constrained by Temburong River, the route of the highway between, and the edge of the Biang Ridge to the south of the town. The centre hub is located on each bank of the river to the north of the Temburong River Bridge. Government offices and Pengiran Isteri Hajjah Mariam Hospital are located on the east and west bank of the river, while commercial entities are focused on the east bank. Residential lots are found on the west bank and to the north.

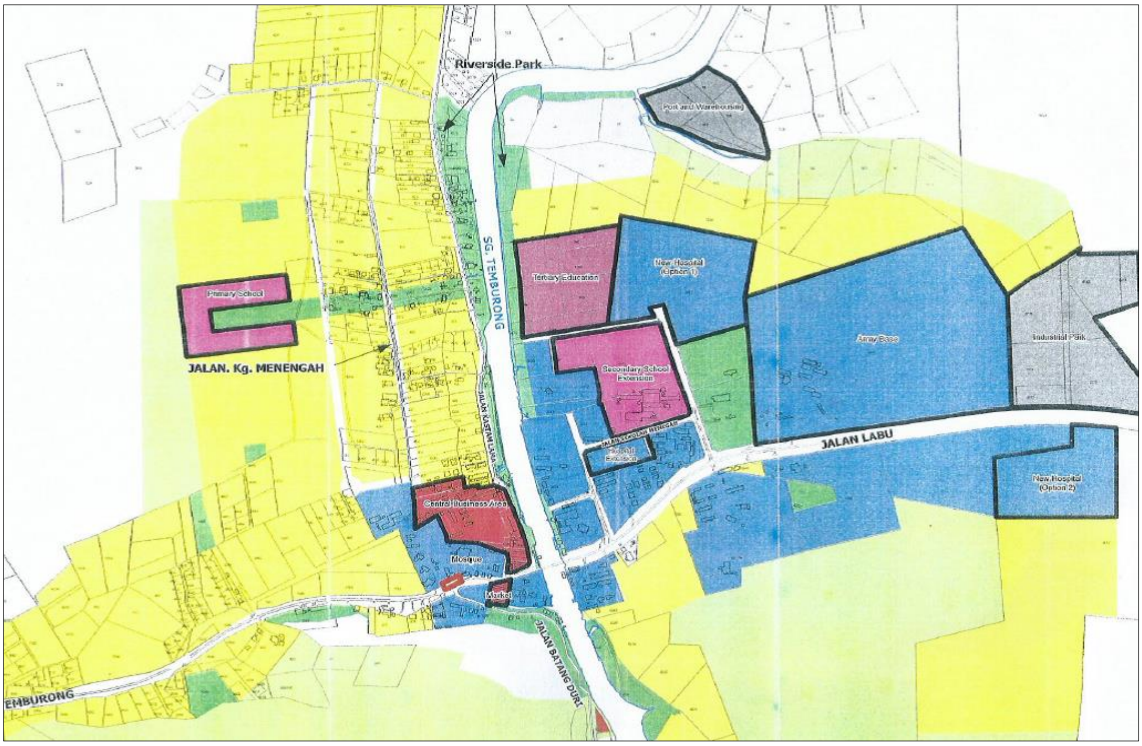
Figure 1.6. Bangar Town

Source: Google Map (2018).

Under the Temburong district plan (Figure 1.7), the following are the key elements of the Bangar urban growth expansion:

- Expansion of the current commercial area, with an allocation of 3.2 hectares (ha) of additional land. This area will also include tourist accommodation (hotel);
- Allocation of 2 ha of land for the expansion of Temburong Industrial Estate to support agricultural and fisheries activities, as well as small service-related industrial activities;
- Allocation of some land for expansion of new government activities in the south of Jalan Labu;
- Allocation of at least 10 ha of land for a new hospital complex, or expansion of the existing Pengiran Isteri Hajjah Mariam Hospital;
- Allocation of some 10 ha of land for the development of tertiary education, i.e. university;
- Allocation of 6 ha of land for a modern port facility, fronting Temburong River to the north east of Bangar;
- Allocation of a new green space to the south of Bangar town; and
- Creation of a new riverside park along the Temburong River.

Figure 1.7. Bangar Proposed Land Use



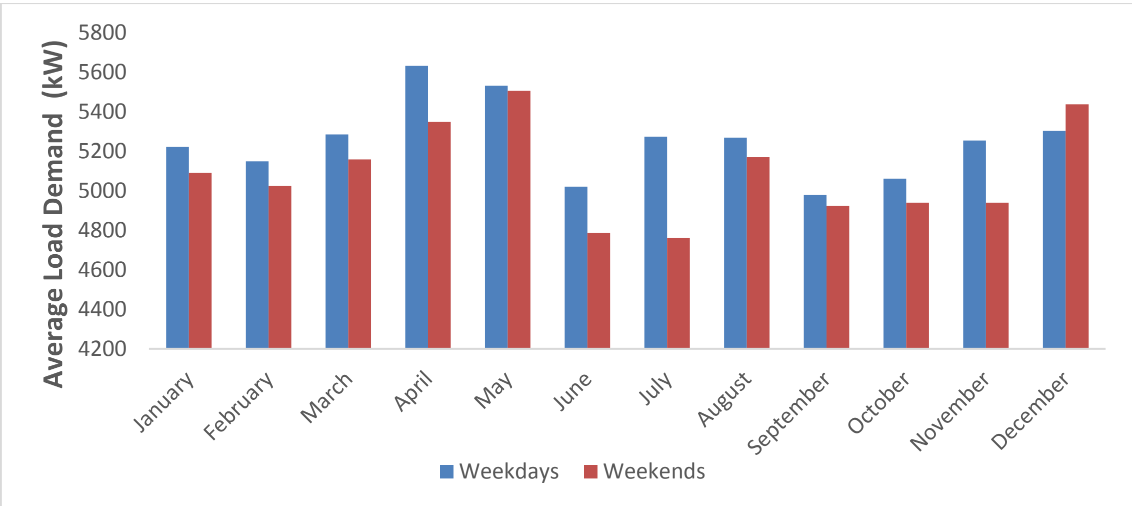
Source: Town and Country Planning Department (2006).

Chapter 2
Forecast of Electricity Demand in Temburong Eco Town

2.1. Actual Electricity Demand Curve in Temburong Area

Actual electricity demand in Temburong area in 2016 is shown in Figure 2.1, Figure 2.2, and Figure 2.3; the data were obtained from the Department of Electrical Services. Electricity demand seemed be highest in April and May and appeared to have dipped in June. The increase in electricity demand could be largely due to the hot period in April and May. The decrease in electricity demand could be due to the Hari Raya Aidil Fitri celebration that fell on 6 July to 8 July 2016. The decrease in electricity demand that occurred in September to November could be due to the rainy season. Figure 2.3 illustrates the typical daily electricity load demand, which seemed to peak in the afternoon and again in the evening.

Figure 2.1. Monthly Average Electricity Load Demand in 2016

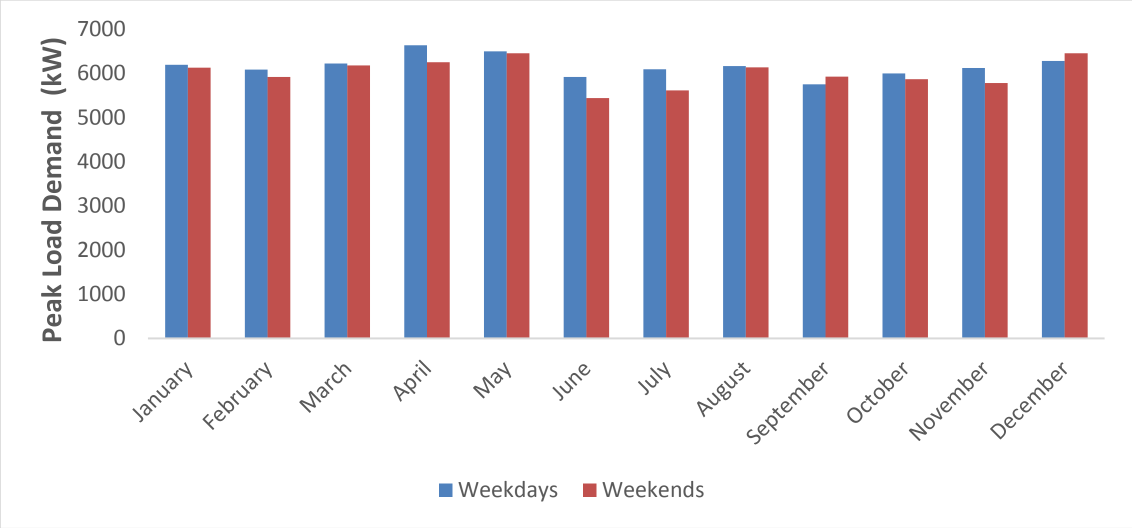


kW = kilowatt.
Source: Department of Electrical Services, Brunei Darussalam (2016).

2.2. Electricity Demand Forecast of Temburong Eco Town in 2025

The electricity demand forecast for Temburong Eco Town in 2025 was based on the information and interpretation of data provided in the Temburong District Plan 2006–2025 published by the Department of Town and Country Planning, Ministry of Development, Brunei Darussalam. The population of Temburong was reported to be 8,900 in 2015. The estimated population based on high growth of 3% is 17,535 by 2025, as set out in the Temburong District Plan. For the purpose of this study, the population was rounded to 20,000. The planning data were developed based on the various developments of anticipated buildings, infrastructures, amenities, and corresponding designated areas, as mentioned in the district plan.

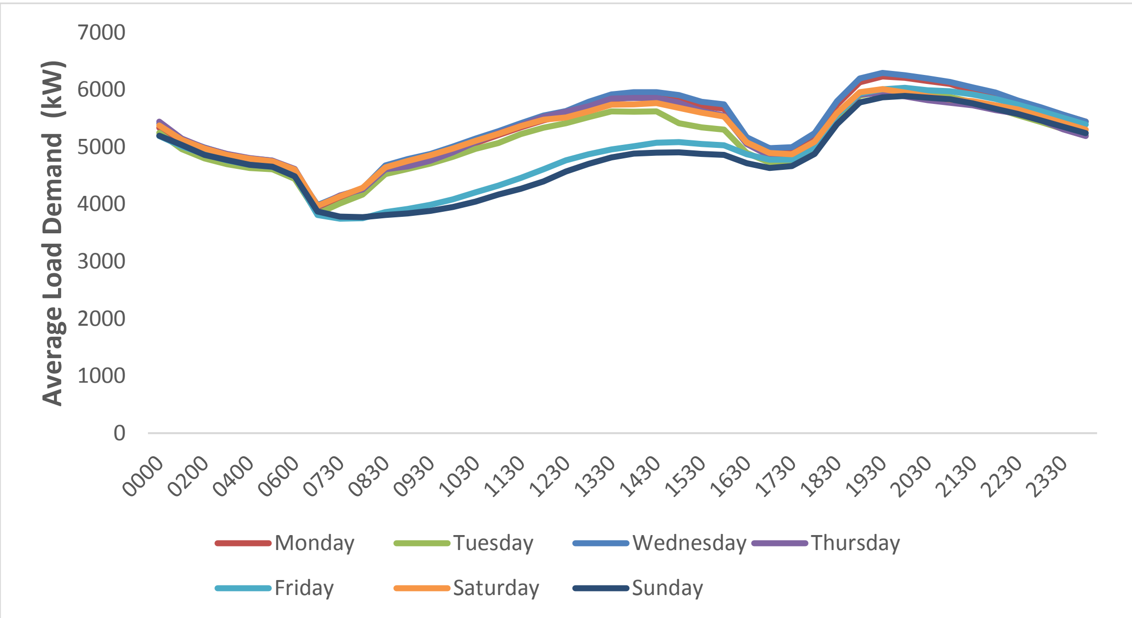
Figure 2.2. Monthly Peak Load Demand in 2016



kW = kilowatt.

Source: Department of Electrical Services, Brunei Darussalam (2016).

Figure 2.3. Typical Daily Load Demand Profile in 2016



kW = kilowatt.

Source: Department of Electrical Services, Brunei Darussalam (2016).

Estimation of building built-up areas was subsequently made based on approximate plot ratio development used in property development practices, with a ratio of approximately 0.6. The planning data are summarised in Table 2.2. However, where land areas are considered to be too large for certain developments, only a portion of the land could be considered for use in this Eco Town development. For other uses such as the building of hotels, the estimation was based on anticipated capacity in terms of the number of hotel rooms.

In Malaysia, the assessment of building energy performance is based on building energy intensity (BEI), which is expressed in kWh per gross floor area (m^2) per year. Similarly, in Singapore BEI is designated as energy use intensity (EUI), which is also expressed in kWh per gross floor area (m^2) per year. Benchmarking values for building energy performance have been established in green building assessment tools for these two countries. For this study, the benchmarking values are based on the Malaysian experience. In addition, Table 2.1 shows the BEI values used in the estimation of electricity consumption for conventional building development, the range of GBI BEI values, and target BEI values for the estimation of electricity demand in Temburong Eco Town development.

Table 2.1. Target Values of Building Energy Intensity (BEI) for Energy-Efficient Buildings

Type of Building	BEI Conventional Building (kWh/m^2/year)	GBI BEI Range (kWh/m^2/year)	Target BEI Energy-Efficient Building (kWh/m^2/year)
Office	250	90–150	120
Hotel	275	≤3-Star: 129–200 4–5 Star: 175–290	233
Hospital	300	• Hospital with limited clinical services: 120–200 • Hospital with major clinical services: 175–290	233
Shopping mall	345	• Average mall: 145–240 • Major mall: 210–350	280

BEI = building energy intensity, GBI = Green Building Index, kWh = kilowatt-hour, m^2 = square metre.
Source: Authors.

2.3. Additional Electricity Demand Based on the Buildings to be Constructed in Temburong Eco Town

It was reported that the existing maximum electricity demand in Temburong was 7.48MW in 2016. This existing maximum demand is added to the forecast of electricity demand to compute the total electricity demand for all of Temburong township, both existing and future, as shown in the last row of Table 2.3. The electricity demand forecast for Temburong was made under two scenarios: (i) conventional building development and (ii) energy-efficient eco town development. Maximum electricity demand in buildings would be estimated for each of the two scenarios. In general, it was assumed that the electricity load demand in energy-efficient buildings is about 20% lower than that in the conventional buildings except where the actual loads are known, e.g. street lighting. The annual electricity consumption was estimated based on the mid-range values of BEI set in the Green Building Index (GBI) assessment tools adopted in Malaysia for buildings that have known BEI targets. For buildings that do not have known BEI targets, maximum electricity demand and appropriate diversity factors used in the general planning of power distribution are adopted as the basis of estimation of electricity consumption.

Table 2.2. Identification of Anticipated Buildings to be Constructed

Building Type	Land Area (hectare)	Built-up Area (m^2)	Capacity	Remarks
Hotel	N/A	10,000	200 hotel rooms	Assumed about double the existing capacity would be required
Shopping mall	3.2	6,000		Assumed 1/3 land area would be used for the development
Shop lots	1.0	6,000	16 units	Assumption
Hospitals	6.0	3,600	100 beds	Assumed 1/10 land area would be used for the development
Government office	1.5	4,000	200 staff	Assumed about half the land would be used for the development
Industrial park	2	12,000		Based on land area of 2 hectares
University campus	10	10,000	800 students	Assumed 1/4 land area would be used and a plot ratio of 0.4 for the campus development
Primary school	4	N/A	800 students	Assumed 25 students per class
Secondary school	8	N/A	1,200 students	Assumed 25 students per class
Students' apartment for university	N/A	N/A	200 students	Assumption
University staff apartment	N/A	N/A	80 staff	Assumption
Hospital staff apartment	N/A	N/A	90 staff	Assumption
Bus terminal building	N/A	1,000	N/A	Assumption
Park & amenities	N/A	N/A	N/A	To provide electricity for park facilities such as water, fountains, and landscape lighting
Port facilities for goods & services including port authority offices & warehouses	6	36,000	100	Based on land area of 6 hectares
Petrol kiosks	N/A	N/A	2 petrol kiosks	Assumed 16 hours daily operation

Building Type	Land Area (hectare)	Built-up Area (m^2)	Capacity	Remarks
Utilities: Wastewater treatment plant	N/A	N/A	7,000 PE	Extracted from Temburong district plan Bangar: 4,000 PE Kg. Rataie: 3,000 PE
Residential houses	253	N/A	1,515 houses	1,715 houses were planned in the Temburong district plan, but it is assumed that 200 houses would be converted to 200 apartment units
Residential apartment	N/A	N/A	200 apartment units	Assumption
Road infrastructure: Street lighting	N/A	N/A	~ 200 km new roads	Estimated road length and street lights to be 30 metres apart

km = kilometre, m^2 = metre, N/A = not applicable, PE = Population Equivalent.

Source: Authors.

Table 2.3. Estimation of Electricity Demand in Normal Township Development and Eco Township Development

Building Type	Maximum Demand Normal Township (kW)	Maximum Demand Eco Town (kW)	Estimated Electricity Consumption Normal Township (kWh/year)	Estimated Electricity Consumption Eco Township (kWh/year)
Hotel	10,000x0.15x0.9 = 1,350	10,000x0.125x0.9 = 1,125	10,000x275 = 2,750,000	10,000x233 = 2,330,000
Shopping mall	6,000x0.11x0.9 = 594	6,000x0.09x0.9 = 486	6,000x345 =2,070,000	6,000x280 = 1,680,000
Shop lots	16x18x0.85 = 245	16x14x0.85 = 190	245x365x0.55x16 = 786,940	190.4x365x0.55x16 = 611,565
Hospital	2,400x0.09x0.9 = 194	2,400x0.07x0.9 = 151	2,400x300 = 720,000	2,400x233 = 559,200
Government office	4,000x0.09x0.7 = 252	4,000x0.07x0.7 = 196	4,000x250 = 1,000,000	4,000x120 = 480,000
Industrial park	12,000x0.08x0.6 = 576	12,000x0.06x0.6 =432	576x365x0.5x16 = 1,681,920	432x365x0.5x16 = 1,261,440
University campus	10,000x0.090x0.7 = 630	10,000x0.07x0.7 = 490	10,000x250 =2,500,000	10,000x120 = 1,200,000
Primary school	800/25x5x0.75	800/25x4x0.75	120x365x8x0.55	96x365x8x0.55

Building Type	**Maximum Demand Normal Township (kW)**	**Maximum Demand Eco Town (kW)**	**Estimated Electricity Consumption Normal Township (kWh/year)**	**Estimated Electricity Consumption Eco Township (kWh/year)**
	= 120	= 96	= 192,720	= 154,176
Secondary school	1,200/25x7x0.75 = 252	1,200/25x6x0.75 = 216	252x365x8x0.45 = 331,128	216x365x8x0.45 = 283,824
Students' apartment for university	200x5x0.7 =700	200x3.75x0.7 = 525	700x365x0.4x24 = 2,452,800	525x365x0.4x24 = 1,839,600
University staff apartment	80x5x0.7 = 280	80x3.75x0.7 = 210	280x365x0.5x24 = 1,226,400	210x365x0.5x24 = 919,800
Hospital staff apartment	90x5x0.7 = 315	90x4x0.7 = 252	315x365x0.5x24 = 1,379,700	252x365x0.5x24 =1,103,760
Bus terminal building	1000x0.1x0.75 = 75	1000x0.07x0.75 = 53	75x365x0.6x16 = 262,800	52.5x365x0.6x16 = 183,960
Park & amenities	80	60	80x365x0.4x4 = 46,720	60x365x0.4x4 = 35,040
Port facilities for goods & services including port authority offices & warehouses	36,000x0.065x0.7 = 1,638	36,000x0.045x0.7 = 1,134	1,638x365x0.55x12 = 3,945,942	1,134x365x0.55x12 = 2,731,806
Petrol kiosks	2x100x0.7 = 140	2x80x0.7 = 112	140x365x0.55x16 = 449,680	112x365x0.55x16 = 359,744
Utilities: Wastewater treatment plant	40x7000/12/(24x12) = 81	81.02x0.9 = 73	81.02x365x0.8x24 = 567,788	72.92x365x0.8x24 = 511,023
Residential houses	1,515x5x0.7 = 5,303	1,515x3.75x0.7 = 3,977	5,302x365x0.5x24 = 23,222,760	3977x365x0.5x24 = 17,419,260
Residential apartment	200x5x0.7 = 700	200x3.75x0.7 = 525	700x365x0.5x24 = 3,066,000	525x365x0.5x24 = 2,299,500
Road infrastructure: Street lighting	200,000x0.25/30 = 1,667	200,000x0.07/30 = 467	1,667x365x8 = 4,867,640	467x365x8 = 1,363,640
Estimated Total Electricity Demand/ Consumption:	15,193	10,770	53,527,486	37,327,338
Estimated Total Electricity Demand	12,914	9,155	N/A	N/A

Building Type	Maximum Demand Normal Township (kW)	Maximum Demand Eco Town (kW)	Estimated Electricity Consumption Normal Township (kWh/year)	Estimated Electricity Consumption Eco Township (kWh/year)
(after diversity factor of 0.85):				
Estimated Total Electricity Demand (after diversity factor & adding existing load):	20,394	16,635	N/A	N/A

kW = kilowatt, kWh = kilowatt-hour, N/A = not applicable.
Source: Authors.

Forecasts of electricity maximum demand and electricity consumption for Temburong in 2025 are given in Table 2.3, which shows the estimates under two scenarios, i.e. normal and eco town developments. It is recognised that the estimates made in this study could only provide an order of magnitude in electricity demand and consumption, as well as trending forecast analyses and comparison of normal and eco township developments. More accurate maximum demand and electricity consumption will need to be recalculated once the Temburong Eco Town planning details are finalised.

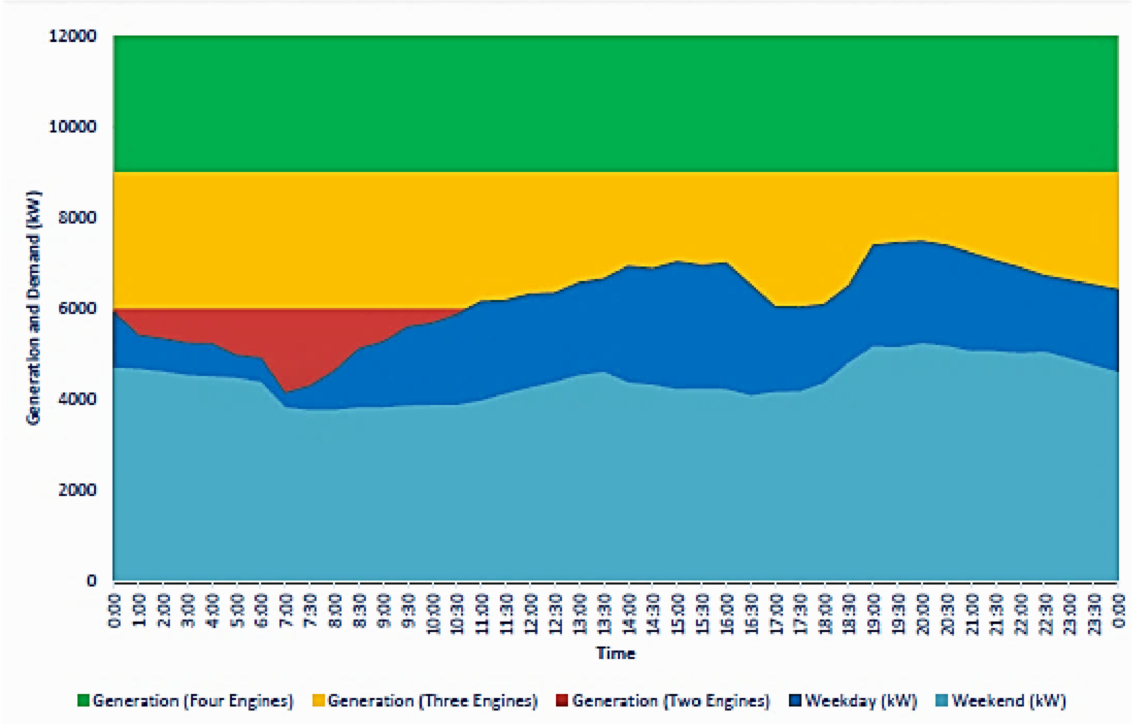
Table 2.3 shows that the additional maximum electricity demand for normal township developments, excluding existing loads, is 12.914MW, and that for eco township developments, excluding existing loads, is 9.155MW. The additional electricity consumption for the conventional and eco town developments is 53,527MWh and 37,327MWh, respectively.

2.4. Existing Electricity Demand

The electricity supply for the existing Temburong township is provided by the Belingus Power Station, which has been operating since 1985. The station has four sets of MAN Mirrlees Blackstone K6 Major Mk3 diesel engine generators with a combined generating capacity of 12MW. The upgrading of local control panels for all diesel engine generators incorporating auto start–stop sequence, remote control, detailed alarm reporting, etc. was completed in 2013. The typical load demand in 2016 is shown in Figure 2.4.

Figure 2.4 shows that three-diesel-engine generators catered mostly for the daytime and night-time loads, and two-diesel-engine generators catered for the overnight load. The daytime load would start to increase from about 7:00 a.m., and peak load seemed to occur at about 4:00 p.m. The load demand would dip after 4:00 p.m. and would peak again to more than 7MW at about 7:00 p.m. Electricity demand would dip thereafter to below 6MW overnight. According to the Department of Electrical Services, Brunei Darussalam, the maximum peak demand recorded in 2016 was 7.48MW. This peak demand value is used in the estimation of total electricity demand for the forecast of electricity demand in Temburong Eco Town.

Figure 2.4. Belingus Power Station Typical Load Demand in 2016



kW = kilowatt.

Source: Department of Electrical Services, Brunei Darussalam (2016).

2.5. Total Electricity Demand

The total electricity demand is based on the maximum peak demand recorded in 2016 at 7.48MW, which is added to the projected total demand (after applying a diversity factor of 0.85) for the new developments in Temburong. Applying a diversity factor is an industry practice since it is anticipated that not all maximum electricity demands would peak at the same time. The total electricity demand estimated for normal township development is 20.394MW and that for eco township development is 16.635MW, as tabulated in Table 2.3 and illustrated in Figure 2.5. This represents a reduction in electricity demand of 18.4% when total electricity demands are compared under the two scenarios, i.e. normal township development and eco township development. Such reduction in electricity demand for eco town is made possible through planning and adoption of passive design measures such as building orientation, building configuration (geometry and layout), building facade, roof design, choice of building materials and colour, insulation, fenestration, and lush landscaping for improved microclimates.

However, it should be pointed out that in a real-case situation, the saving in electricity demand could be increased. The reason is that in deriving an electricity demand reduction of 18.4%, the existing electricity demand is assumed to remain constant. However, through promotion and greater public awareness of eco town benefits or through legislative requirements, the existing load demand would have been reduced by 2025. Such development will result in further reduction in total electricity demand in the Temburong area when full-scale eco township is comprehensively developed. Therefore, it may be possible to see a saving of at least 25% in total electricity demand for a complete eco township development. Table 2.3 shows that reduction in yearly electricity consumption that can be achieved from eco township development is 16,200MWh, which is about 30% saving in yearly electricity consumption.

Reduction in total electricity demand can be translated into the following savings:

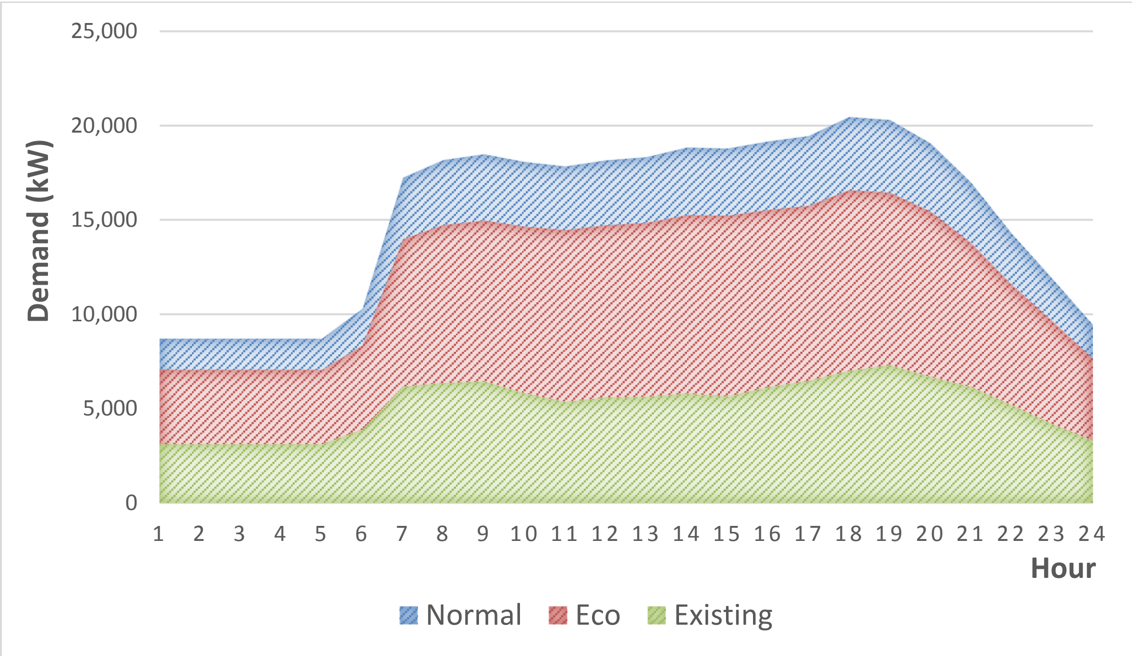
(1) Savings in constructing a power plant with smaller capacity;

(2) Savings in capital purchase of smaller capacity air-conditioning equipment;

(3) Savings in electricity consumption with the operation of more energy-efficient equipment and appliances; and

(4) Savings due to reduced use of air-conditioning equipment resulting from eco township design dwellings and commercial buildings.

Figure 2.5. Daily Electricity Demand Comparison of Eco Township Development vs Normal Township Development

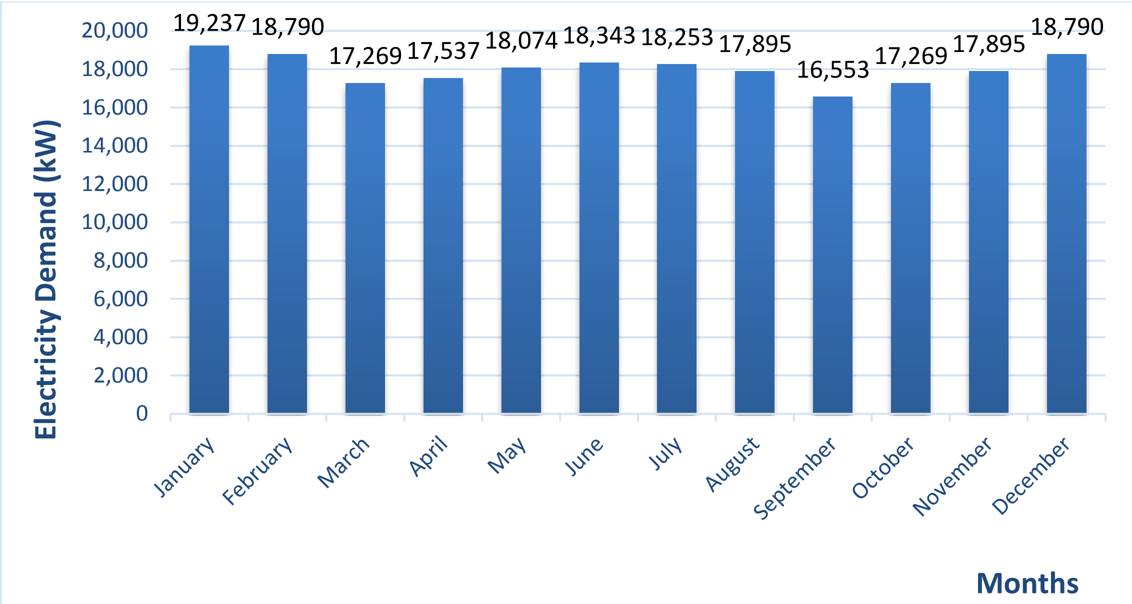


kW = kilowatt.

Source: Authors.

Figure 2.5 compares the electricity demand of normal township development and that of eco township development. If the existing township will also adopt the eco township energy-efficient measures, the difference in electricity demand between these two types of development will be bigger. In other words, the combined reduction in electricity demand for both the existing township and new eco township developments will be greater.

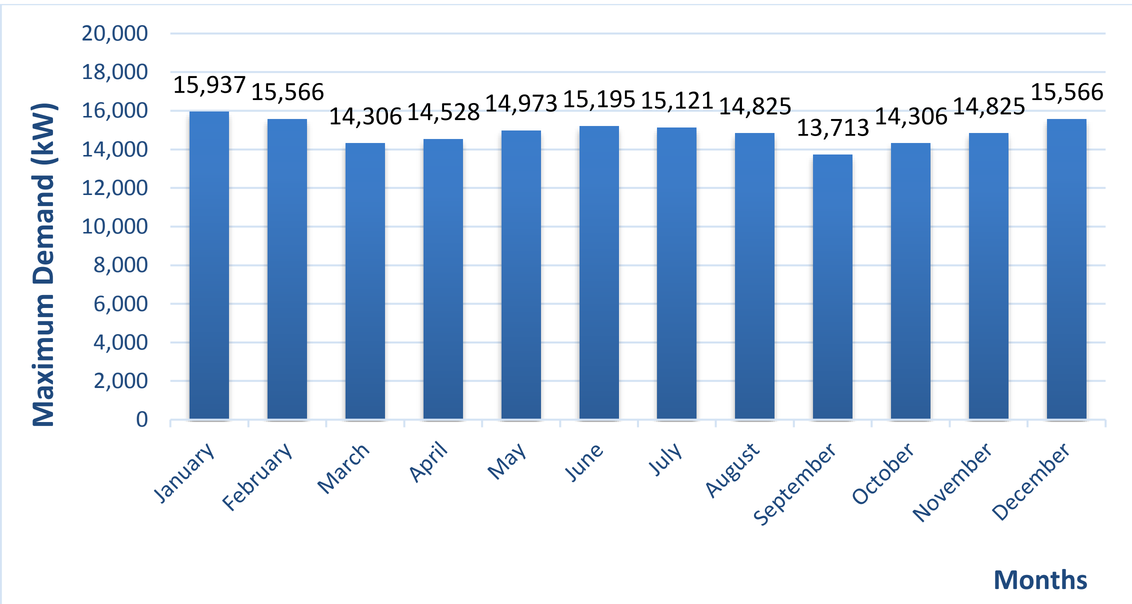
Figure 2.6. Monthly Electricity Demand for Normal Township Development (Forecast for January–December 2025)



kW = kilowatt.

Source: Authors.

Figure 2.7. Monthly Electricity Demand for Eco Township Development (Forecast for January–December 2025)



kW = kilowatt.

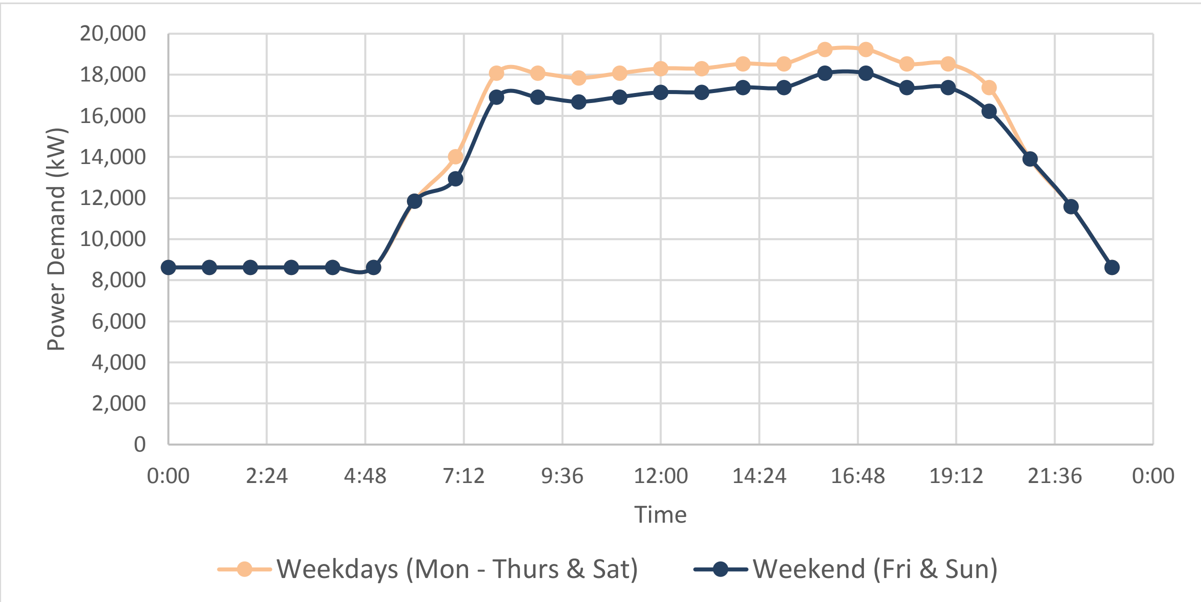
Source: Authors.

Figure 2.6 and Figure 2.7 show the forecast for monthly electricity demand in 2025, which is essentially modelled on 2016 electricity demand. In 2025, the Eid al- Fitr celebration will begin in the evening of 30 March and will end in the evening of 1 April. Electricity demand is expected to dip a little in the month preceding the festive celebration. The demand trend shows that it will gradually increase after the Hari Raya celebration and will peak around the middle of the year. Electricity demand is expected to be lower during the rainy period, which is usually from September to January. The increase in demand in December may be due to year-end school holidays. Based on the higher electricity demand forecast for January 2025, Figure 2.8 and Figure 2.9 show the projected load profiles for normal township and eco township developments.

2.6. Breakdowns of Total Electricity Demand

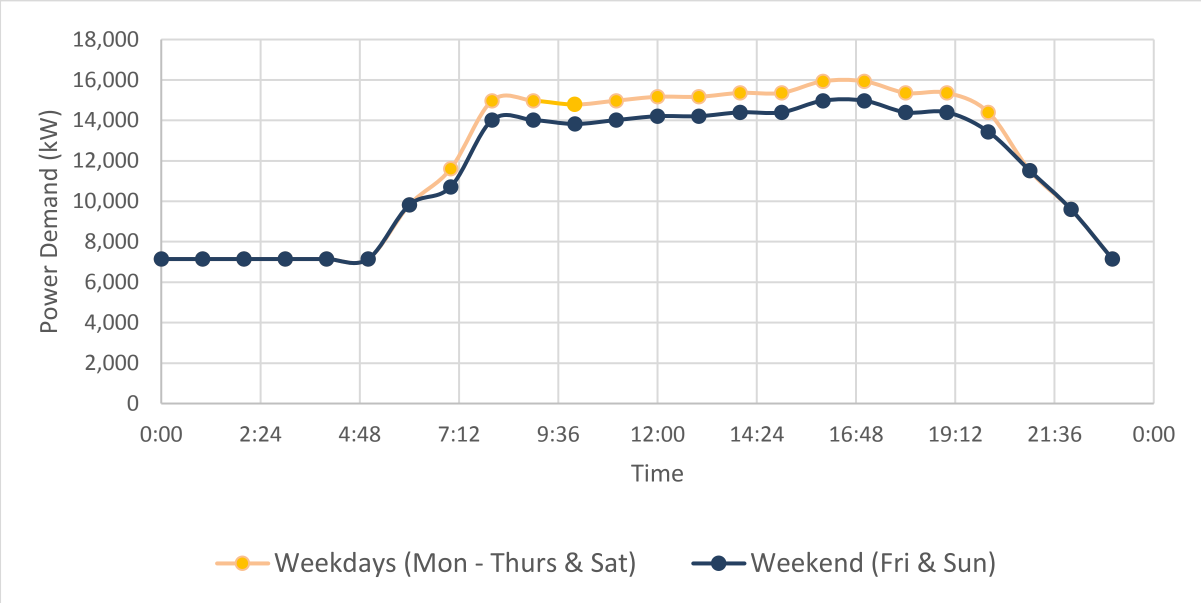
Table 2.3 tabulates the estimates of breakdowns of electricity demand for normal and eco township developments. Figure 2.10 and Figure 2.11 illustrate the projected daily load profile of each of the various sectors such as residential, commercial, industrial, institutional buildings, and infrastructure, as well as the total electricity demand trending for normal and eco township developments based on the assumptions and estimates made in this study. The residential sector has the highest proportion of electricity demand, taking up about 40% of the total electricity demand under both scenarios. It may be anticipated that the commercial sector will take up a more substantial proportion. However, due to lack of information on detailed township planning for this study, electricity demand for the commercial sector is not significant since conservative estimates were made on the premise that there was no extensive commercial development. If there were plans to have more and larger hotels and resorts, larger shopping malls, theme parks, etc., electricity demand for the commercial sector would take up a larger proportion.

Figure 2.8. Projected Daily Load Profile in January 2025 for Normal Township Development



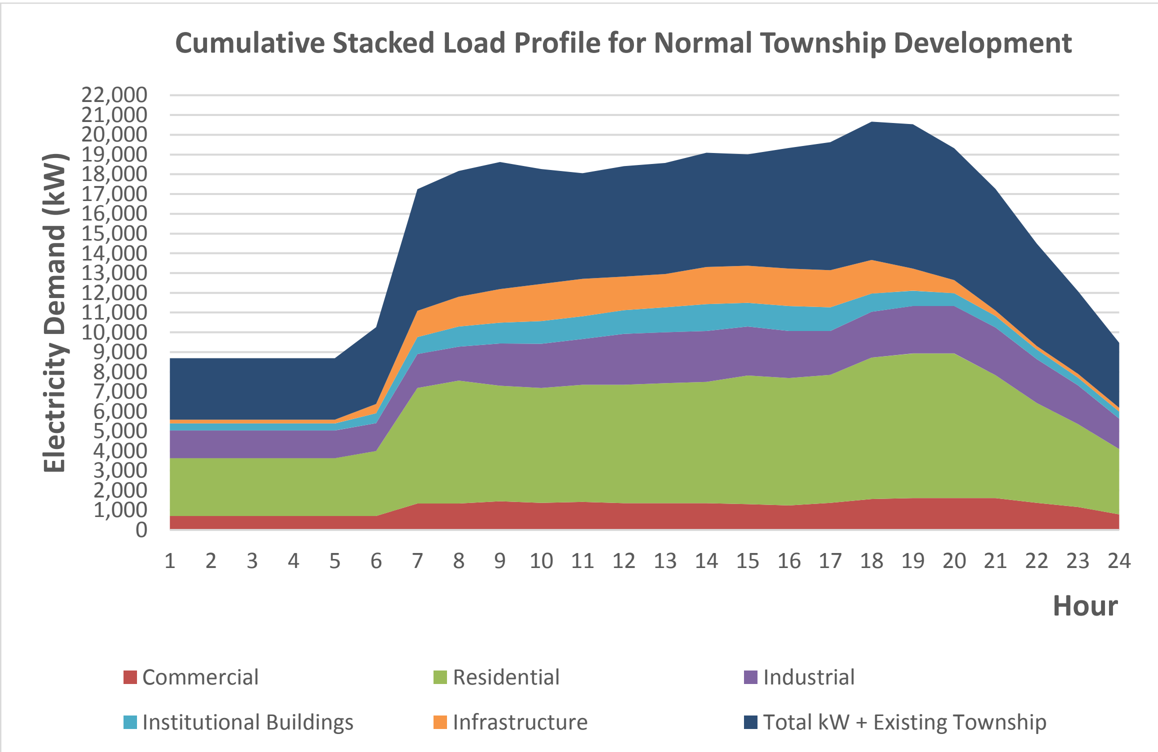
kW = kilowatt.
Source: Authors.

Figure 2.9. Projected Daily Load Profile in January 2025 for Eco Township Development



kW = kilowatt.
Source: Authors.

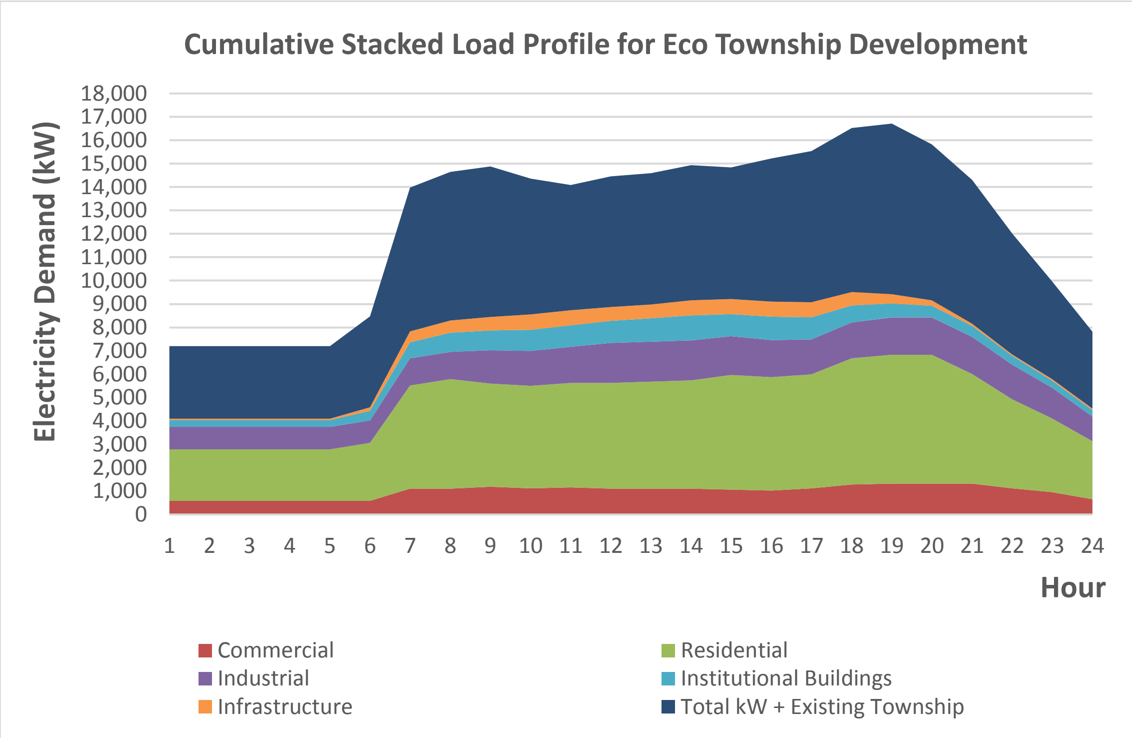
Figure 2.10. Daily Electricity Load Demand Profile Showing Breakdowns and Total Demand for Normal Township Development



kW = kilowatt.
Source: Authors.

Figure 2.10 and Figure 2.11 show similar trends in the daily electricity demand for normal and eco township developments. The difference is mainly in the values of electricity demand. The graphs for eco township development show reduced electricity demand. The residential sector is the largest electricity consumer. However, if larger and greater numbers of commercial developments are planned for the Temburong township, electricity demand from the commercial sector will increase substantially.

Figure 2.11: Daily Electricity Load Demand Profile Showing Breakdowns and Total Demand for Eco Township Development



kW = kilowatt.

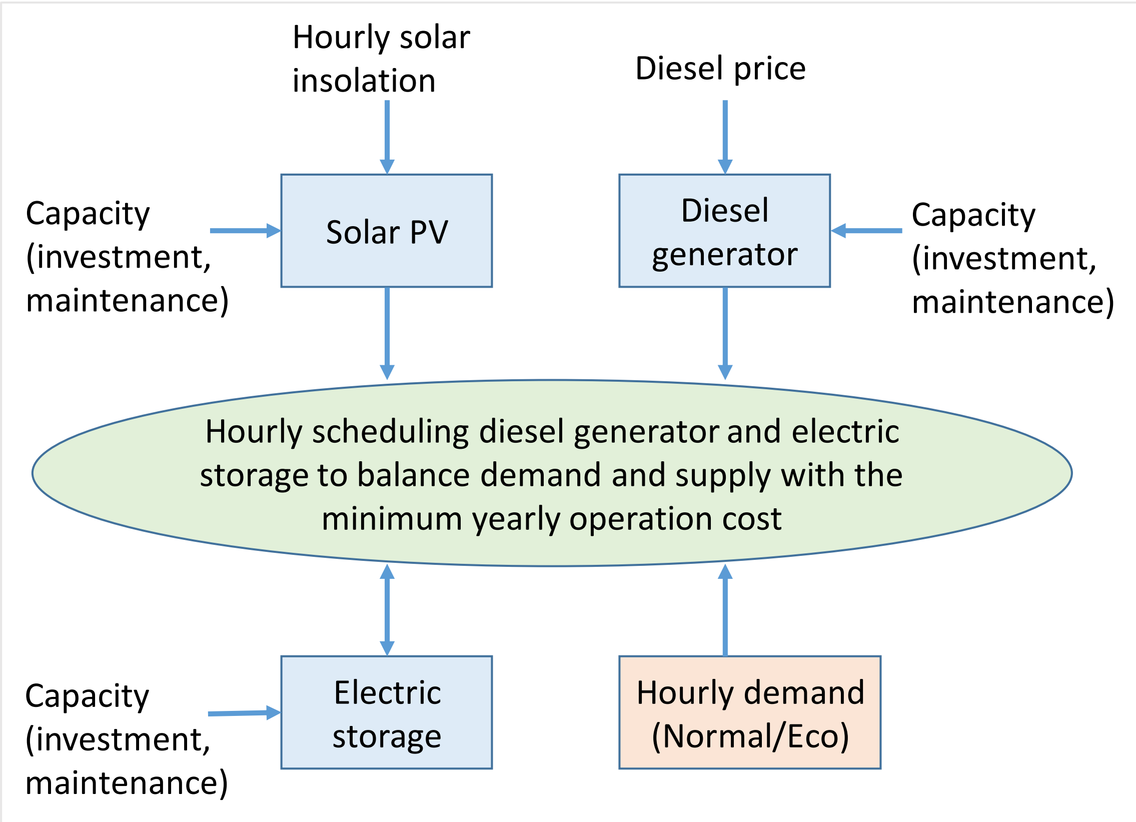
Source: Authors.

Chapter 3
Seeking Best Mix of Power Generation System for Temburong Eco Town

3.1. Basic Concept of Simulation Model

Operation schedule of diesel generators and electricity storage was simulated to balance demand and supply with minimum operation cost. Two electricity demands (normal and eco) estimated in Chapter 2 were used as inputs of the simulation. Generated electricity in solar photovoltaic (PV) was estimated using a given capacity and observed hourly solar radiation data described in Chapter 1. Diesel generator and electricity storage were operated to balance demand and supply of electricity with given capacities of diesel generator and electricity storage and diesel fuel price. Basic concept of the simulation model is schematically shown in Figure 3.1. The simulation model was formulated as a mixed integer linear mathematical programing (Ikeda, et al., 2012; Ikeda and Ogimoto, 2013; Ikeda and Ogimoto, 2014) and simulated operation schedule of diesel generators and electricity storage with minimum fuel cost of diesel generator. Solar PV, diesel generators, and electricity storage require investment and maintenance costs. Considering fuel, investment, and maintenance costs, levelised cost of energy (LCOE) was estimated for a given mix of power generation system.

Figure 3.1. Basic Concept of Simulation Model



PV = photovoltaic.

Source: Authors.

3.2. Scenario Setting

There are three power sources available in Temburong: (i) existing diesel generator, (ii) solar PV plant, and (iii) electricity storage. We have three different scenarios for diesel generators, i.e. 12MW, 6MW, and 0MW. Capacity of solar PV is in the range of 0MW to 192MW. Stored electricity is in the range of 12MWh to 570 MWh (0MW–95 MW). Tables 3.1 to 3.6 summarise the scenarios. Table 3.7 shows cost assumptions for each power source (Lazard, 2014; Fu et al., 2016).

Table 3.1. Existing Diesel Generators (12MW) + Solar PV + Storage for the Normal Demand

Demand	Normal
Diesel (MW)	12 (number of generators=4)
PV (MW)	0, 9.6, 24.0, 38.4, 52.8, 67.2
Stored electricity (MWh)	24, 42, 60, 78, 90
Rated power of electric storage ((MW)	4, 7, 10, 13, 15

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.2. Existing Diesel Generators (12MW) + Solar PV + Storage for the Eco Demand

Demand	Eco
Diesel (MW)	12 (number of generators=4)
PV (MW)	0, 4.8, 19.2, 33.6
Stored electricity (MWh)	12, 30, 48, 66
Rated power of electric storage (MW)	2, 5, 8, 11

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.3. Half of Diesel Generators (6MW) + Solar PV + Storage for the Normal Demand

Demand	Normal
Diesel (MW)	6 (number of generators=2)
PV (MW)	96, 120, 144, 168
Stored electricity (MWh)	150, 180, 210, 240
Rated power of electric storage (MW)	25, 30, 35, 40

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.4. Half of Diesel Generators (6MW) + Solar PV + Storage for the Eco Demand

Demand	Eco
Diesel (MW)	6 (number of generators=2)
PV (MW)	48, 72, 96, 120
Stored electricity (MWh)	90, 120, 150, 180, 210
Rated power of electric storage (MW)	15, 20, 25, 30, 35

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.5. Zero Diesel Generator + Solar PV + Storage for the Normal Demand

Demand	Normal
Diesel (MW)	None
PV (MW)	120, 144, 168, 192
Stored electricity (MWh)	450, 480, 510, 540, 570
Rated power of electric storage (MW)	75, 80, 85, 90, 95

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.6. Zero Diesel Generator + Solar PV + Storage for the Eco Demand

Demand	Eco
Diesel (MW)	None
PV (MW)	96, 120, 144, 168
Stored electricity (MWh)	360, 390, 420, 450, 480
Rated power of electric storage (MW)	60, 65, 70, 75, 80

MW = megawatt, MWh = megawatt hour.
Source: Authors.

Table 3.7. Assumptions for Cost of Each Power Source

	Diesel generator	Solar PV	Electric storage
Status	Existing	Newly Installed	Newly Installed
Initial Cost	0	US$3/W	US$200/kWh
Fuel Cost	US$0.32/liter	0	0
OM Cost	US$15,000/MW/Year	US$15,000/MW/Year	US$20,000/MW/Year

KWh = kilowatt-hour, MW = megawatt, OM = Operations and Maintenance, W = watt.
Source: Authors.

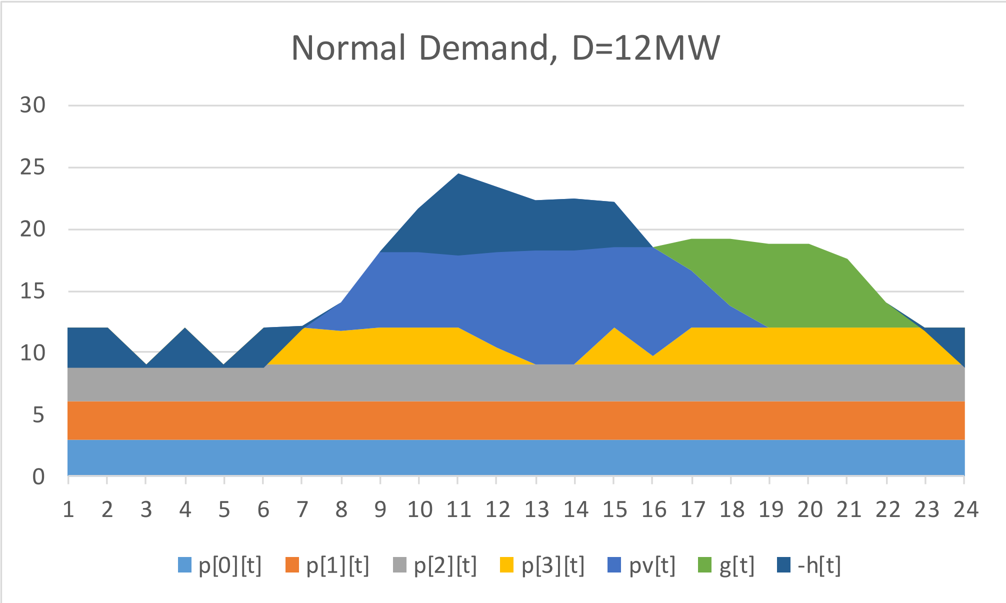
3.3. Comparison of Results among the Scenarios

3.3.1. Demand and Supply Balance

Scheduling diesel generator and electricity storage was simulated for scenarios summarised in Table 3.1 to Table 3.6 for 1 year with 1-hour intervals. The obtained results for demand and supply balance are shown in Figure 3.2 to Figure 3.7. Here ‘p[0]’, ‘p[1]’, ‘p[2]’, and ‘p[3]’ indicate generated electricity in four diesel generators; ‘PV’ is generated electricity in solar PV; ‘g’ and ‘-h’ are discharged electricity from the storage and charged electricity in the storage. Note that ‘-h’ during daytime is surplus electricity from solar PV and is therefore charged in the storage.

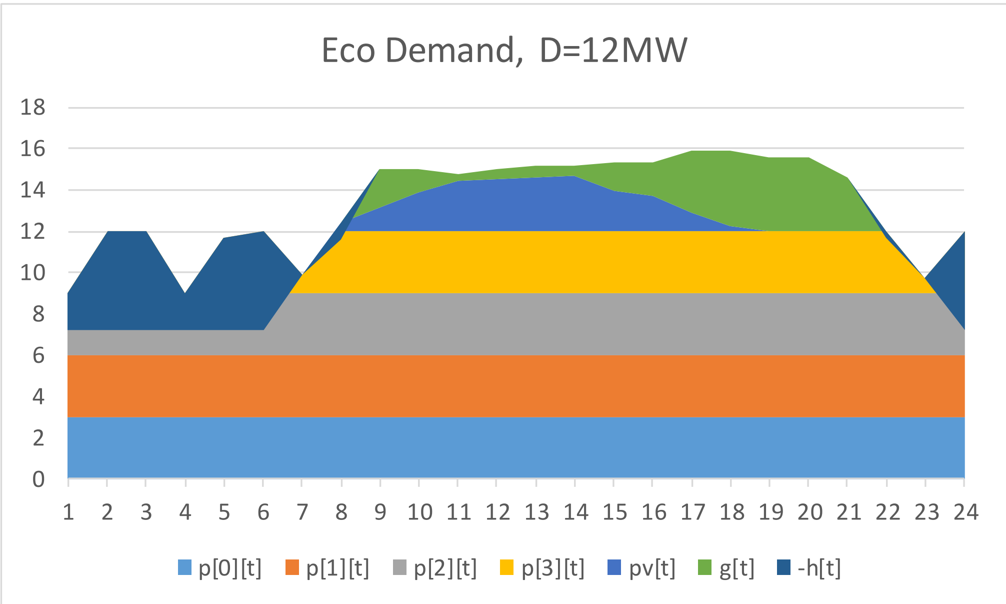
Figure 3.2 shows demand and supply balance in early January for the scenario summarised in Table 3.1. Three diesel generators are operated at rated power and one unit is managed for its generated power to balance demand and supply. In the case of lower solar radiation, solar PV generates electricity for daytime peak and a diesel power charges electricity in the storage at night-time. Figure 3.3 shows demand and supply balance in early January for the scenario summarised in Table 3.2. Three diesel generators are operated at rated power and one unit is managed for its generated power during daytime. Solar PV and diesel power charge their surplus electricity in the storage for night-time use. Figure 3.4 shows demand and supply balance in early January for the scenario summarised in Table 3.3. Solar PV generates a large amount of electricity at daytime and charges surplus electricity in the storage for night-time use. However, in the case of lower solar radiation, two diesel generators are needed at night-time. Figure 3.5 shows demand and supply balance in early January for the scenario summarised in Table 3.4. Solar PV generates a large amount of electricity in daytime and charges surplus electricity in the storage for night-time use. Figure 3.6 and Figure 3.7 show demand and supply balance in early January for the scenario summarised in Table 3.5 and Table 3.6. Solar PV generates a large amount of electricity in daytime and charges surplus electricity in the storage for night-time use.

Figure 3.2. Supply Electricity with D=12MW, PV= 24MW, Storage=78MWh for the Normal Demand



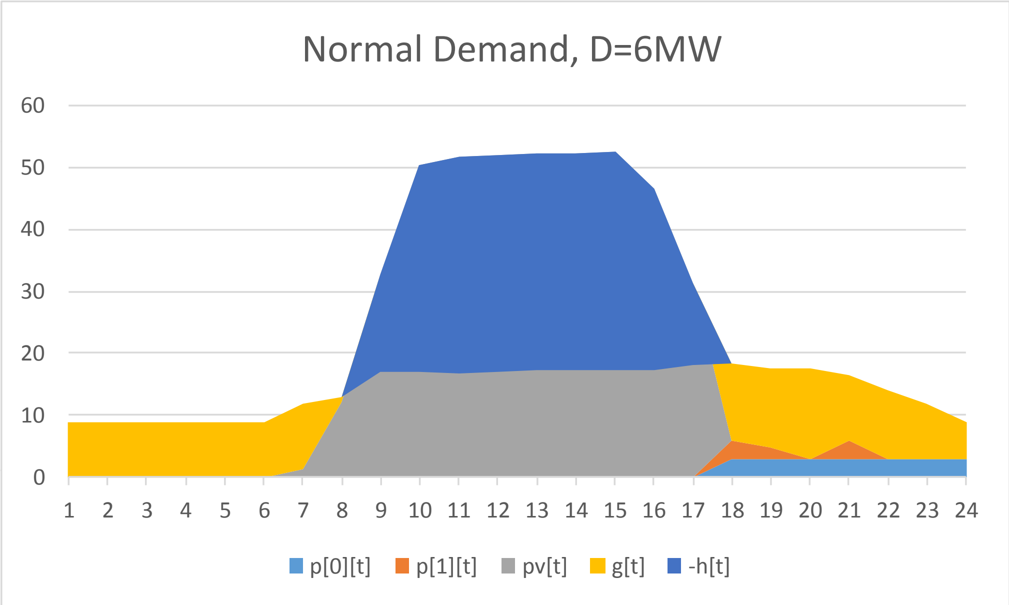
D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

Figure 3.3. Supply Electricity with D=12MW, PV= 4.8MW, Storage=48MWh for the Eco Demand



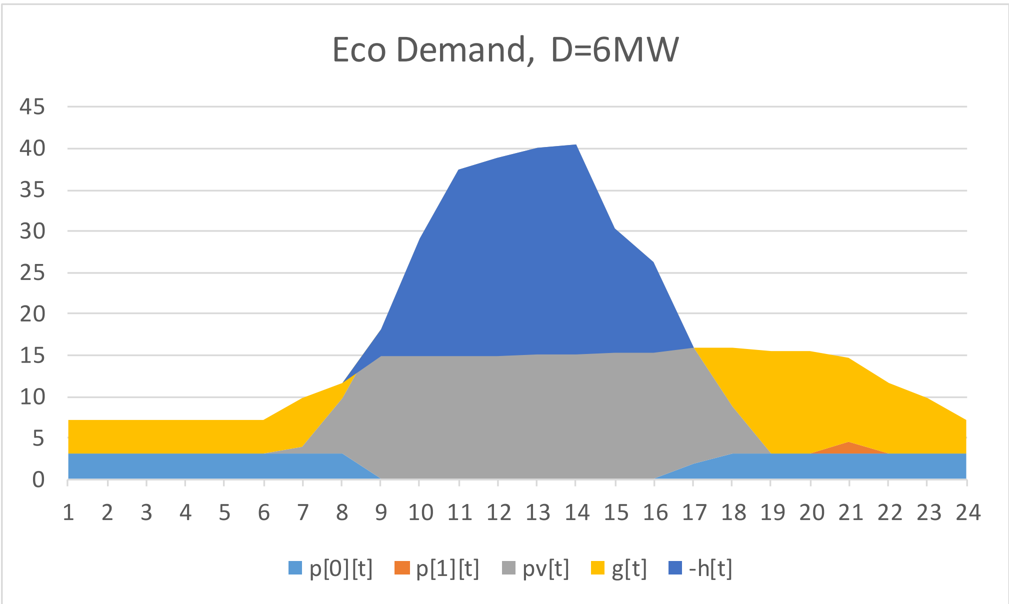
D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

Figure 3.4. Supply Electricity with D=6MW, PV=120MW, Storage=210MWh for the Normal Demand



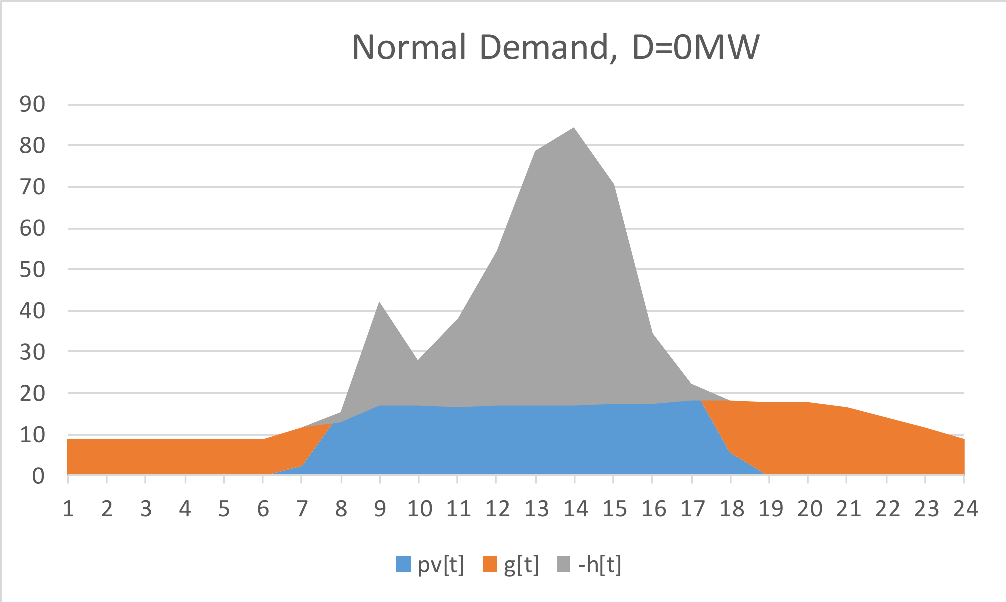
D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

Figure 3.5. Supply Electricity with D=6MW, PV=72MW, Storage=180MWh for the Eco Demand



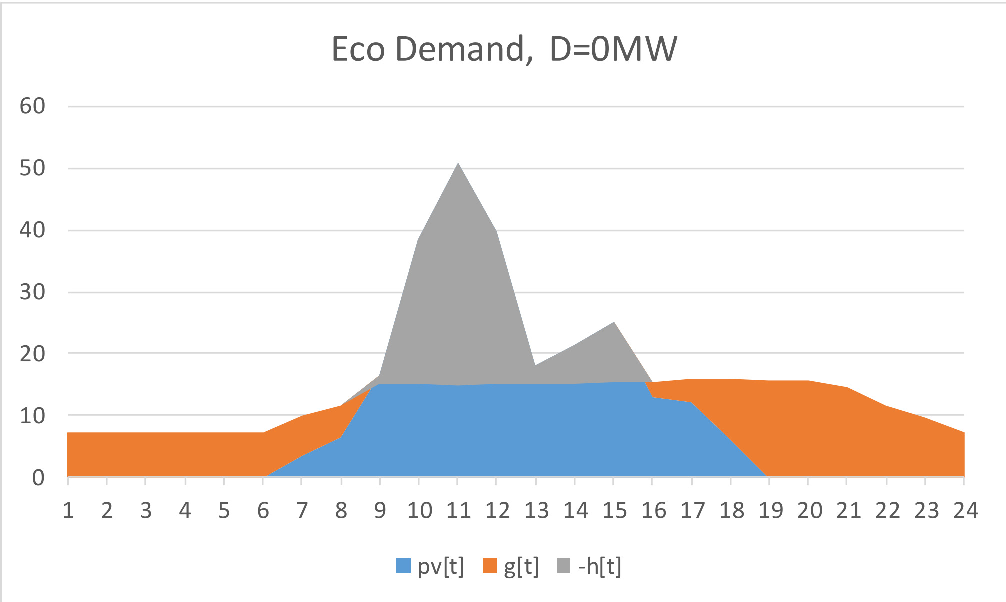
D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

Figure 3.6. Supply Electricity with D=0MW, PV=144MW, Storage=540MWh for the Normal Demand



D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

Figure 3.7. Supply Electricity with D=0MW, PV=120MW, Storage=450MWh for the Eco Demand



D = capacity of diesel generator, g = discharged electricity from the storage, -h = charged electricity in the storage, MW = megawatt, MWh = megawatt hour, p = generated electricity in diesel generator, PV = generated electricity in solar photovoltaic, t = time in hour.
Source: Authors.

3.3.2. Best mix of Power Generation Source

Operation schedule of diesel generators and electricity storage with minimum fuel cost of diesel generator was simulated using the model shown in Figure 3.1, and for the scenarios of solar PV and electricity storage described in Table 3.1 to Table 3.6. LCOE was estimated using the fuel cost obtained in the simulation, investment cost, and maintenance cost described in Table 3.7. The following is the formula for LCOE:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where I_t, M_t, F_t, E_t are investment expenditures, operations and maintenance expenditures, fuel expenditures, and electricity generation. Discount rate $r = 5\%$ and life of the system $n = 20$ years are assumed in the calculation of LCOE. The results of LCOE estimations are summarised in Table 3.8 to Table 3.13. The scenarios from which demand supply balance was not obtained for the given capacities of solar PV and electricity storage are indicated by 'infeasible'. Additional results on electricity supply in Temburong Eco Town are described in Annex 3.

The best power mixes are identified in terms of the smallest LCOE and are summarised in Table 3.14 and Table 3.15. Under the condition without diesel generator, combination of solar PV and storage is a technically feasible solution, but large capacities are required for both solar PV and storage.

Table 3.8. LCOE with D=12MW for the Normal Demand (US$/MWh)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	146	148
38	Infeasible	Infeasible	158	161	163
53	Infeasible	176	177	179	181
67	Infeasible	202	202	202	203

D = capacity of diesel generator, LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.

Source: Authors.

Table 3.9. LCOE with D=12MW for the Eco Demand (US$/MWh)

PV(MW)\Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	123	127
19	Infeasible	138	141	145
34	Infeasible	158	161	164

D = capacity of diesel generator, LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.

Source: Authors.

Table 3.10. LCOE with D=6MW for the Normal Demand (US$/MWh)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	299	303
144	Infeasible	344	347	351
168	Infeasible	393	397	401

D = capacity of diesel generator, LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.

Source: Authors.

Table 3.11. LCOE with D=6MW for the Eco Demand (US$/MWh)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	245	250
96	Infeasible	289	290	293	297
120	Infeasible	346	347	350	355

D = capacity of diesel generator, LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.

Source: Authors.

Table 3.12. LCOE with D=0MW for the Normal Demand (US$/MWh)

PV(MW)\Storage (MWh)	450	480	510	540	570
120	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
144	Infeasible	Infeasible	Infeasible	395	400
168	Infeasible	436	441	446	451
192	Infeasible	487	492	497	502

D = capacity of diesel generator, LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.

Source: Authors.

Table 3.13. LCOE with D=0MW for the Eco Demand (US$/MWh)

PV(MW)\Storage (MWh)	360	390	420	450	480
96	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	Infeasible	397	403
144	Infeasible	447	453	459	465
168	Infeasible	509	515	521	526

D = capacity of diesel generator, MW = megawatt, MWh = megawatt hour, PV = photovoltaic.
Source: Authors.

Table 3.14. The Best Power Mixes for the Normal Demand

	Diesel Power Plant: 12MW	Diesel Power Plant: 6MW	No Diesel Power Plant
Solar PV (MW)	24	120	144
Storage (MWh)	78	210	540

MW = megawatt, MWh = megawatt hour, PV = photovoltaic.
Source: Authors.

Table 3.15. The Best Power Mixes for the Eco Demand

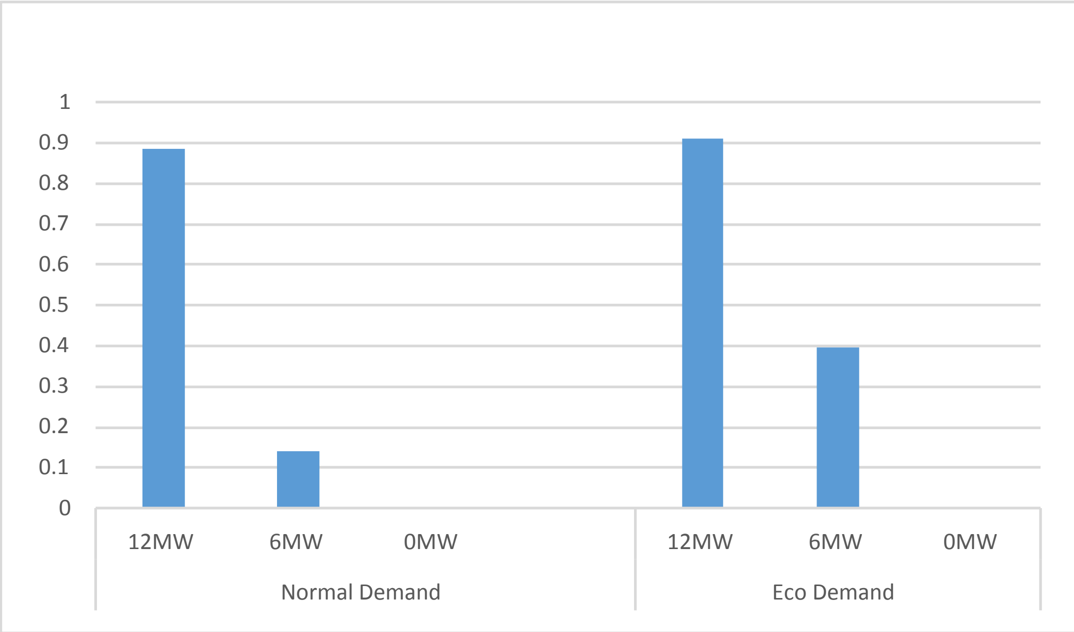
	Diesel Power Plant: 12MW	Diesel Power Plant: 6MW	No Diesel Power Plant
Solar PV (MW)	5	72	120
Storage (MWh)	48	180	450

MW = megawatt, MWh = megawatt hour, PV = photovoltaic.
Source: Authors.

3.3.3. Diesel Operation Rate at the Best Power Mix

Figure 3.8 shows the operation rate of the diesel generators at the best power mix corresponding to Table 3.14 and Table 3.15. These are calculated using simulation results shown in Table A3.1 to Table A3.5 of Annex 3. In case of 12MW, the operation rate is about 90% for both the normal and eco demands. On the other hand, in case of 6MW it is 40% for the eco demand and 14% for the normal demand. This may be caused by the difference of capacity of solar PV. In case of 6MW, to avoid blackout significant capacity of solar PV will be needed – 120MW for the normal demand and 72MW for the eco demand as shown in Table 3.14 and Table 3.15. Solar PV generates electricity during daytime and charges the surplus electricity in the storage. Therefore, diesel power generation is less needed during night-time because charged electricity in storage will be discharged at night-time.

Figure 3.8. Diesel Operation Rate at the Best Power Mix

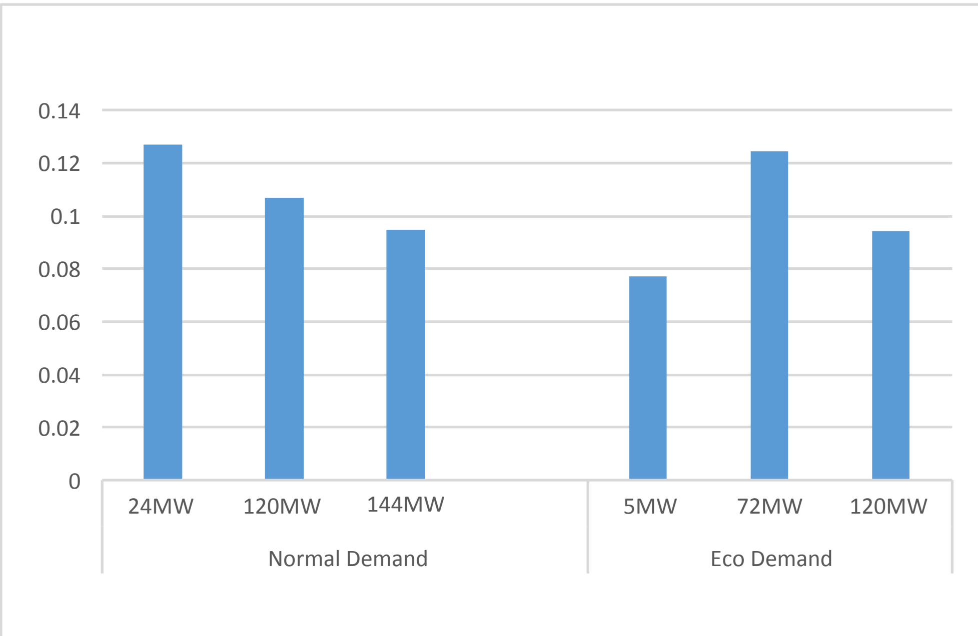


MW = megawatt.
Source: Authors.

3.3.4. Solar PV Load Factor at the Best Power Mix

Solar PV load factor at the best power mix corresponding to Table 3.14 and Table 3.15 is calculated using simulation results shown in Table A3.6 to Table A3.10 of Annex 3, and the calculated results are shown in Figure 3.9. Operation rates of solar PV are in the range of 8%–13% as shown in Figure 3.9. These rates are considered appropriate in the ASEAN region.

Figure 3.9. Solar PV Load Factor at the Best Power Mix

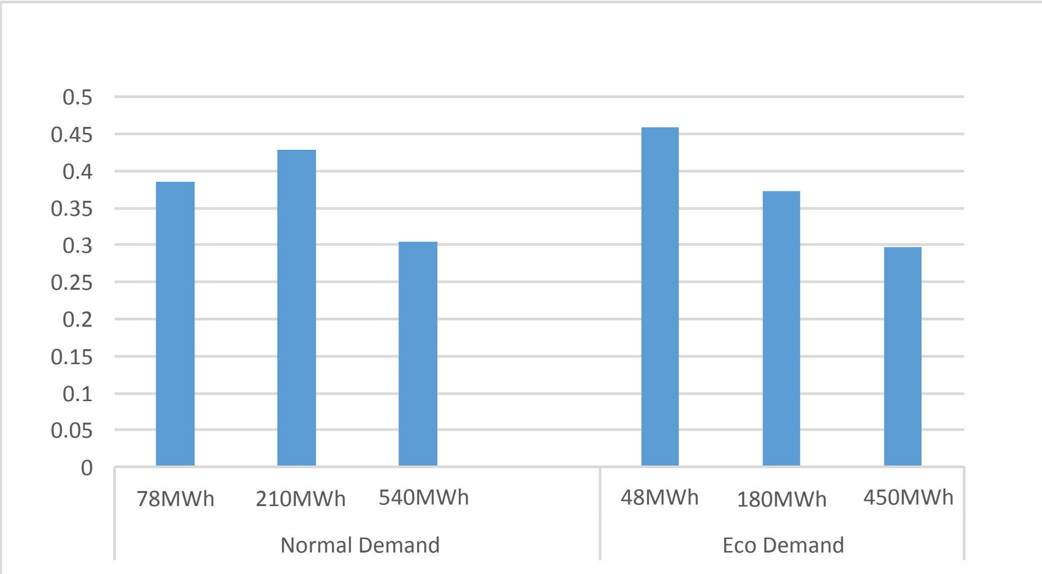


MW = megawatt.
Source: Authors.

3.3.5. Storage Operation Rate at the Best Power Mix

Average values of storage operation rate at the best power mix are calculated using simulation results shown in Table A3.11 to Table A3.16 of Annex 3, and the calculated results are shown in Figure 3.10. The average values of storage operation rate are in the range of 30%–45%. The minimum and maximum are close to 0% and 100%. This means that the storage is efficiently used to balance demand and supply under the fluctuation of solar PV-generated electricity.

Figure 3.10. Storage Operation Rate at the Best Power Mix

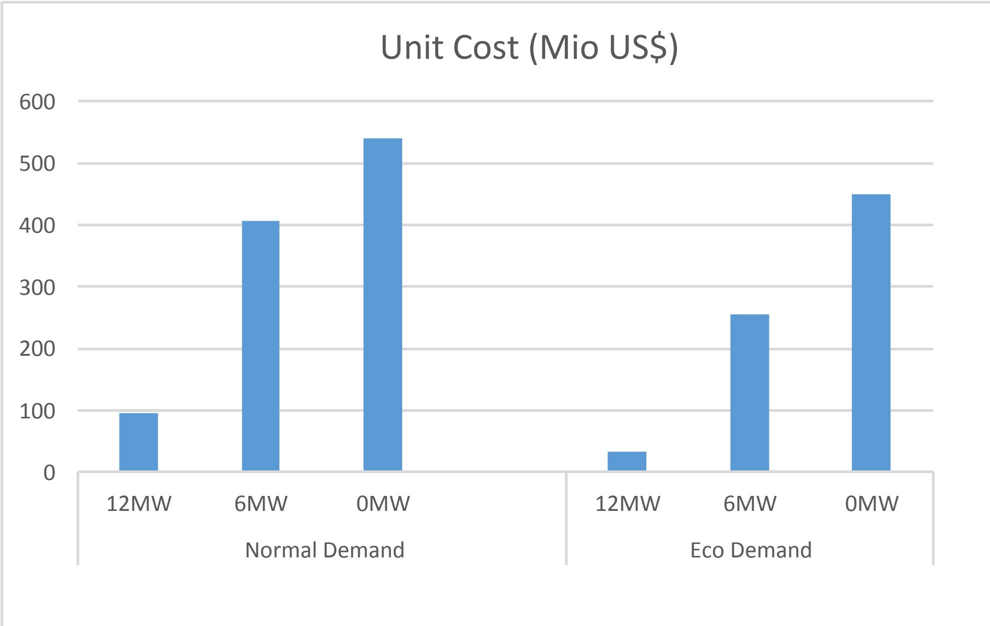


MWh = megawatt hour.
Source: Authors.

3.3.6. Initial Investment Cost at the Best Power Mix

Initial investment costs at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated using simulation results shown in Table A3.17 to Table A3.22 of Annex 3, and the calculated results are shown in Figure 3.11. Without using the diesel generator, combination of solar PV and storage will be technically feasible to supply Temburong Eco Town with electricity although its initial cost is still very high. Cost of solar PV will be dominant, about 80%, followed by cost of electricity storage. If Temburong Eco Town seeks completely carbon-free power supply, more than US$400 million will be required under application of currently available technologies.

Figure 3.11. Initial Investment Cost at the Best Power Mix

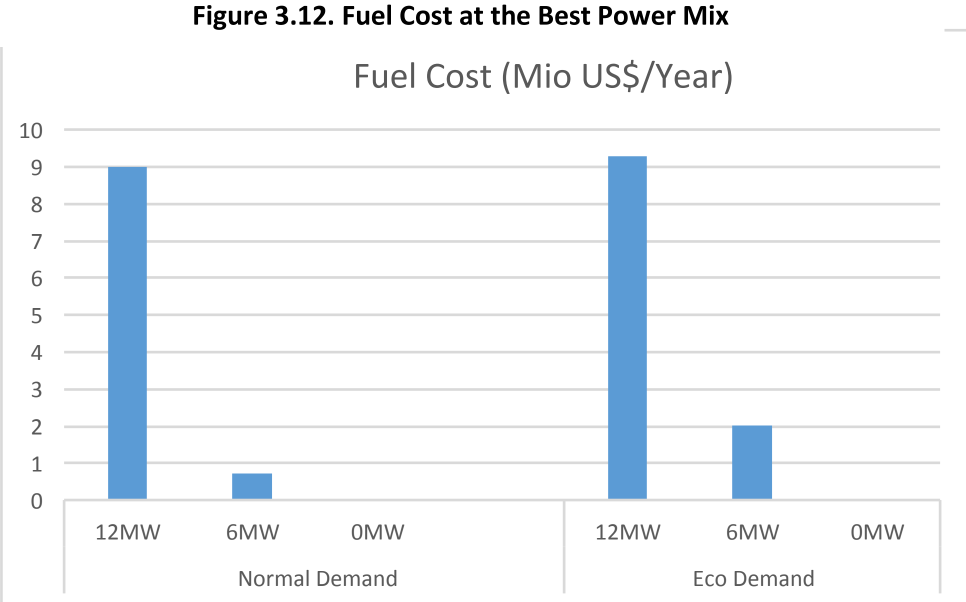


mio = million, MW = megawatt.
Source: Authors.

3.3.7. Fuel Cost at the Best Power Mix

Fuel costs of diesel generators at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated using simulation results shown in Table A3.23 to Table A3.26 of Annex 3, and the calculated results are shown in Figure 3.12. The costs are equivalent for the normal demand and the eco demand. However, these are slightly different by reflecting the diesel operation rate shown in Figure 3.8.

Figure 3.12. Fuel Cost at the Best Power Mix

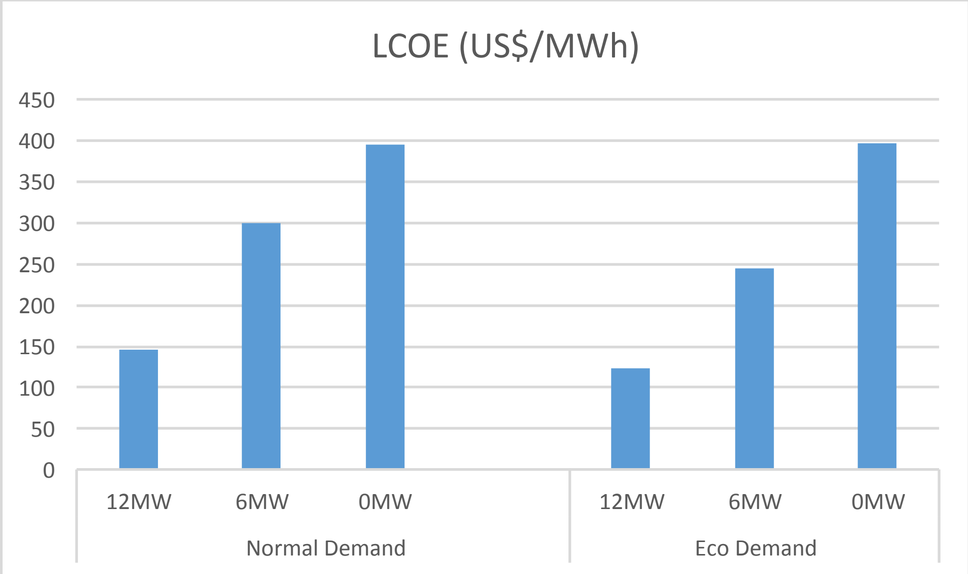


mio = million, MW = megawatt.
Source: Authors.

3.3.8. LCOE at the Best Power Mix

LCOE at the best power mix corresponding to Table 3.14 and Table 3.15 is shown in Fig. 3.13. Completely carbon-free power system with combination of solar PV and electricity storage will be very expensive although significant cost reduction of solar PV and storage is expected. Thus, gradual shifting to a carbon-free power system is a realistic energy policy in Temburong Eco Town development.

Figure 3.13. LCOE at the Best Power Mix



LCOE = levelised cost of energy, MW = megawatt, MWh = megawatt hour.
Source: Authors.

3.4. Conclusion

Operation schedule of diesel generators and electricity storage was simulated to balance demand and supply with the minimum operation cost. Considering fuel cost and investment and maintenance costs, LCOE was estimated for a given mix of power generation system. The best power mixes are identified in terms of the smallest LCOE. Diesel operation rate, solar PV load factor, storage operation rate, initial investment cost, and fuel cost are compared with the best power mixes. The analysis shows that a completely carbon-free power system with a combination of solar PV and electricity storage will be very expensive although cost reduction of solar PV and storage is expected. Therefore, a gradual shift to a carbon-free power system is recommended as a realistic energy policy in Temburong Eco Town development.

Chapter 4
Conclusion

This research study consists of mainly four parts:

(1) Data collection in Brunei Darussalam
  - Temburong district development plan
  - Hourly solar radiation data at Brunei International Airport in 2015 and 2016
  - Hourly rainfall data at Bangar, Temburong District in 2015 and 2016

(2) Assuming floor area of each type of building to be constructed as eco town
(3) Estimating hourly electricity load profile of the new buildings in 2025
(4) Seeking best capacity mix of diesel power, solar PV, and electric storage in 2025

Based on the Temburong district development plan, an ERIA energy efficiency expert assumed the following floor area of buildings to be constructed as eco town in Temburong District:

(1) Hotel: 10,000 m^2 (200 rooms)
(2) Shopping mall: 6,000 m^2 (1/3 of land area [3.2 hectare] will be developed)
(3) Government office: 4,000 m^2 (200 staff)

The expert assumed two building energy intensities (BEI), ordinary and eco, with the following details:

Type of Building	Ordinary	Eco	Unit
Office	250	120	$kWh/m^2/year$
Hotel	275	233	$kWh/m^2/year$
Hospital	300	233	$kWh/m^2/year$

Using the floor area and the BEIs, the expert did a 1-year electricity demand forecast for each building type. The expert made a breakdown of monthly electricity demand and hourly electricity load profile from 1 January to 31 December 2025 based on the existing hourly/daily/monthly load profile in Temburong District. The results show that if eco township will be applied for the construction of an eco town in Temburong District, annual electricity consumption from the buildings will be 37,327 MWh, and reduction from the ordinary township will be 16,200 MWh. It will be 30% of annual electricity consumption of the buildings applied for the ordinary township.

Based on the hourly electricity load profile of the Temburong Eco Town in 2025 and the hourly solar radiation data at Brunei International Airport in 2016, an ERIA smart-grid expert determined the best capacity mix of diesel power, solar PV, and electricity storage applying the static simulation model. The same solar radiation data were assumed for the Temburong District in 2025. The simulation study provided the following results:

(1) Although it was hot season from March to May in Brunei Darussalam, several days were rainy and deep cloudy in 2016. Thus, operation rate of solar PV will be 8%–13% due to lower radiation data.
(2) Three scenarios were conducted as the static simulation approach:

- Case 1: Diesel power (12MW) + Solar/PV + Storage
- Case 2: Diesel power (6MW) + Solar/PV + Storage
- Case 3: Solar/PV + Storage

The results show that the necessary capacity of solar PV will be 5MW–144MW and the storage will be 48MWh–540 MWh, which will have the lowest levelised cost of energy (LCOE).

(3) In Case 3, power supply will be available technically but at a very high cost, of around US$ .40 as LCOE, and it has to be owned by Temburong District.

(4) Case 1, under the eco township, will have the lowest LCOE, at US$ .12.3. It is suggested that Temburong District has to accept the use of diesel power at the initial stage and gradually increase solar PV and storage, leading to lower cost of both solar PV and storage.

This study will provide ample information for the development of Temburong Eco Town in Brunei Darussalam as regards energy efficiency of buildings and power supply using renewable energy sources. Nevertheless, several issues emerged:

(1) There is no energy conservation act in Brunei Darussalam. The Ministry of Energy and Industry is urgently requested to propose a law on energy conservation and clearly specify the application of Green Building Index (GBI) to newly constructed buildings in Brunei Darussalam.

(2) Developing energy managers is also an urgent action plan. Energy managers will apply passive and active energy efficiency technologies to buildings and promote GBI in Brunei Darussalam.

(3) The hourly solar radiation data in 2016 are not enough. Based on 5–10 years solar radiation data, normal distribution of solar radiation will be produced and will forecast solar radiation of next hour applying the Monte Carlo simulation approach.

(4) Future cost of solar PV and storage is needed to forecast technology development.

It is gratifying that this study could contribute to the development of an eco town in Temburong District.

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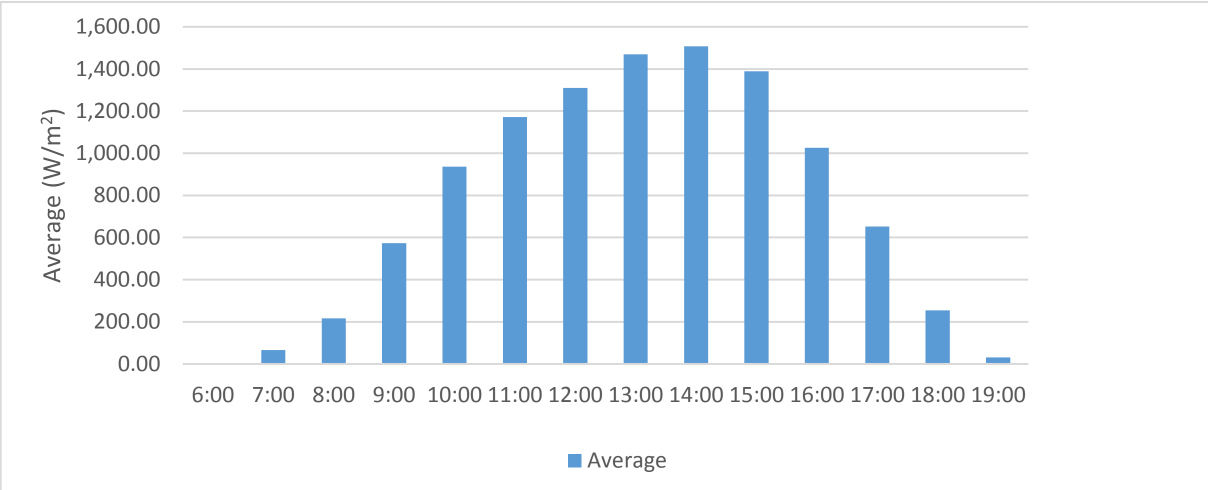
Annex 1
Hourly Solar Radiation

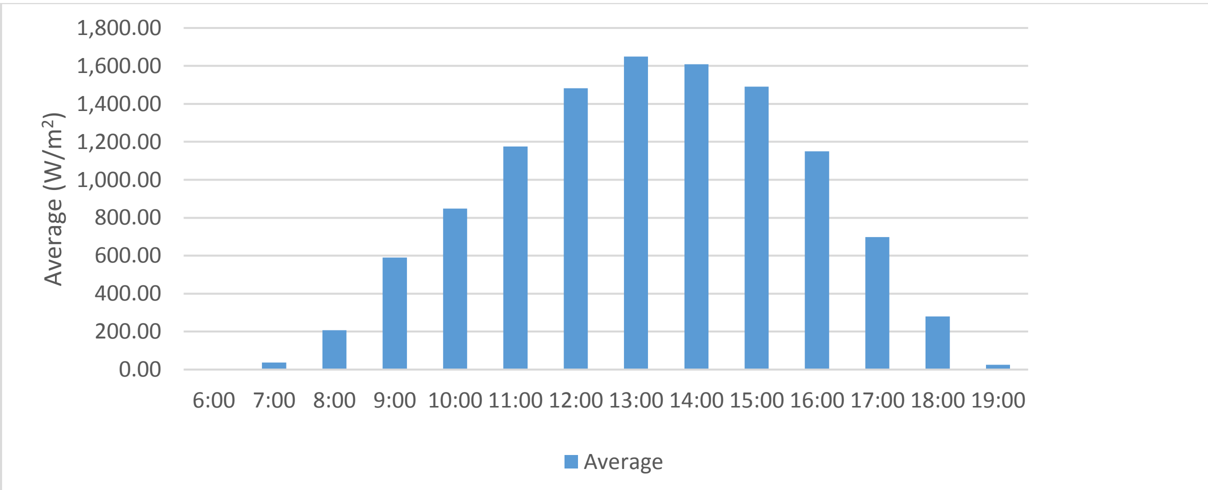
Annex 1 provides hourly solar radiation data in Brunei Darussalam in 2016. Brunei Darussalam Meteorological Department recorded the solar radiation data in Brunei International Airport meteorological station. The trend of monthly average daily solar radiation in 2015–2016 is shown in Figure 1.1, Chapter 1.

Figure A1.1. Average Hourly and Maximum Solar Radiation, January 2016 (W/m^2)



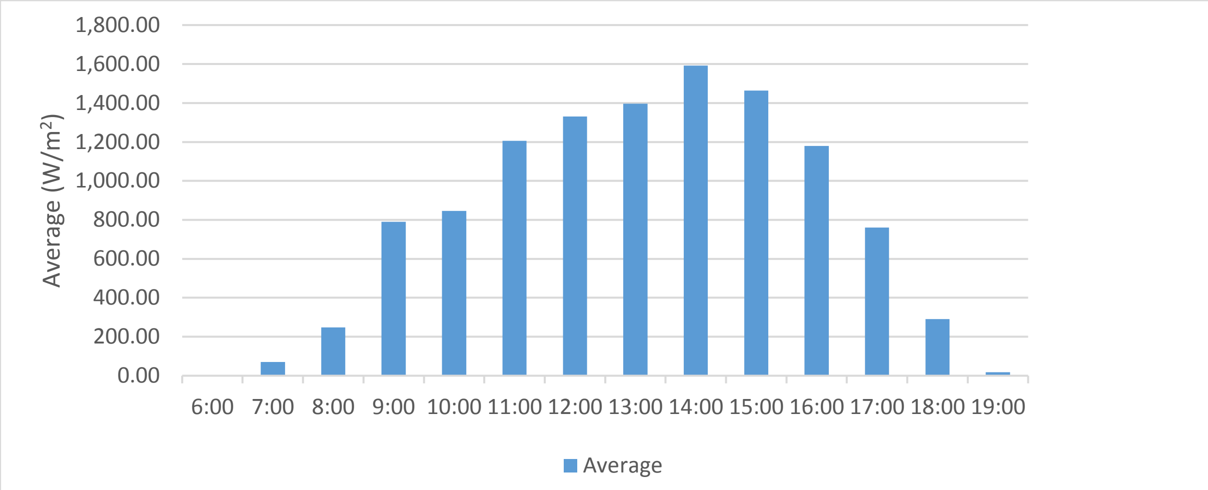
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.2. Average Hourly and Maximum Solar Radiation, February 2016 (W/m^2)



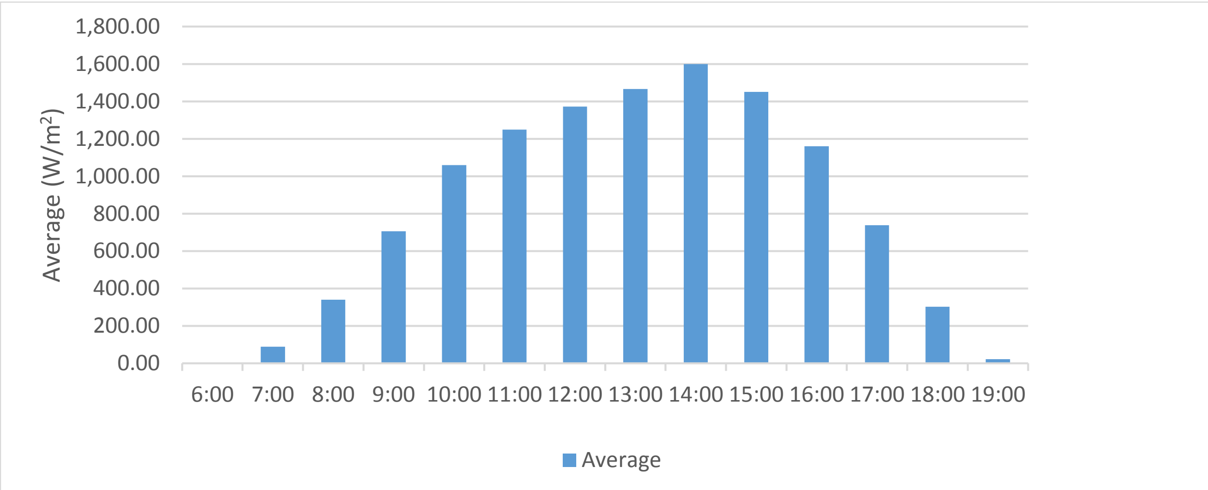
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.3. Average Hourly and Maximum Solar Radiation, March 2016 (W/m²)



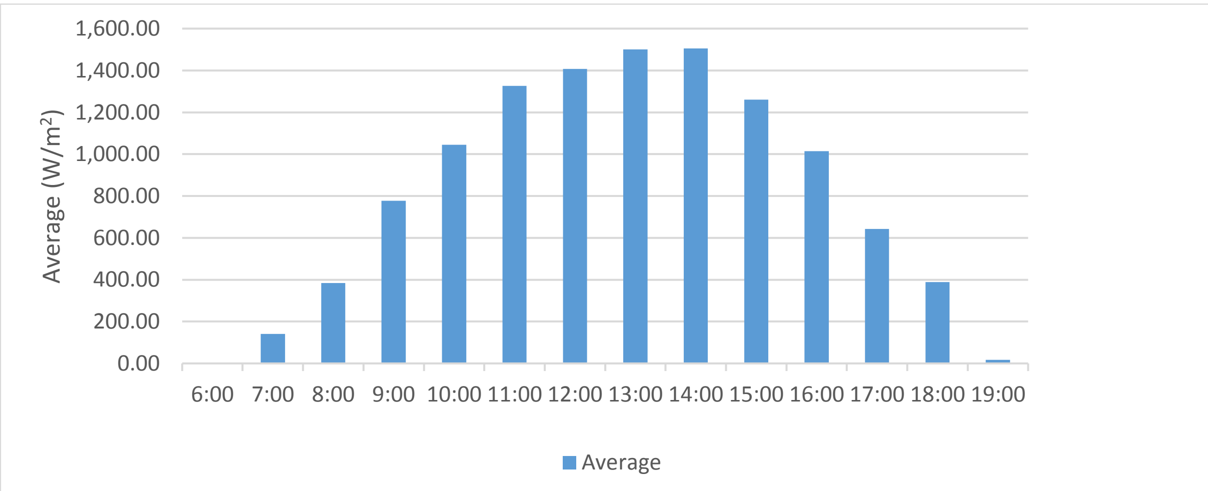
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.4. Average Hourly and Maximum Solar Radiation, April 2016 (W/m²)



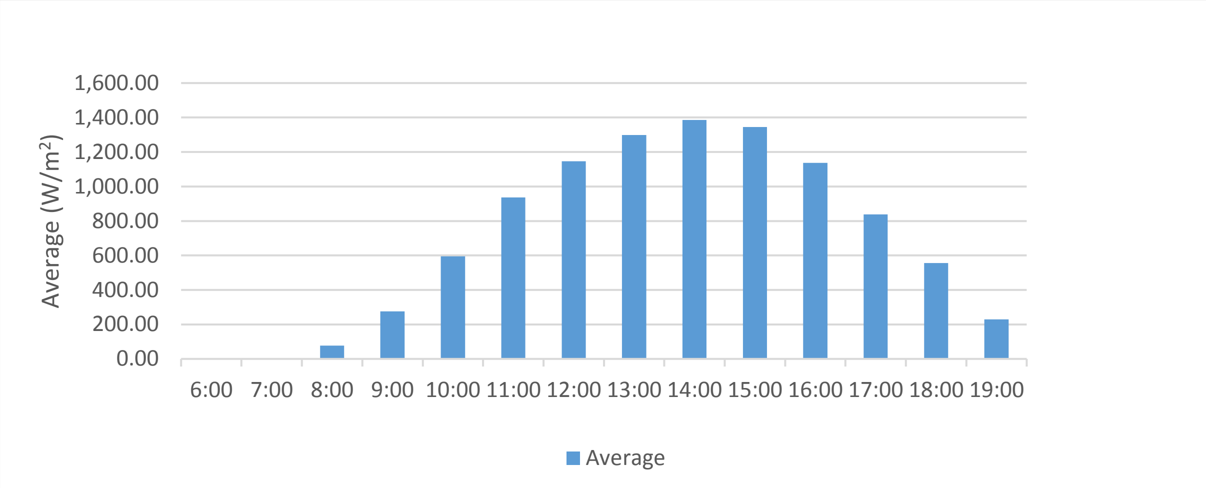
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.5. Average Hourly and Maximum Solar Radiation, May 2016 (W/m²)



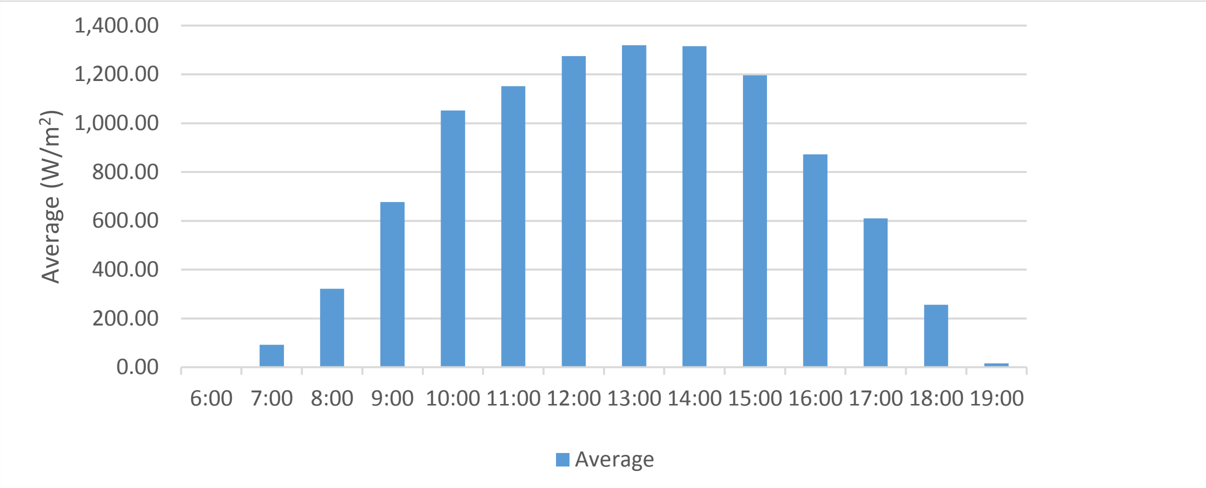
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.6. Average Hourly and Maximum Solar Radiation, June 2016 (W/m²)



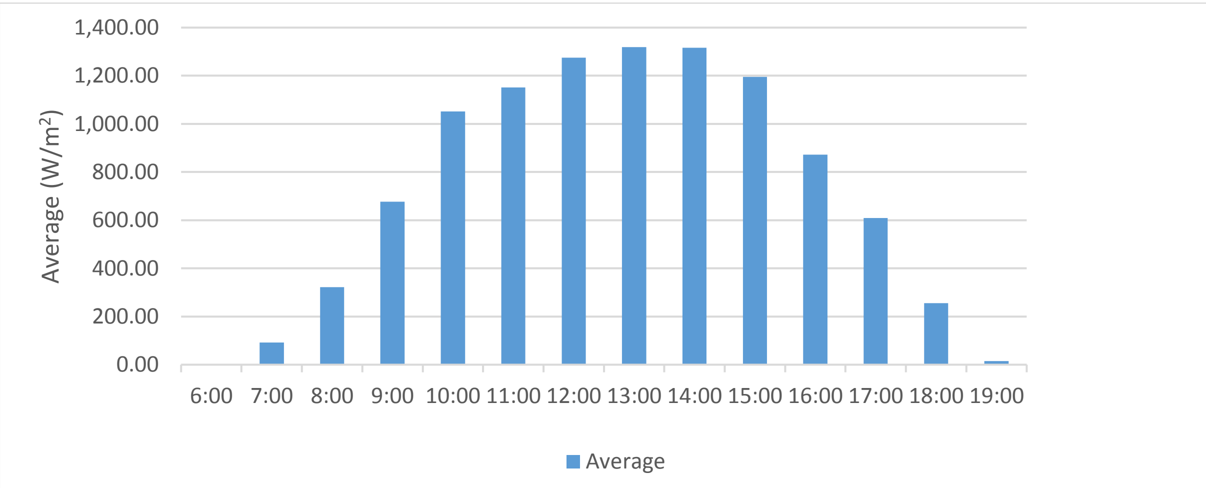
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.7. Average Hourly and Maximum Solar Radiation, July 2016 (W/m²)



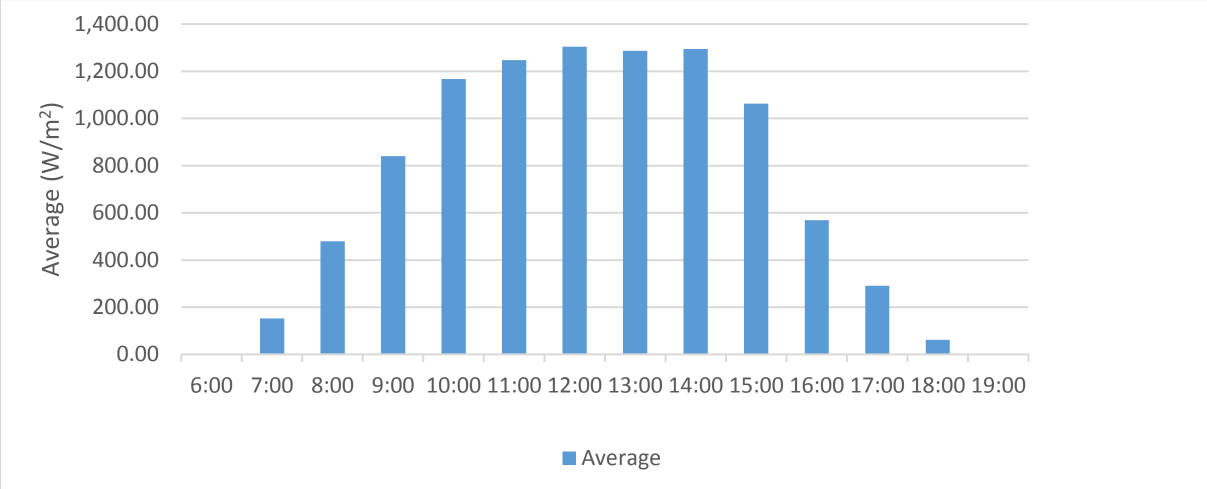
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.8. Average Hourly and Maximum Solar Radiation, August 2016 (W/m²)



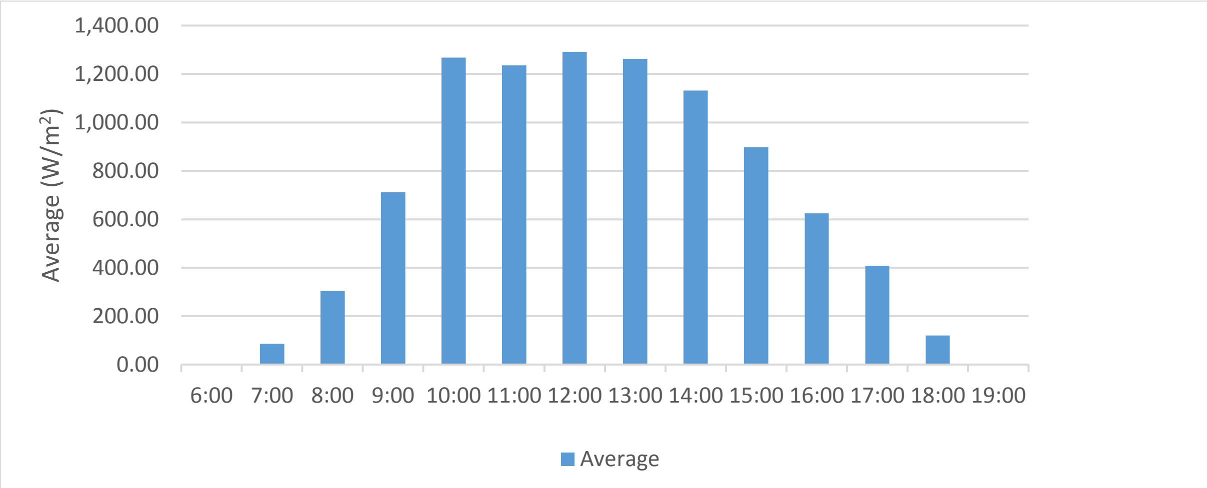
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.9. Average Hourly and Maximum Solar Radiation, September 2016 (W/m²)



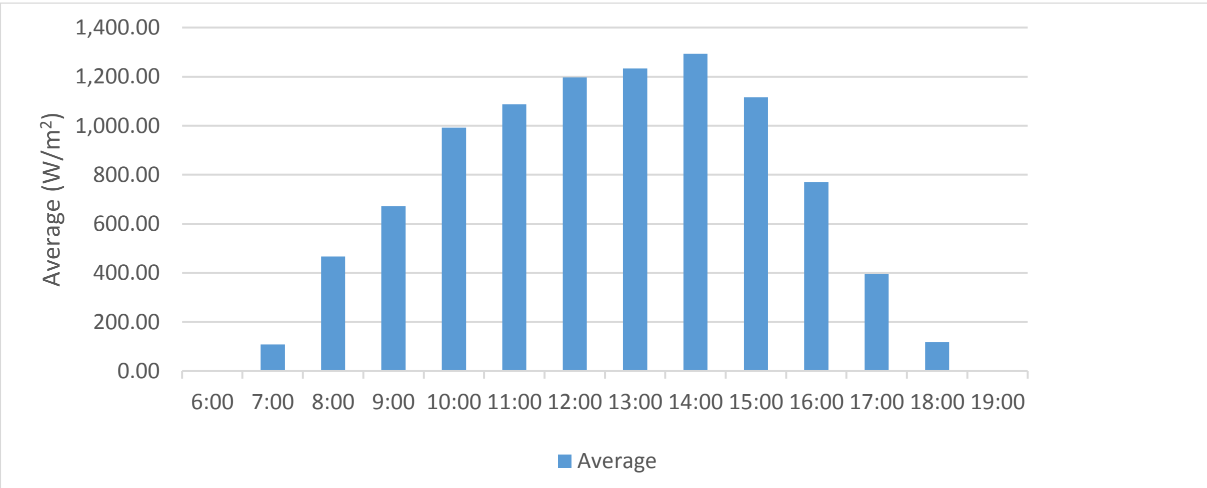
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.10. Average Hourly and Maximum Solar Radiation, October 2016 (W/m²)



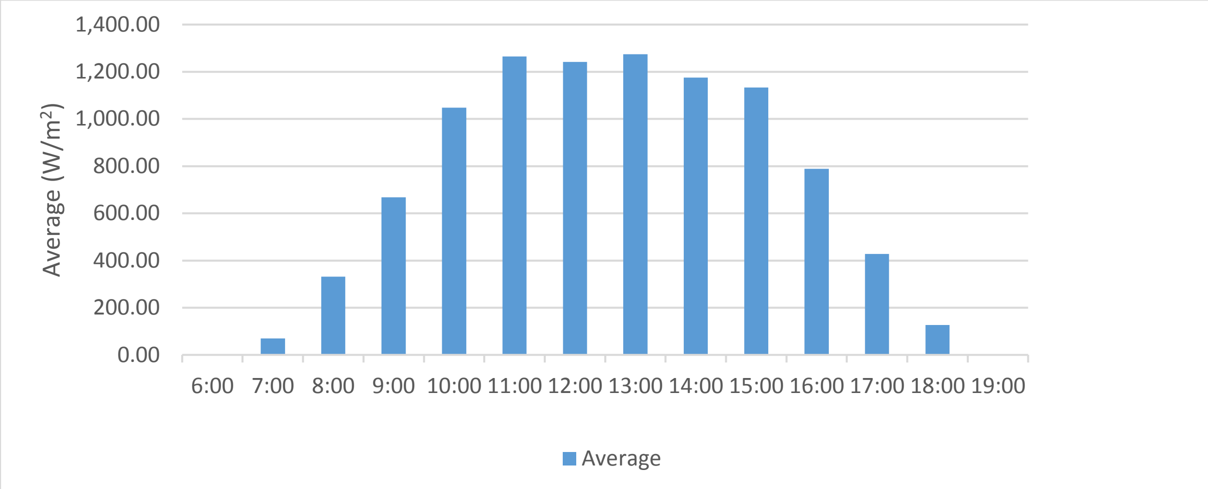
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.11. Average Hourly and Maximum Solar Radiation, November 2016 (W/m²)



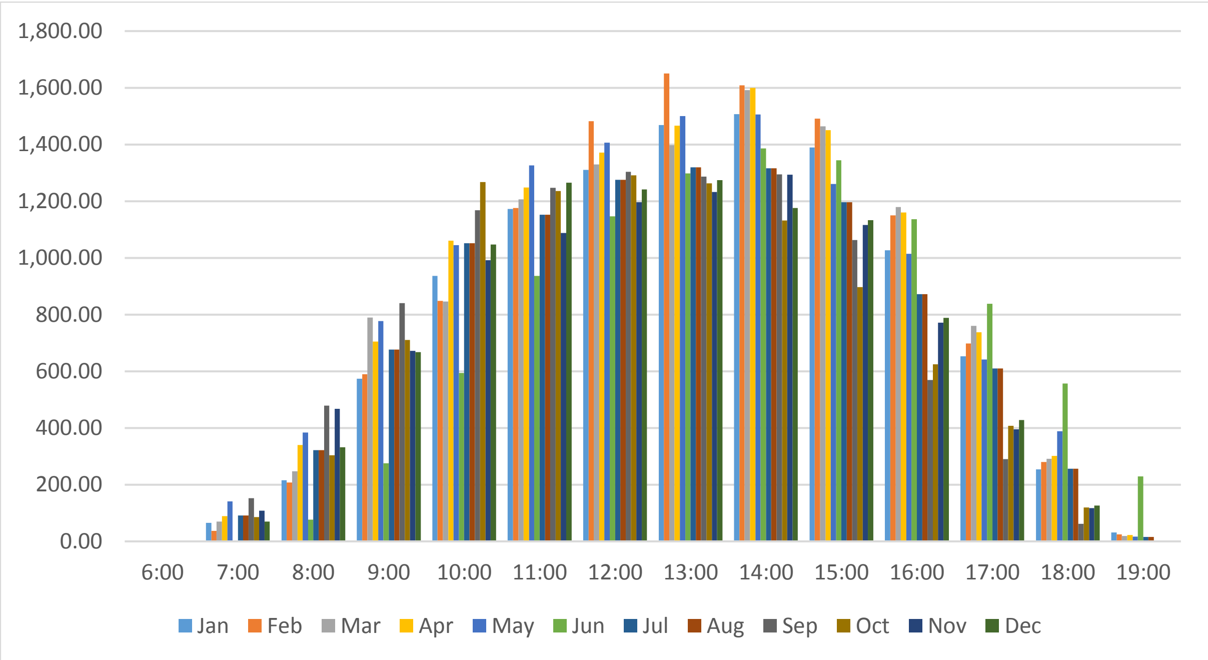
Source: Brunei International Airport Meteorological Station (2016).

Figure A1.12. Average Hourly and Maximum Solar Radiation, December 2016 (W/m²)



Source: Brunei International Airport Meteorological Station (2016).

Figure A1.13. Average Hourly Solar Radiation within 12 Months (W/m²)



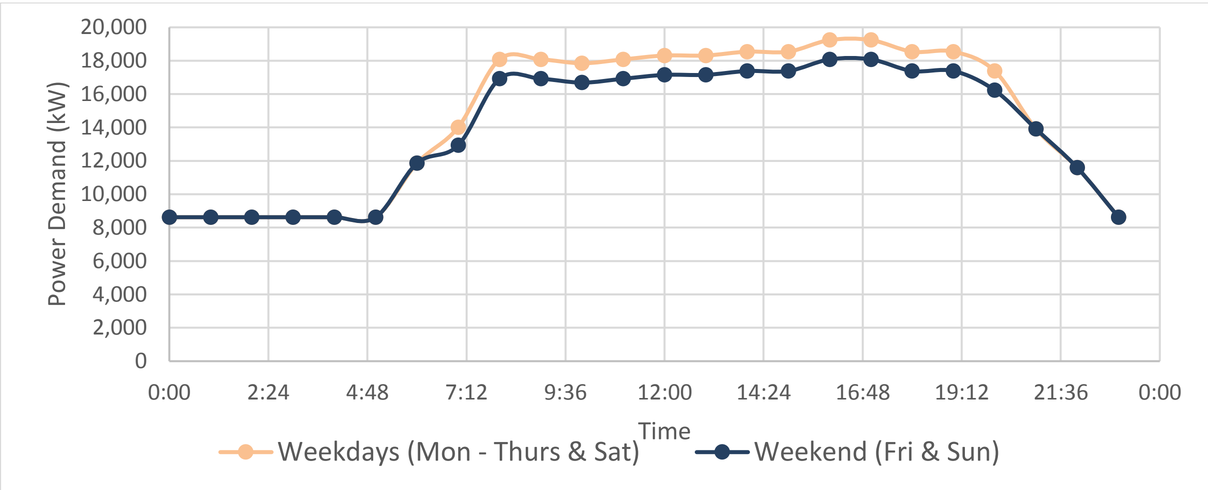
Source: Brunei International Airport Meteorological Station (2016).

Annex 2
Forecast of Hourly Electricity Load Demand Profile in Temburong District (2025)

Annex 2 provides forecast data of hourly electricity load demand profile from January to December 2025 using two scenarios, normal development and eco development, to support data presentation in Chapter 2. The electricity demand forecast of Temburong Eco Town in 2025 was based on the information and interpretation of data provided in the Temburong District Plan 2006–2025 published by the Department of Town and Country Planning, Ministry of Development, Brunei Darussalam. The forecast of monthly electricity demand trends in 2025 for both scenarios are based on the electricity demand trends in 2016.

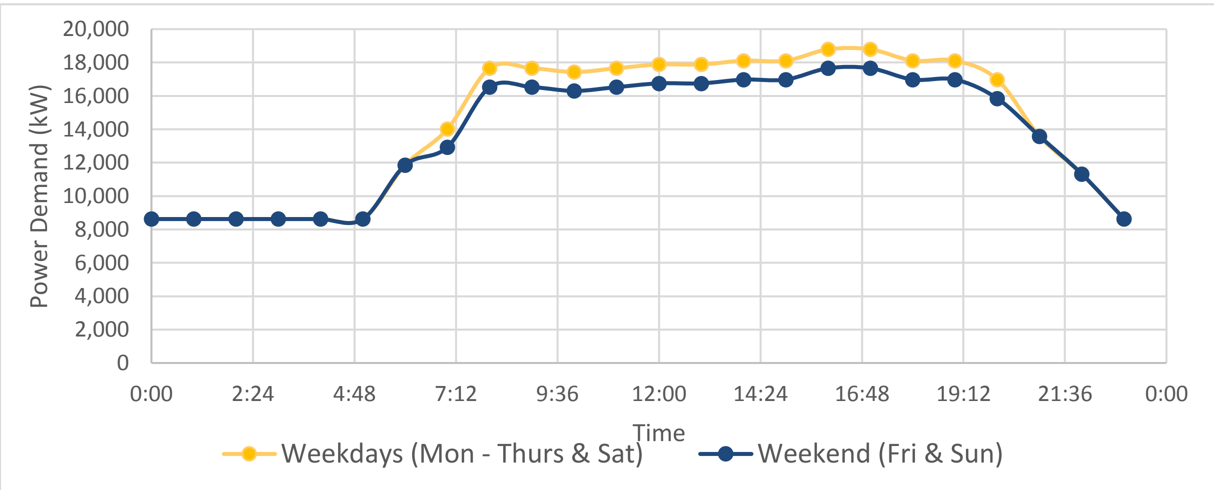
Forecast of Electricity Demand in Temburong Area in 2025 with 12-Month Normal Township Development Scenario

Figure A2.1. Daily Electricity Load Demand Profile, January 2025 (W/m²)



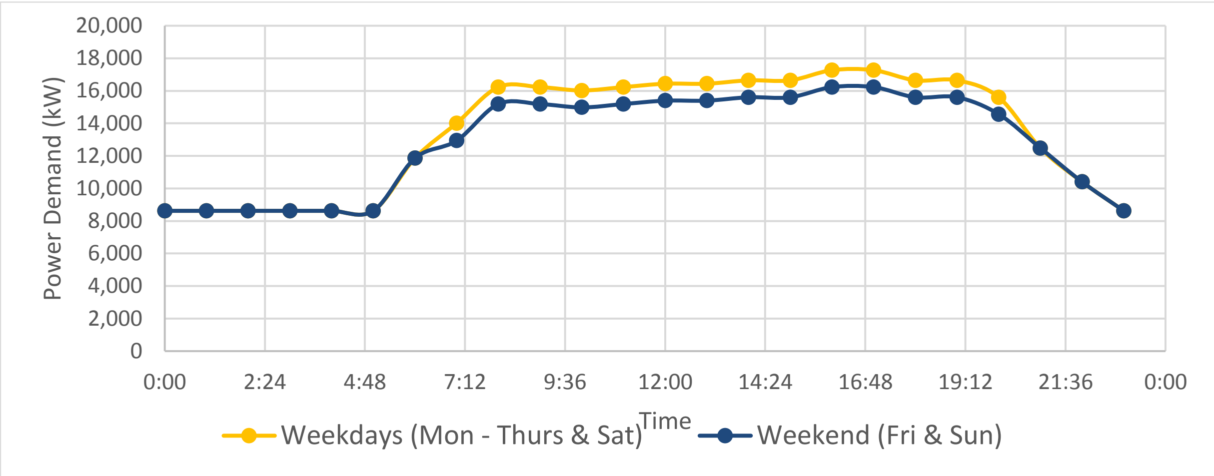
Source: Authors.

Figure A2.2. Daily Electricity Load Demand Profile, February 2025 (W/m²)



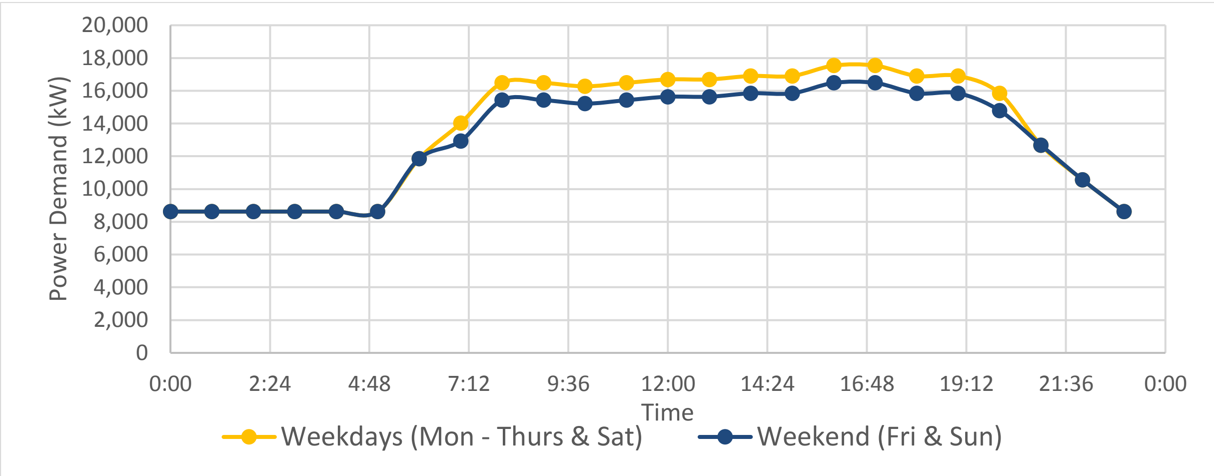
Source: Authors.

Figure A2.3. Daily Electricity Load Demand Profile, March 2025 (W/m²)



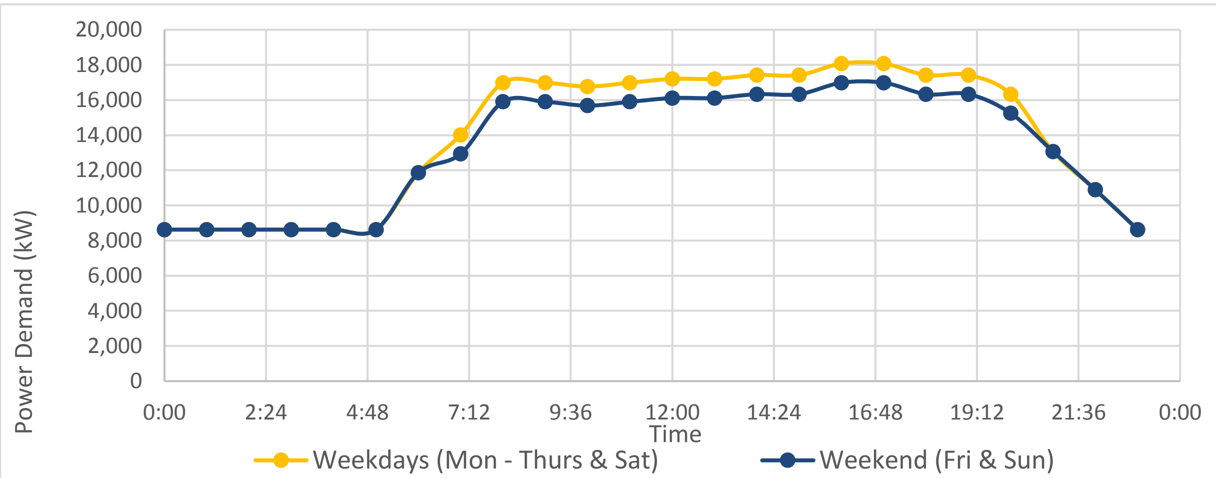
Source: Authors.

Figure A2.4. Daily Electricity Load Demand Profile, April 2025 (W/m²)



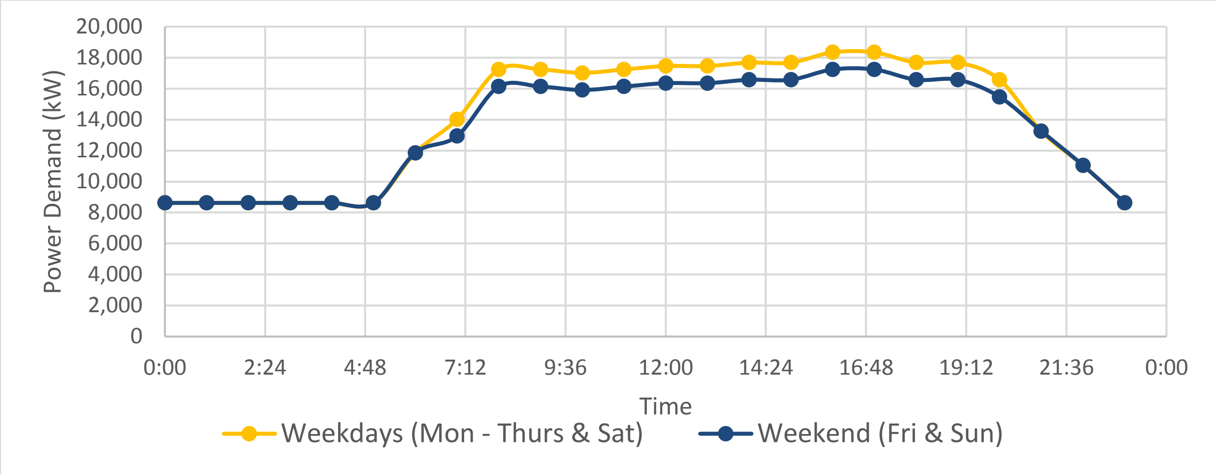
Source: Authors.

Figure A2.5. Daily Electricity Load Demand Profile, May 2025 (W/m²)



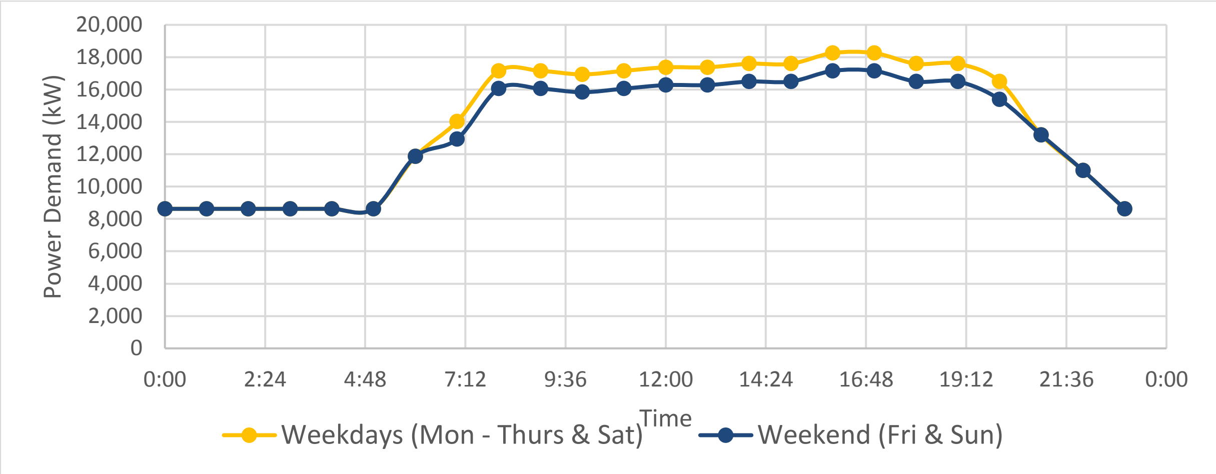
Source: Authors.

Figure A2.6. Daily Electricity Load Demand Profile, June 2025 (W/m^2)



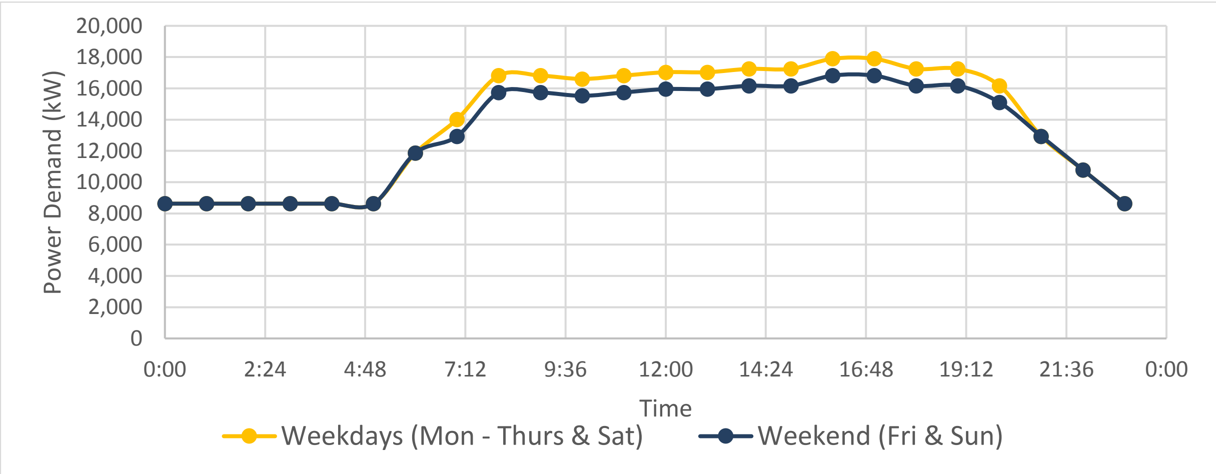
Source: Authors.

Figure A2.7. Daily Electricity Load Demand Profile, July 2025 (W/m^2)



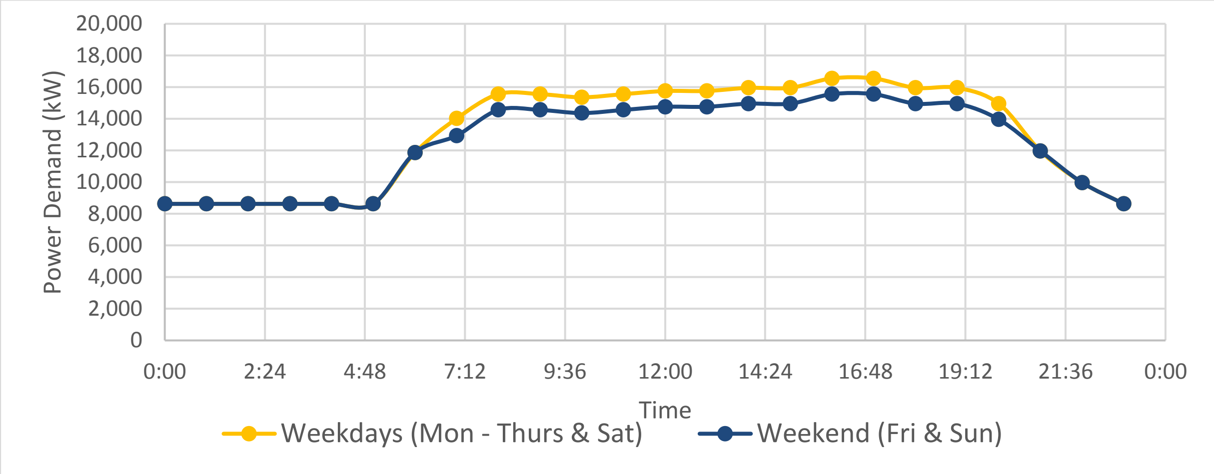
Source: Authors.

Figure A2.8. Daily Electricity Load Demand Profile, August 2025 (W/m^2)



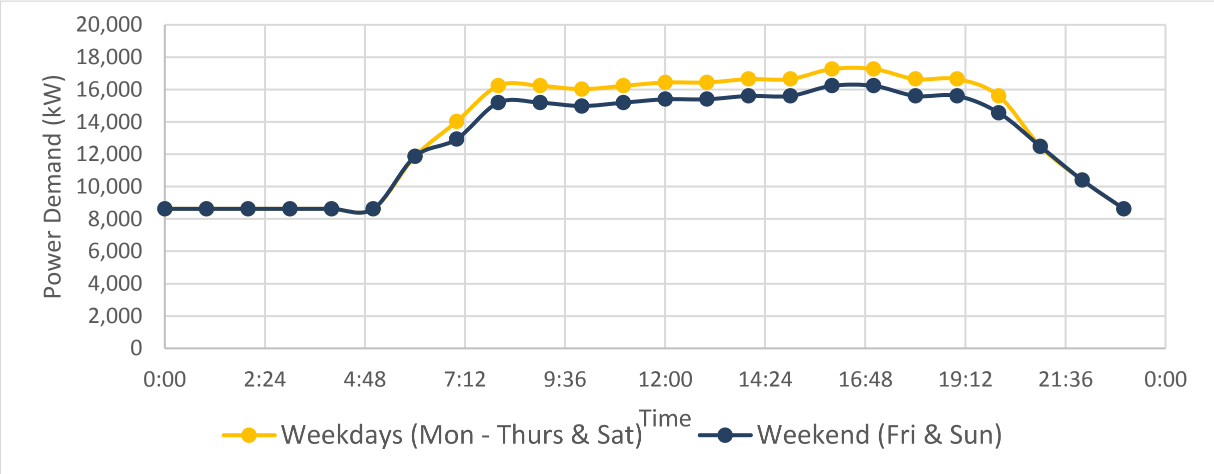
Source: Authors.

Figure A2.9. Daily Electricity Load Demand Profile, September 2025 (W/m²)



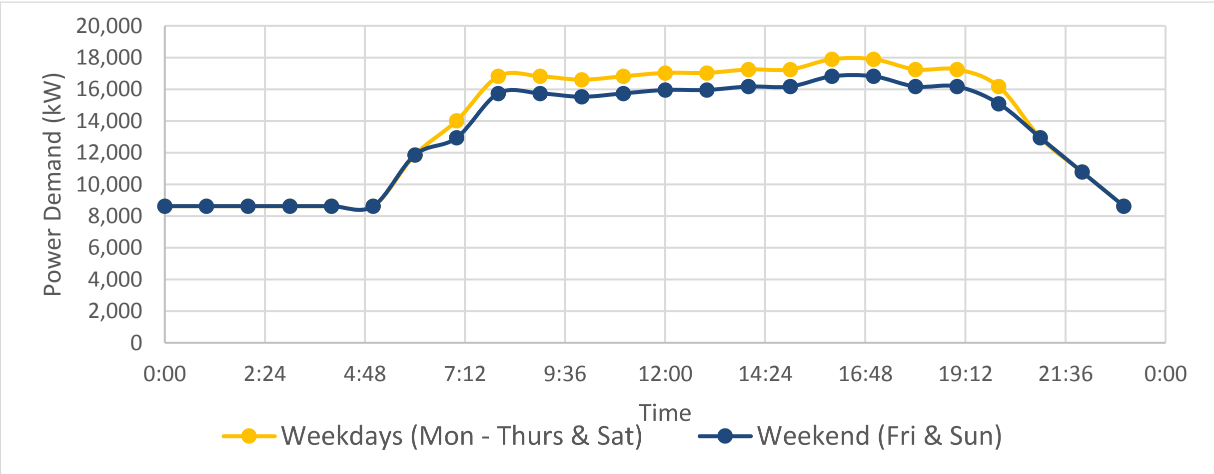
Source: Authors.

Figure A2.10. Daily Electricity Load Demand Profile, October 2025 (W/m²)



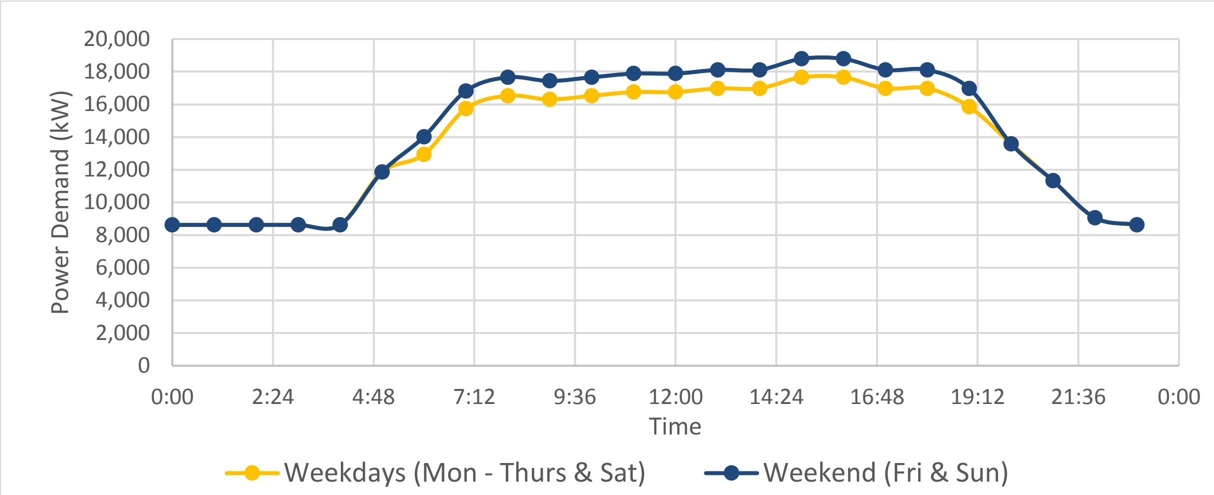
Source: Authors.

Figure A2.11. Daily Electricity Load Demand Profile, November 2025 (W/m²)



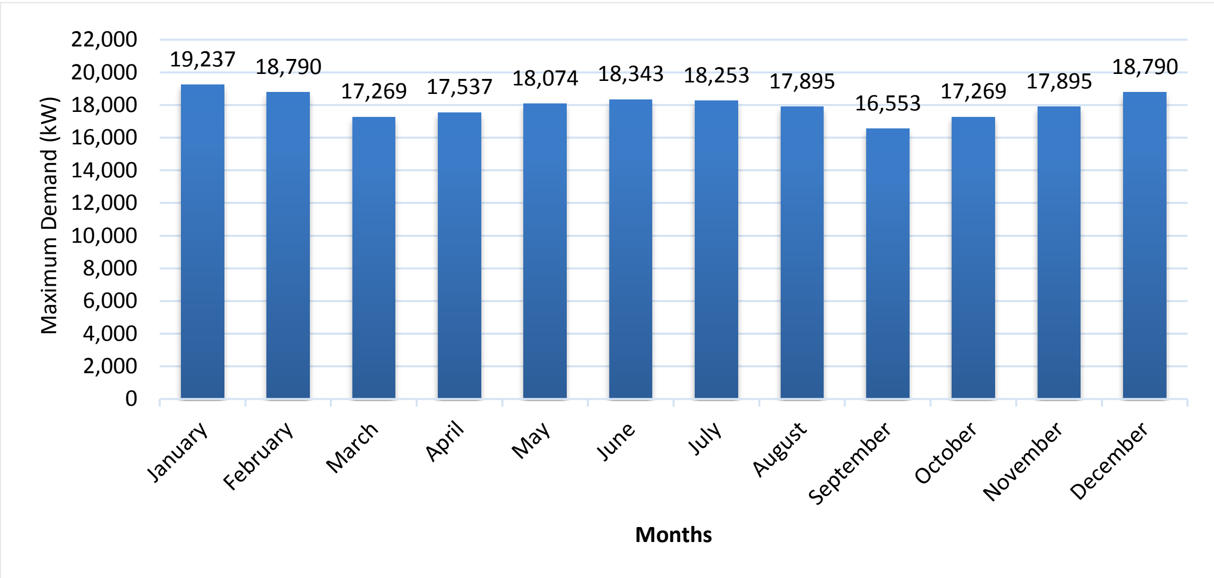
Source: Authors.

Figure A2.12. Daily Electricity Load Demand Profile, December 2025 (W/m^2)



Source: Authors.

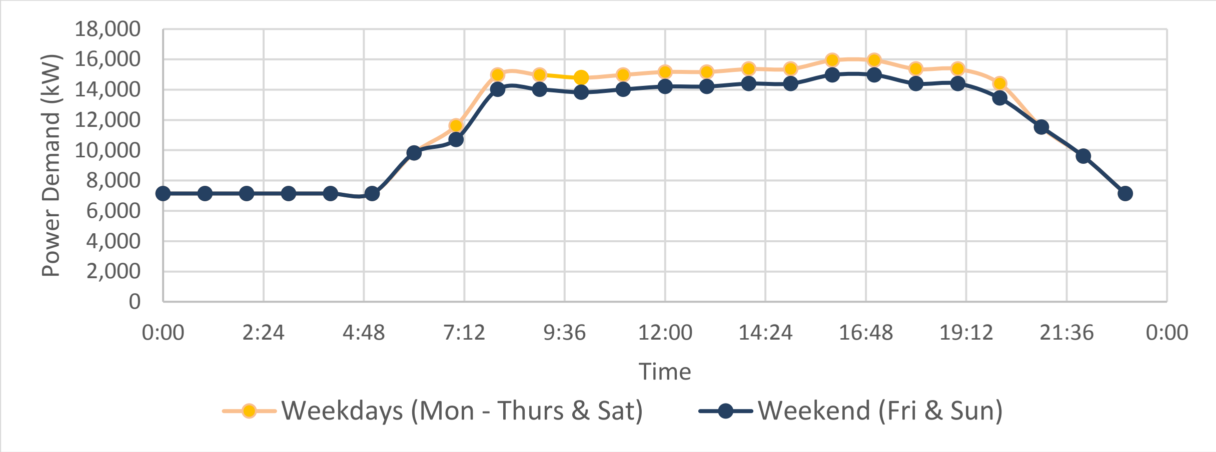
Figure A2.13. Forecast of Maximum Demand per Month, January–December 2025 (W/m^2)



Source: Authors.

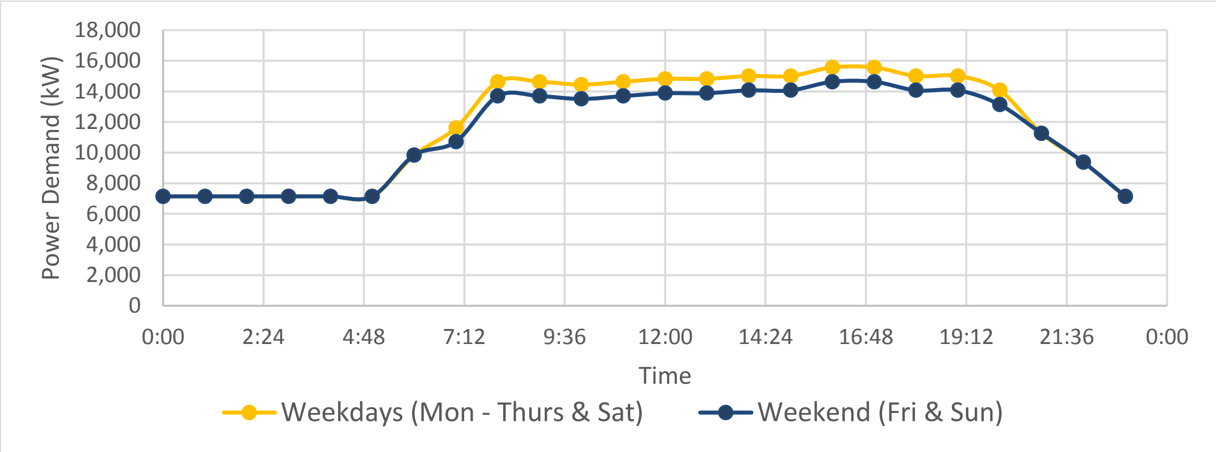
Forecast of Electricity Demand in Temburong Area in 2025
with 12-Month Eco Development Scenario

Figure A2.14. Daily Electricity Load Demand Profile, January 2025 (W/m²)



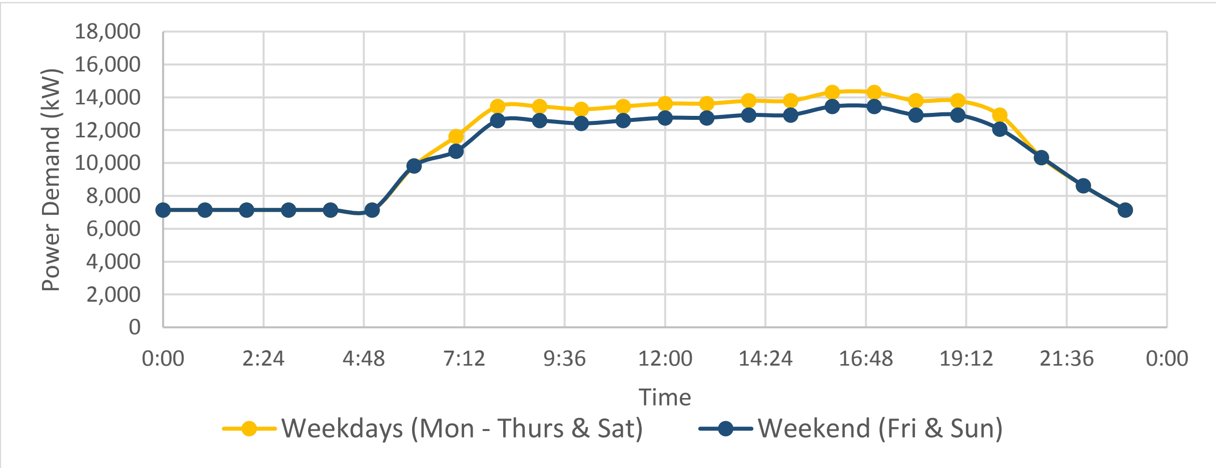
Source: Authors.

Figure A2.15. Daily Electricity Load Demand Profile, February 2025 (W/m²)



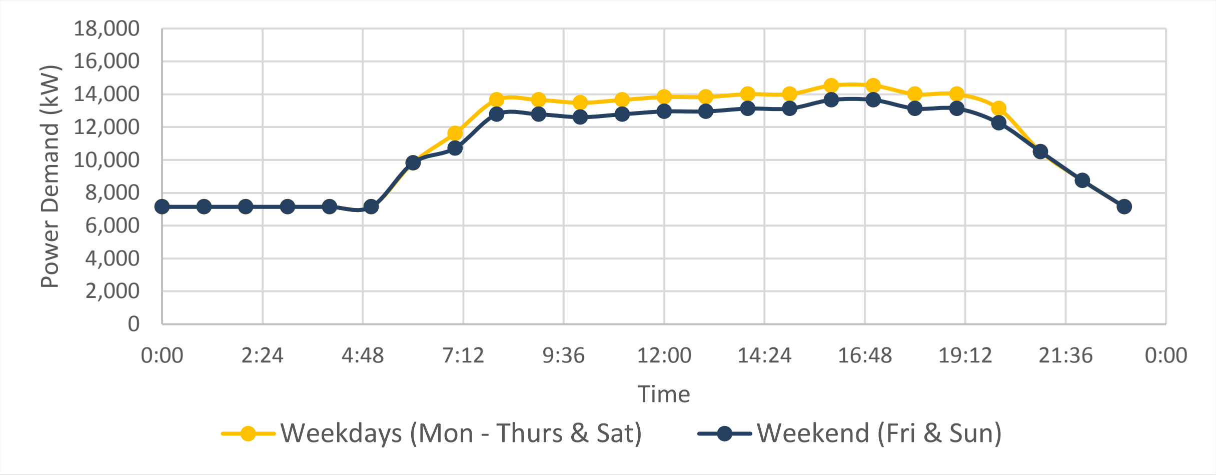
Source: Authors.

Figure A2.16. Daily Electricity Load Demand Profile, March 2025 (W/m²)



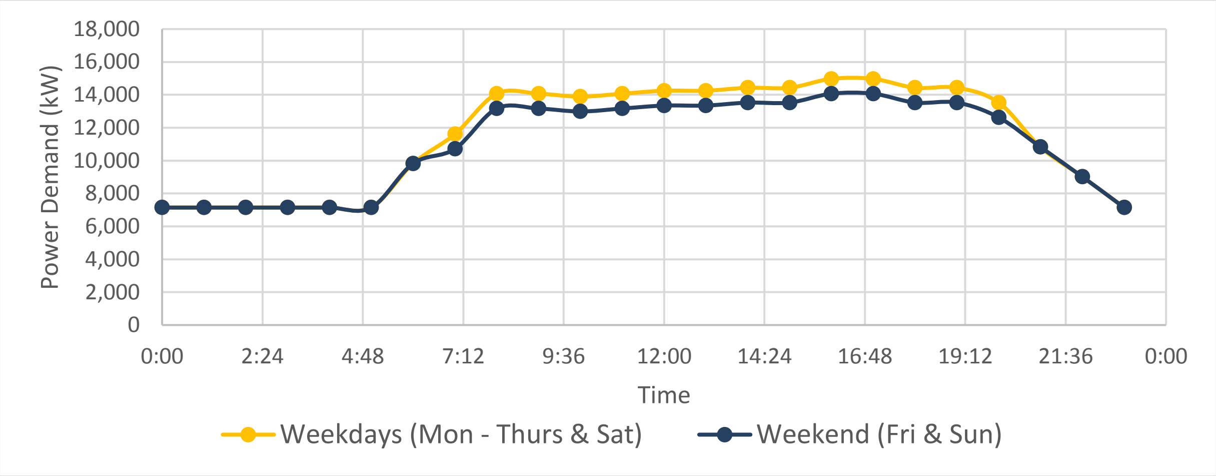
Source: Authors.

Figure A2.17. Daily Electricity Load Demand Profile, April 2025 (W/m²)



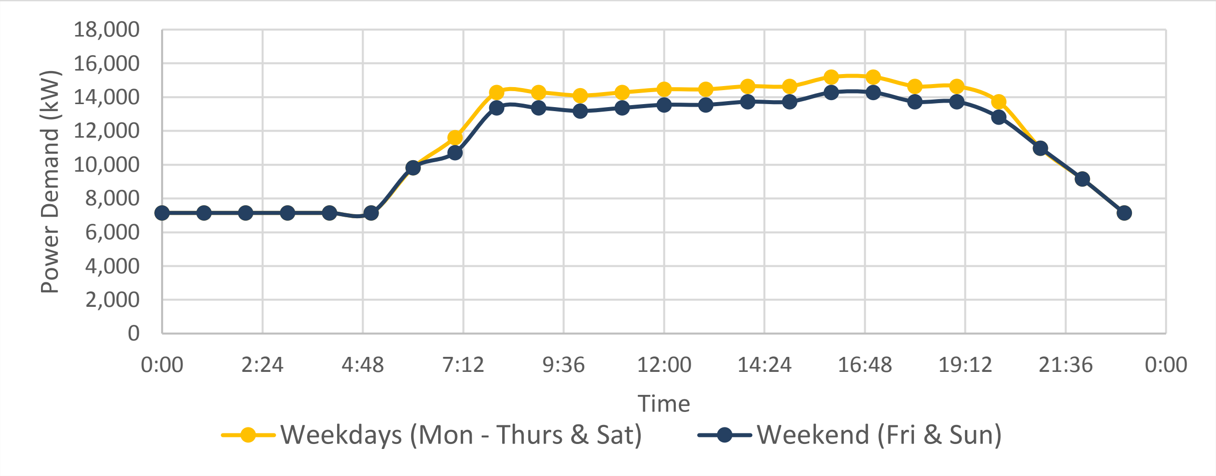
Source: Authors.

Figure A2.18. Daily Electricity Load Demand Profile, May 2025 (W/m²)



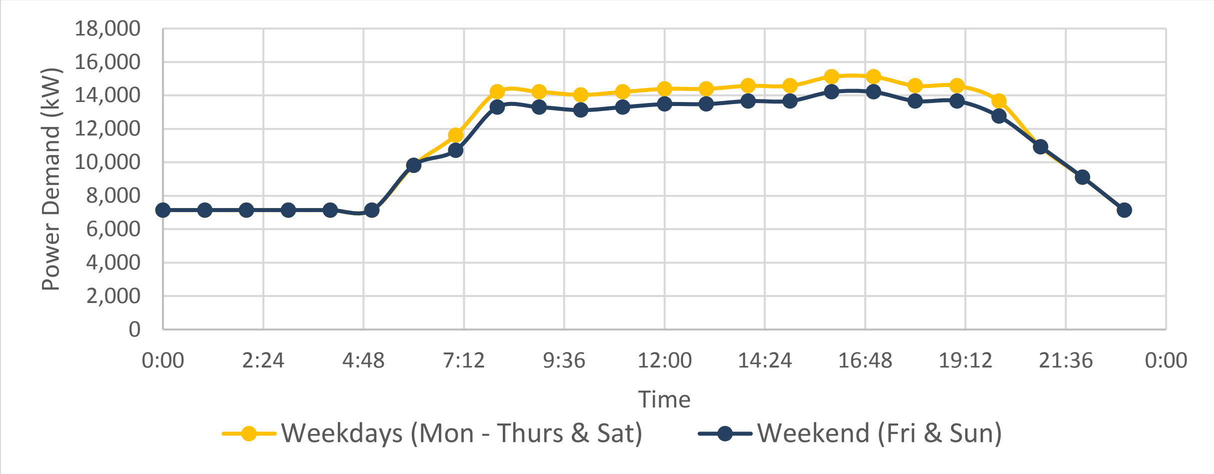
Source: Authors.

Figure A2.19. Daily Electricity Load Demand Profile, June 2025 (W/m²)



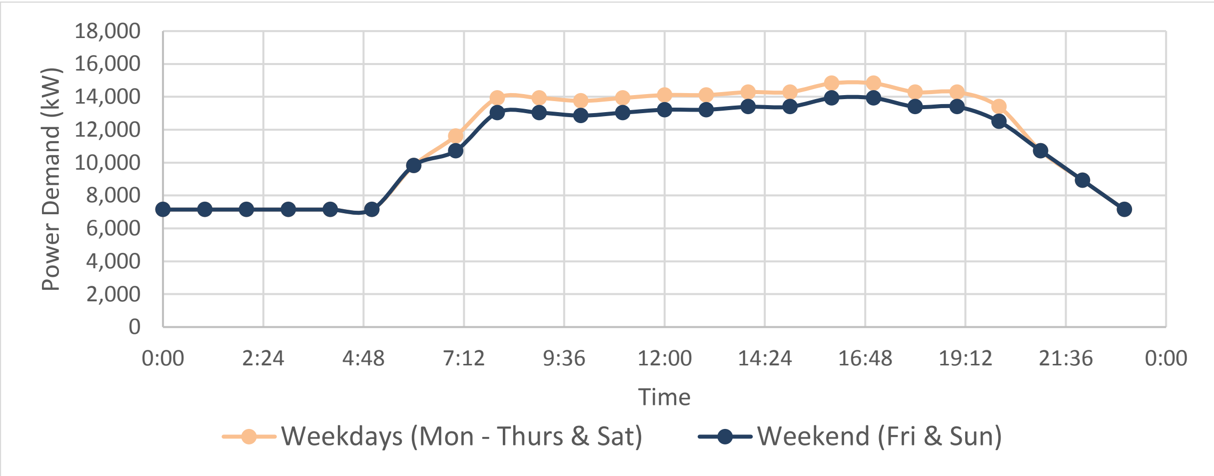
Source: Authors.

Figure A2.20. Daily Electricity Load Demand Profile, July 2025 (W/m²)



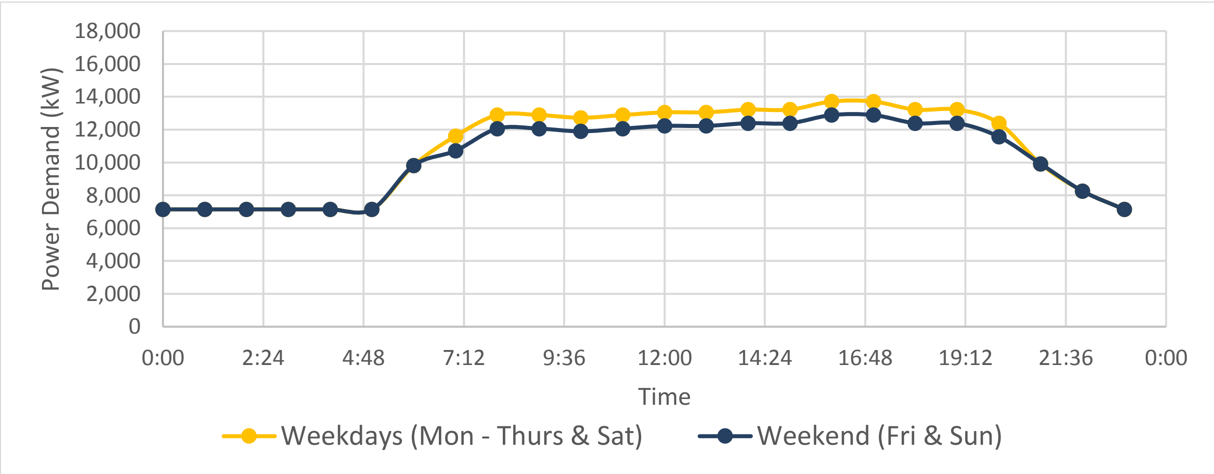
Source: Authors.

Figure A2.21. Daily Electricity Load Demand Profile, August 2025 (W/m²)



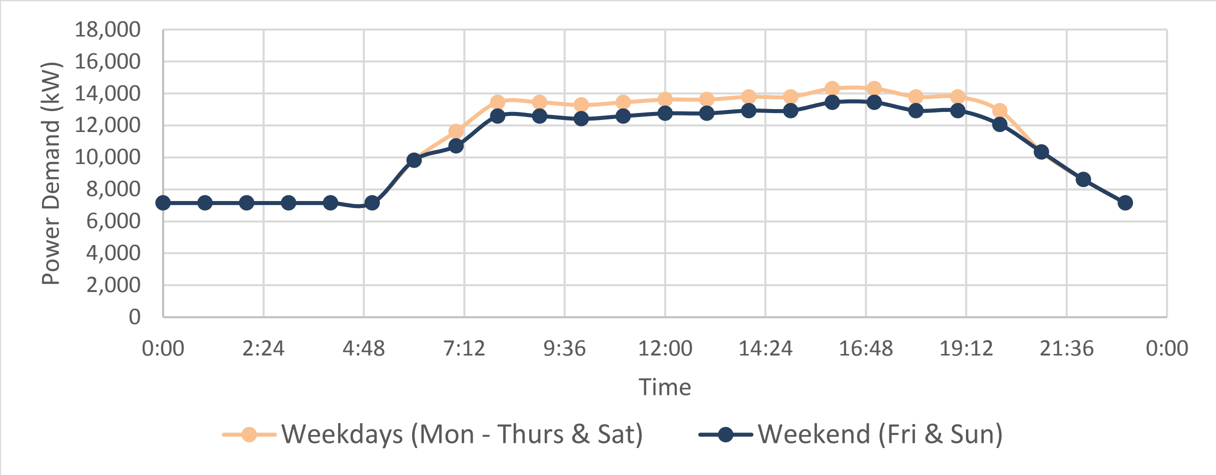
Source: Authors.

Figure A2.22. Daily Electricity Load Demand Profile, September 2025 (W/m²)



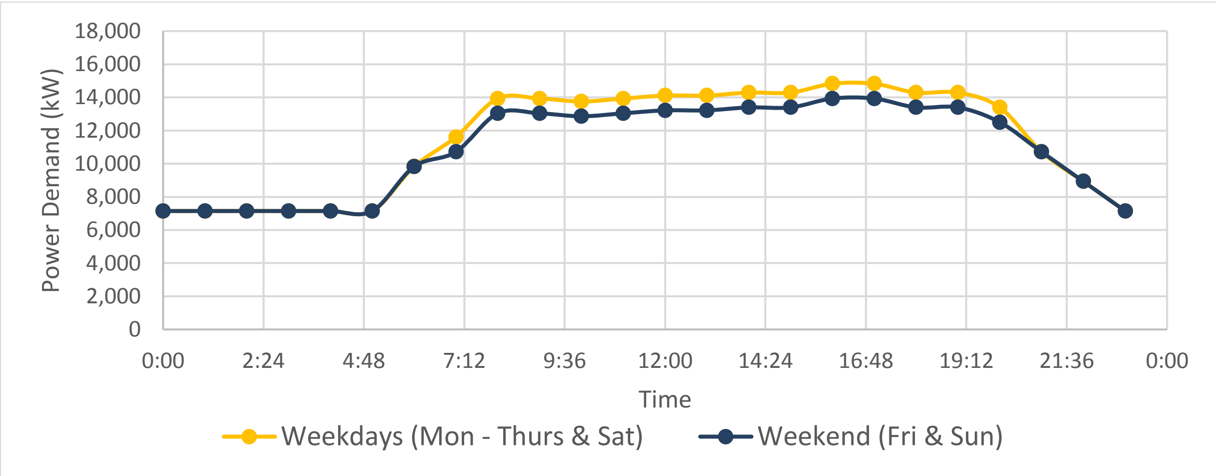
Source: Authors.

Figure A2.23. Daily Electricity Load Demand Profile, October 2025 (W/m²)



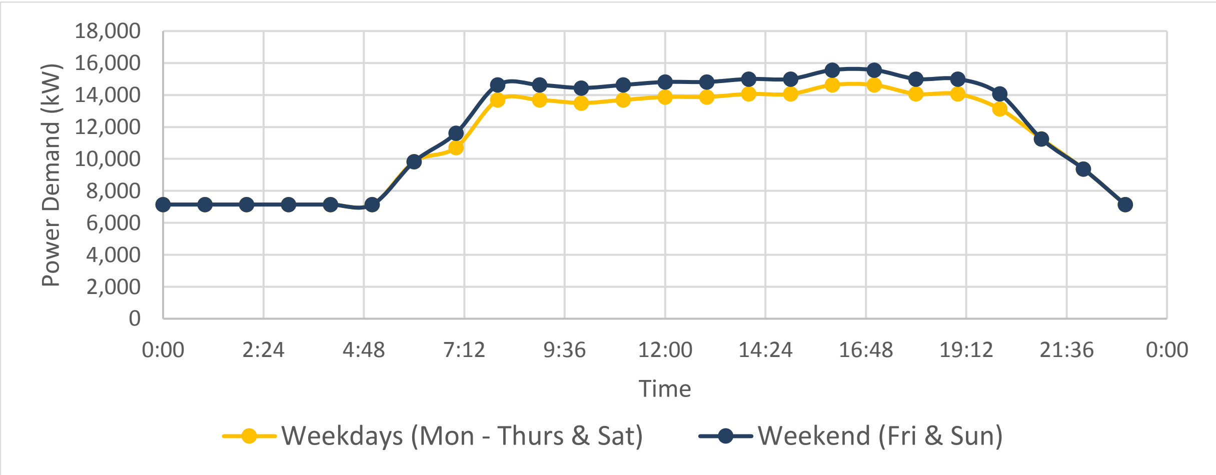
Source: Authors.

Figure A2.24. Daily Electricity Load Demand Profile, November 2025 (W/m²)



Source: Authors.

Figure A2.25. Daily Electricity Load Demand Profile, December 2025 (W/m²)



Source: Authors.

Figure A2.26. Forecast of Maximum Demand per Month, January–December 2025 (W/m²)

Source: Authors.

Annex 3
Additional Results on Electricity Supply in Temburong Eco Town

Operation schedule of diesel generators and electricity storage with minimum fuel cost of diesel generator was simulated using the model shown in Figure 1 and for the scenarios of solar PV and electricity storage described in Table 3.1 to Table 3.6 of Chapter 3. The scenarios from which demand supply balance was not obtained for the given capacities of solar PV and electricity storage are indicated by 'infeasible'.

I. Generated Electricity of Diesel Generator

Generated electricity of diesel generator is shown for each of the various capacities of PV and electricity storage in Table A3.1. to Table A3.5. Using these results, operation rates of diesel generators at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated and shown in Figure 3.8 of Chapter 3.

Table A3.1. Generated Electricity by Diesel Generator with D=12MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	93098	93098
38	Infeasible	Infeasible	74055	73982	73971
53	Infeasible	61914	59789	58500	57984
67	Infeasible	55287	51852	49081	47588

Source: Authors.

Table A3.2. Generated Electricity by Diesel Generator with D=12MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	95897	95897
19	Infeasible	76264	76264	76264
34	Infeasible	58893	58272	58141

Source: Authors.

Table A3.3. Generated Electricity by Diesel Generator with D=6MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	7434	5310
144	Infeasible	5579	2820	1404
168	Infeasible	2986	1204	480

Source: Authors.

Table A3.4. Generated Electricity by Diesel Generator with D=6MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	20896	20380
96	Infeasible	15120	9902	6804	4944
120	Infeasible	9703	4445	1901	831

Source: Authors.

Table A3.5. Generated Electricity by Solar PV with D=12MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	26729	26729
38	Infeasible	Infeasible	45772	45844	45856
53	Infeasible	57913	60037	61327	61843
67	infeasible	64540	67974	70746	72239

Source: Authors.

II. Generated Electricity by Solar PV

Generated electricity by solar PV is shown for each of the various capacities of PV and electricity storage in Table A3.6 to Table A3.10. Using these results, solar PV load factor at the best power mix corresponding to Table 3.14 and Table 3.15 is calculated and shown in Figure 3.9 of Chapter 3.

Table A3.6. Generated Electricity by Solar PV with D=12MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	3379	3379
19	Infeasible	23011	23011	23011
34	Infeasible	40383	41004	41135

Source: Authors.

Table A3.7. Generated Electricity by Solar PV with D=6MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	112393	114517
144	Infeasible	114248	117007	118423
168	Infeasible	116841	118622	119347

Source: Authors.

Table A3.8. Generated Electricity by Solar PV with D=6MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	78380	78896
96	Infeasible	84156	89374	92472	94331
120	Infeasible	89573	94831	97375	98445

Source: Authors.

Table A3.9. Generated Electricity by Solar PV with D=0MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	450	480	510	540	570
120	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
144	Infeasible	Infeasible	Infeasible	119827	119827
168	Infeasible	119827	119827	119827	119827
192	Infeasible	119827	119827	119827	119827

Source: Authors.

Table A3.10. Generated Electricity by Solar PV with D=0MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	360	390	420	450	480
96	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	Infeasible	99276	99276
144	Infeasible	99276	99276	99276	99276
168	Infeasible	99276	99276	99276	99276

Source: Authors.

III. Average Charged Electricity in Storage

Average charged electricity in storage is shown for each of the various capacities of PV and electricity storage in Table A3.11 to Table A3.16. Using these results, average values of storage operation rate at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated and shown in Figure 3.10 of Chapter 3.

Table A3.11. Average Charged Electricity in Storage with D=12MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	30	35
38	Infeasible	Infeasible	24	31	36
53	Infeasible	16	22	29	35
67	Infeasible	15	23	31	35

Source: Authors.

Table A3.12. Average Charged Electricity in Storage with D=12MW for Eco Demand (MWh)

PV(MW)\ Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	22	32
19	Infeasible	11	20	27
34	Infeasible	11	18	28

Source: Authors.

Table A3.13. Average Charged Electricity in Storage with D=6MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	90	103
144	Infeasible	79	89	99
168	Infeasible	79	88	96

Source: Authors.

Table A3.14. Average Charged Electricity in Storage with D=6MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	67	77
96	Infeasible	51	65	75	88
120	Infeasible	52	65	77	86

Source: Authors.

Table A3.15. Average Charged Electricity in Storage with D=0MW for Normal Demand (MWh)

PV(MW)\Storage (MWh)	450	480	510	540	570
120	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
144	Infeasible	Infeasible	Infeasible	164	189
168	Infeasible	160	160	176	163
192	Infeasible	151	156	176	176

Source: Authors.

Table A3.16. Average Charged Electricity in Storage with D=0MW for Eco Demand (MWh)

PV(MW)\Storage (MWh)	360	390	420	450	480
96	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	Infeasible	134	154
144	Infeasible	124	131	141	134
168	Infeasible	120	143	127	132

Source: Authors.

IV. Initial Investment Cost

Initial investment cost is shown for each of the various capacities of PV and electricity storage in Table A3.17 to Table A3.22. Using these results, fuel costs of diesel generators at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated and shown in Figure 3.12 of Chapter 3.

Table A3.17. Initial Cost with D=12MW for Normal Demand (US$)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	95,400,000	97,800,000
38	Infeasible	Infeasible	135,000,000	138,600,000	141,000,000
53	Infeasible	174,600,000	178,200,000	181,800,000	184,200,000
67	Infeasible	217,800,000	221,400,000	225,000,000	227,400,000

Source: Authors.

Table A3.18. Initial Cost with D=12MW for Eco Demand (US$)

PV(MW)\Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	31,800,000	35,400,000
19	Infeasible	71,400,000	75,000,000	78,600,000
34	Infeasible	114,600,000	118,200,000	121,800,000

Source: Authors.

Table A3.19. Initial Cost with D=6MW for Normal Demand (US$)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	405,900,000	411,900,000
144	Infeasible	417,900,000	477,900,000	483,900,000
168	Infeasible	543,900,000	549,900,000	555,900,000

Source: Authors.

Table A3.20. Initial Cost with D=6MW for Eco Demand (US$)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	255,900,000	261,900,000
96	Infeasible	315,900,000	321,900,000	327,900,000	333,900,000
120	Infeasible	387,900,000	393,900,000	399,900,000	405,900,000

Source: Authors.

Table A3.21. Initial Cost with D=0MW for Normal Demand (US$)

PV(MW)\Storage (MWh)	450	480	510	540	570
120	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
144	Infeasible	Infeasible	Infeasible	540,000,000	546,000,000
168	Infeasible	6,000,000	606,000,000	612,000,000	618,000,000
192	Infeasible	672,000,000	678,000,000	684,000,000	690,000,000

Source: Authors.

Table A3.22. Initial Cost with D=0MW for Eco Demand (US$)

PV(MW)\Storage (MWh)	360	390	420	450	480
96	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	Infeasible	450,000,000	456,000,000
144	Infeasible	510,000,000	516,000,000	522,000,000	528,000,000
168	Infeasible	582,000,000	588,000,000	594,000,000	600,000,000

Source: Authors.

V. Fuel Cost of Diesel Generator

Fuel cost of diesel generator is shown for each of the various capacities of PV and electricity storage in Table A3.23 to Table A3.26. Using these results, initial investment costs at the best power mix corresponding to Table 3.14 and Table 3.15 are calculated and shown in Figure 3.11 of Chapter 3.

Table A3.23. Fuel Cost of Diesel Generator with D=12MW for Normal Demand (US$/Year)

PV(MW)\Storage (MWh)	24	42	60	78	90
10	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
24	Infeasible	Infeasible	Infeasible	9,003,538	9,003,537
38	Infeasible	Infeasible	7,167,505	7,145,458	7,153,310
53	Infeasible	5,987,409	5,781,847	5,657,124	5,607,127
67	Infeasible	5,346,351	5,014,082	4,745,951	4,607,519

Source: Authors.

Table A3.24. Fuel Cost of Diesel Generator with D=12MW for Eco Demand US$/Year)

PV(MW)\Storage (MWh)	12	30	48	66
0	Infeasible	Infeasible	Infeasible	Infeasible
5	Infeasible	Infeasible	9,274,361	9,274,360
19	Infeasible	7,374,949	7,374,947	7,374,945
34	Infeasible	5,695,007	5,634,900	5,622,208

Source: Authors.

Table A3.25. Fuel Cost of Diesel Generator with D=6MW for Normal Demand (US$/Year)

PV(MW)\Storage (MWh)	150	180	210	240
96	Infeasible	Infeasible	Infeasible	Infeasible
120	Infeasible	Infeasible	718,637	513,310
144	Infeasible	539,311	272,603	135,729
168	Infeasible	288,606	116,427	46,433

Source: Authors.

Table A3.26. Fuel Cost of Diesel Generator with D=6MW for Eco Demand (US$/Year)

PV(MW)\Storage (MWh)	90	120	150	180	210
48	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible
72	Infeasible	Infeasible	Infeasible	2,020,088	1,970,174
96	Infeasible	1,461,629	957,195	657,768	477,971
120	Infeasible	937,971	429,692	183,726	80,351

Source: Authors.