ERIA Research Project Report 2020, No. 19

Temburong Ecotown Development Phase 4

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Preface

The Economic Research Institute for ASEAN and East Asia (ERIA) has since 2016 had an excellent and close relationship with the Government of Brunei Darussalam and has been providing expertise in the efforts to improve, preserve, and protect Brunei’s natural and built environment. Part of the collaboration has entailed a series of studies of the Temburong District Ecotown Projects which identified several potentials and implications of the projects, especially in the field of energy. Temburong district is known as Brunei's ‘green jewel’ with its flowing hills, lush flora, and babbling streams, and is home to large expanses of unspoiled rainforests and rich varieties of rare flora and fauna. The district is becoming more attractive due to the easy access from Bandar Seri Begawan with the opening of Temburong Bridge on 17 March 2020, positioning Temburong to be a good example of a successful ecotown or smart city in the Association of Southeast Asian Nations (ASEAN).

Phase 1 of the Temburong Ecotown study conducted in 2016–2017 reviewed energy technologies related to ecotowns or smart cities and contributed to promoting energy efficiency and conservation (EEC), clean transport, and variable renewable energy (vRE) with smart-grid technologies. Phase 2 sought to identify the best mix of existing diesel power generation, new solar/PV power generation, and new battery storage capacity. It applied a simulation approach on an hourly basis solar radiation data and hourly basis future electricity demand in Temburong district. Phase 3 featured a master plan for Temburong ecotown development in collaboration with Nikken Sekkei Civil Engineering Ltd., which touched on the urban design of Temburong district.

Phase 4 conducted in 2019–2020 and set out in this report focused on saving energy in commercial buildings, creating a clean electricity supply, and creating cleaner transport systems. Three concrete and applicable aspects to support Temburong’s ecotown development are provided in the report – first, preparation of energy efficiency guidelines for commercial buildings (both new buildings and retrofitting) in Temburong district; second, clean electricity supply to Temburong district applying smart-grid technology; and third, a proposal for a smart transport system for the district. In addition, an overall road map for the development of an ecotown in the district was included. This study has been the result of close cooperation with the Ministry of Energy (ME) Brunei Darussalam and ERIA is looking forward to discussing further steps based on the study results.

Building on this good momentum, the development of Temburong ecotown must be carefully monitored and managed to ensure the right balance of development and preservation of natural assets, local culture, as well as the rural character of the district. It is of the utmost importance that the development benefits the local population in maintaining inclusiveness, generation of new jobs, and income growth. Hence, ERIA looks forward to building on the Temburong Eco Town Masterplan based on all of our previous studies with greater focus on industries and sectors that can be globally competitive and on economic activities that ensure inclusiveness of the district's residents.

Professor Hidetoshi Nishimura

President, Economic Research Institute for ASEAN and East Asia

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Special acknowledgement is also given to Pengiran Haji Jamra Weira bin Pengiran Haji Petra, Deputy Permanent Secretary, Ministry of Energy, Brunei Darussalam, for his very helpful comments and suggestions.

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Abbreviations and Acronyms

ACE	ASEAN Centre for Energy
ACMV	air-conditioning and mechanical ventilation
AGC	automatic generation control
AGC	automatic generation control
APEC	Asia-Pacific Economic Cooperation
BPC	Berakas Power Company Sdn Bhd
BAU	business-as-usual scenario
BoD	basis of design
BEI	building energy intensity
BEM	building energy modelling
BEMS	building energy management system
BES	building energy simulation
BEV	battery electric vehicle
BSB	Bandar Seri Begawan
CCS	carbon capture and sequestration
CIQS	customs, immigration, quarantine, and security
CO2	carbon dioxide
CSPF	cooling seasonal performance factor
DES	Department of Electrical Services
EIDPMO	Energy and Industry Department at the Prime Minister’s Office
EMS	energy management system
EEC	energy efficiency and conservation
EEI	energy efficiency indicator
EV	electric vehicle
FC	fuel cell
FCEV	fuel-cell hydrogen electric vehicle
FIT	feed-in-tariff
IRENA	International Renewable Energy Agency
IEC	International Electrotechnical Commission
LEAP	Long-Range Energy Alternatives Planning System
LEED	Leadership in Energy and Environmental Design

HEV	hybrid electric vehicle
LTMP	Land Transport Master Plan
METI	Ministry of Economy, Trade and Industry
MOE	Ministry of Energy
MEPS	minimum energy performance standard
MOD	Ministry of Development
O&M	operation and maintenance
OTTV	overall thermal transfer value
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PV	photovoltaic
R&D	research and development
RPS	renewable portfolio standard
RT	refrigeration tonne
RTTV	roof thermal transfer value
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
TSB	Tenaga Suria Brunei Power Station
TSO	transmission system operator
vRE	variable renewable energy
UNISSA	University Islam Sultan Sharif Ali (Islam University)
U-value	thermal transmittance value

Executive Summary

Once Temburong's ecotown development starts, several commercial buildings – such as a convention centre for international and regional conferences, five-star and higher luxurious hotels for visitors to Temburong district, sophisticated shopping malls, etc. – will be constructed in the district. Commercial buildings should apply energy efficiency and conservation (EEC) designs to curb the escalation of electricity consumption whilst showcasing the concept of ecotown development in Brunei Darussalam. Thus, ERIA prepared the EEC guidelines for commercial buildings. These guidelines covered definitions of designated buildings, necessary labelling of building energy intensity for designated buildings, minimum energy performance standard (MEPS) for energy-intensive equipment and appliances to be used for the designated buildings, and the approval process of new building proposals (concerning building energy system), which the developers of the designated buildings will submit. Also, the EEC guidelines should be upgraded to a regulation on the construction of commercial buildings incorporating the EEC design in Temburong district to establish a mandatory basis for implementation.

Temburong ecotown development should also consider clean energy supply, especially electricity supply from zero-emission power sources, such as variable renewable energy (vRE) including solar/PV and wind. This study assumes to establish a 60 MW solar/PV system in Temburong district and analyses whether this will be available with respect to frequency conditions applying an energy management system (EMS) with automatic generation control (AGC) function. According to analysis and calculation, the 60 MW system will be available to realise optimal generation control to maximise the solar/PV output technically and provide enough capacity to supply electricity to Temburong Ecotown. These comprise 49 GWh yearly demand and 78 GWh yearly generation and transfer surplus electricity to Bandar Seri Begawan (BSB) through a new transmission line on the Temburong Bridge but only for daytime consumption. However, two major issues remain: (i) a huge land area required for solar/PV system (300–600 acres) and (ii) significant investment for solar/PV system (US$160–US$268 million).

Clean transport is also an important concept of an ecotown or smart city. Brunei Darussalam has two options: electric vehicle (EV) and fuel cell electric vehicle (FCEV). EV will be the priority because the price of lithium ion batteries for EV has been decreasing. Another reason is that since Brunei is a relatively small country, large-scale batteries of 500–600 kWh will not be needed. But the introduction of EV will increase electricity demand and, therefore, natural gas consumption for power generation will also increase. Eventually, with the use of EVs plus natural gas consumption for power generation, carbon dioxide (CO_2) will be negative but by just a few percentages from the business-as-usual scenario (BAU) (all internal combustion engine vehicles). Because of hydrogen production in Brunei Darussalam applying the steam reforming process to natural gas, FCEV is an option. However, it will not be available commercially until after 2030 due to further technology development on FCEV and the scale-up of hydrogen production. However, FCEV will be much better than EV in terms of CO_2

mitigation, if Brunei Darussalam will apply carbon capture utilisation and storage (CCUS) for disposing of CO_2 coming from the steam reforming process. Hydrogen can be used as fuel to generate power, so that combining hydrogen power generation and EV will also be another option. Regarding clean transport system in Temburong district, three types of traffic flows should be considered: (i) internal traffic in Temburong district, (ii) out and in traffic of BSB, and (iii) through traffic from and to Sabah and Sarawak. Due to clean transport regulations in Temburong district, only EV and FCEV will be available to internal traffic in terms of passenger cars. Buses and trucks should implement a 'park and ride' programme.

Last but not least, this study also prepares a road map of the Temburong ecotown development. In other words, it provides a guide to necessary infrastructure development in the Temburong district. This road map covers eight major infrastructures: energy (electricity supply), transportation (road), water supply, tourism (hotel), education (university), industry (R&D centre), housing and urban centre (Bangar). On the other hand, the road map is divided into four periods: present–2021, 2022–2023, 2024–2030, and 2031–2040. So far, there is no detailed ecotown development plan in Temburong district. Thus, this road map may seem primitive because of the inconsistency between the infrastructure construction and the timeline. However, this road map will be a useful reference for the people in charge of the Temburong district development.

This report on the phase 4 study shows an overall Temburong ecotown development plan, especially the necessary infrastructure. In terms of energy, this report provides in-depth information, insights, and the concept and methodology of promoting EEC in commercial buildings, clean electricity supply, and clean transport system related to Temburong ecotown development. On the objectives of this report, ERIA wishes that the Ministry of Energy, Brunei Darussalam will (i) prepare an EEC regulation for commercial buildings in collaboration with the Ministry of Development, (ii) construct a solar/PV system connected to Berakas Power Company/Department of Electrical Services (DES) grid network, which will be supported by EMS with AGC, and (iii) prepare a clean transport regulation mandating the use of EV and FCEV in Temburong district.

Chapter 1
Energy Efficiency and Conservation Guidelines

1. Introduction to Energy Efficiency and Conservation

Temburong development, anticipated to occur soon after the completion of the Temburong Bridge linking Temburong district to Bandar Seri Begawan (BSB), offers Bruneians an opportunity to incorporate energy sustainability in developing an ecotown. These guidelines intend to assist the Ministry of Energy (MOE), Brunei Darussalam, in formulating a plan and a guide incorporating energy efficiency and conservation (EEC) measures in Temburong ecotown development. These guidelines aim to establish EEC practice requirements, minimum building energy performance, and other review and assessment requirements of the EEC section of a development plan submission. Henceforth, these are referred to as EEC building design submission as part of the overall building development plan submission to develop the Temburong ecotown.

These guidelines provide guidance on best practices, methodology, and assessment regarding minimum energy performance and other EEC assessment requirements to achieve energy efficiency in commercial and public service buildings in Temburong district. These buildings are expected to become a major load demand centre for energy besides the transport sector. The Ministry of Development (MOD) approves building development applications. However, the building energy performance assessment is deemed a subset of the overall building development application. These guidelines were prepared for the responsible department in the MOE (expected to be the Sustainable Energy Department) to review and assess the design compliance according to the EEC assessment criteria provided, in addition to the existing building regulations in Brunei Darussalam. In case of any contradiction between the requirements of these guidelines and the current building regulations, the requirements of the latter shall take precedence.

As these guidelines focus on EEC technical guidance, the administrative procedures and the existing statutory requirements for the building plan submission, processing, compliance, and approval are not included. This aspect of the building plan submission and processing procedures will be addressed by the ministries and authorities concerned. Successful implementation of the EEC strategies and measures recommended in these guidelines will depend on whether the existing regulatory requirements are adequate or whether specific EEC regulations will be introduced because implementation on a voluntary basis will not be effective.

1.1. Definitions

a) Designated buildings

This guideline sets out the guidance on EEC building requirements for commercial and public service buildings. For definition purposes, this guideline shall apply to the following categories of buildings, which are defined as designated buildings:

1) All new building works involving a gross floor area of 2,000 m^2 or more[1]
2) Additions or extensions to existing buildings which involve increasing the gross floor area of the existing buildings by 2,000 m^2
3) Building works involving major retrofitting to existing buildings with a gross floor area of 2,000 m^2 or more
4) All buildings meeting any criteria listed in the above will be classified as designated buildings

b) Commercial buildings

Commercial buildings are non-residential buildings used for commercial purposes, which include mixed developments. Typical commercial buildings comprise offices, hotels, and malls.

c) Public service buildings

Public service buildings are government buildings, including public service offices, and institutional buildings, such as hospitals and universities.

d) Qualified person

A qualified person shall be a building professional who submits building plans to the MOD for approval following the statutory requirements.

1.2. Approval process of EEC building proposals

For designated buildings, as defined in Section 1.1.a), the developer or building owner shall include a section on EEC building design details. Such details confirm that the buildings were designed with EEC measures or features (including passive and active EEC measures) and suitable materials and energy management system (EMS) in their overall building plan submissions. (Refer to Section 4 of this report for EEC assessment and compliance requirements).

The person who designs this EEC building submission must be a qualified person who, together with other appropriate practitioners (i.e. mechanical and electrical professional engineers), will ensure that the minimum building energy performance and other EEC building requirements are met in their EEC building design submission. An example of the format for this section of the submission is in Appendix 3.

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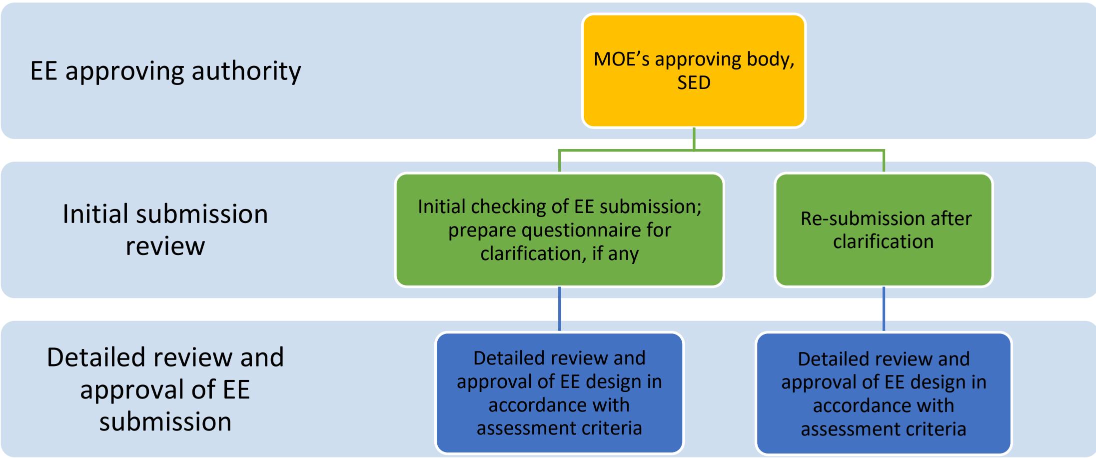
[1] Per the consultative meeting held in Brunei Darussalam in February 2020.

Figure 1.1 shows that the Sustainable Energy Department in the MOE is expected to review and approve the EEC building design submission under a sub-approval process to the existing overall building plan's approval process. The administrative aspect of this approval process is left to the relevant ministries and authorities to address and administer. Section 4 details the EEC assessment requirements.

Figure 1.1: Sub-approval Process for the Assessment of EEC Building Design Submission

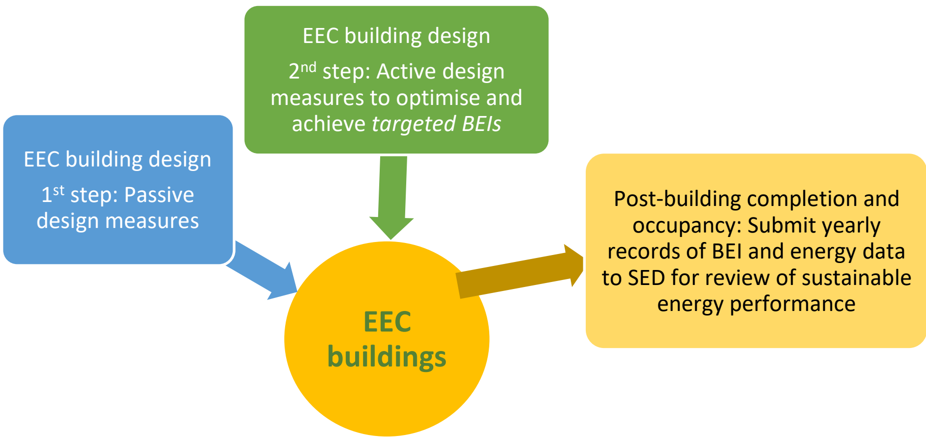


EE = energy efficiency, MOE = Ministry of Energy, SED = Sustainable Energy Department.
Source: Author.

1.3. Minimum and sustainable building energy performance requirements

The minimum building energy performance of a designated building shall have a level of energy performance that meets the requirements stipulated in the Piawai Brunei Darussalam (PBD) 12 EEC: 2015 Energy Efficiency & Conservation Building Guidelines. This EEC guideline for Temburong ecotown development complements the existing statutory requirements and policies. Figure 1.2 explains the concept of developing EEC buildings in Temburong district, which includes an action plan in the post-building completion and occupancy phase to ensure sustainable energy performance of designated buildings in Temburong district.

Figure 1.2: Guide for the Development of EEC Buildings in Temburong District



BEI = building energy intensity, EEC = energy efficiency and conservation, SED = Sustainable Energy Department.
Source: Author.

This EEC guideline provides the criteria for achieving minimum and sustainable building energy performance, as summarised below. For details of the passive design measures, refer to PBD 12 EEC:2015 Guidelines and MS1525:2019 (if updated information is required). These EEC requirements would form the basis for the assessment of EEC building design submission. Figure 1.7 shows the overall EEC assessment requirements and procedures, and Section 4 of this report discusses the details. The review criteria should comprise two main EEC design measures: passive and active design measures.

1.3.1. Passive Design Measures

a) Building envelope: façade design measures

Adequate façade design measures will ensure that the building envelope minimises heat gain into buildings via conduction and solar radiation. In a hot and humid climate, solar heat gain in air-conditioned buildings will substantially increase the cooling load. Therefore, minimising solar heat gain in a building is a critical consideration in designing an energy-efficient building. Such design consideration is based on the overall thermal transfer value (OTTV) concept computed for the façade design. Refer to PBD12 EEC:2015[2] and MS1525:2019 for further details.

The OTTV of the building envelope for a designated building must be 50 W/m^2 or less.[3] The OTTV shall apply to all external walls of the building and is computed by equations 1 and 2 below.

$$OTTV = \frac{(A1\ x\ OTTV1)+(A2\ x\ OTTV2)+\cdots+(An\ x\ OTTVn)}{A1+A2+\cdots+An} \quad \text{--------- (1)}$$

where:

Ai = gross exterior wall area for orientation i
OTTV*i* = OTTV for orientation *i* from equation (2).

For a fenestration at any given orientation, the formula is given as follows:

$$OTTVi = 15\alpha\,(1-WWR)Uw + 6(WWR)Uf + (194\ x\ OF\ x\ WWR\ x\ SC) \quad \text{------- (2)}$$

where:

WWR = window-to-gross exterior wall area ratio for the orientation under consideration

α	= solar absorptivity of the opaque wall
Uw	= thermal transmittance of opaque wall (W/m^2 K)
Uf	= thermal transmittance of the fenestration system (W/m^2 K)
OF	= solar orientation factor

SC is the effective shading coefficient of the fenestration system, whereby solar heat gain coefficient (SHGC) = SC x 0.87.

[2] PBD12 EEC:2015 Energy Efficiency Building Guidelines 2015.

[3] Reference is made to PBD12 EEC:2015 Energy Efficiency Building Guidelines 2015, and MS1525:2019 Malaysian Standard, Energy Efficiency and Use of Renewable Energy for Non-residential Buildings.

b) Building envelope: roof design measures

There are two considerations in minimising heat gain through the roof. Firstly, the roof shall be designed to achieve a thermal transmittance (U-value) equal to or less than the value tabulated in Table 1.1.

Table 1.1: Maximum U-value for Roof (W/m^2 K)

Roof Type	Maximum U-value (W/m^2 K)
Lightweight (under 50 kg/m^3) (Non-concrete roof construction)	0.4
Heavyweight (above 50 kg/m^3) (Concrete roof construction)	0.6

Source: PBD12 EEC:2015.

In addition to the requirement in Table 1.1, the maximum recommended roof thermal transfer value (RTTV) for roofs with skylight is 25 W/m^2 or less. The concept of RTTV applies to an air-conditioned building where the roof is provided with skylight, and the entire enclosure is fully air-conditioned. The RTTV of the roof is given by equation 3 below.

$$RTTV = \frac{(Ar\ x\ Ur\ x\ TDeq)+(As\ x\ Us\ x\ \Delta T)+(As\ x\ SC\ x\ SF)}{A0} \qquad \text{----------}\ (3)$$

where,

RTTV	= roof thermal transfer value (W/m^2)
Ar	= opaque roof area (m^2)
Ur	= thermal transmittance of opaque roof area (W/m^2 K)
TDeq	= equivalent temperature difference (K)
As	= skylight area
Us	= thermal transmittance of skylight area (W/m^2)
ΔT	= temperature difference between exterior and interior design conditions
SC	= shading coefficient of skylight
SF	= solar factor
A_0	= gross roof area (m^2) where A_0 = Ar + As

1.3.2. Active Design Measures

Active design measures shall include the adoption of best practices in the design of energy-intensive systems. These include the selection of equipment and appliances that meet the minimum energy performance standard (MEPS). (Refer to Section 3 on MEPS for energy-intensive equipment.) Active design measures are summarised below. For further details, refer to PBD 12 EEC:2015 Guidelines and MS1525:2019 for updated information.

a) MEPS

As detailed in Section 3, MEPS is a specification containing several performance requirements for an energy-using device that prescribes a measurement of the energy performance of the device indicating its level of energy efficiency. MEPS can help the designer select devices or equipment to be incorporated into his design to achieve the desired level of energy efficiency.

b) *Building energy intensity (BEI)*

BEIs are energy efficiency indicators (EEIs) for the building sector. (Refer to Sections 2 and 4 for details.)

c) *Energy management system (EMS)*

The EMS, a subset of the building management system, provides a full complement of energy management features designed and programmed to control, monitor, and report energy consumption, intensities, and trending with tracking capability. (Refer to Section 1.4 for assessment requirements.) The records of BEIs and energy consumption data, including system loads, must be submitted to the Sustainable Energy Department yearly during the operation of designated buildings to monitor sustainable building energy performance.

In summary, Section 1.3 aims to ensure the achievement of minimum and sustainable energy performance in designated buildings by adopting a combination of passive and active design strategies, and by stipulating the requirements of continuous reporting and monitoring of BEIs during building operation (Figure 1.2) for sustainable building energy performance.

1.4. EEC legal framework

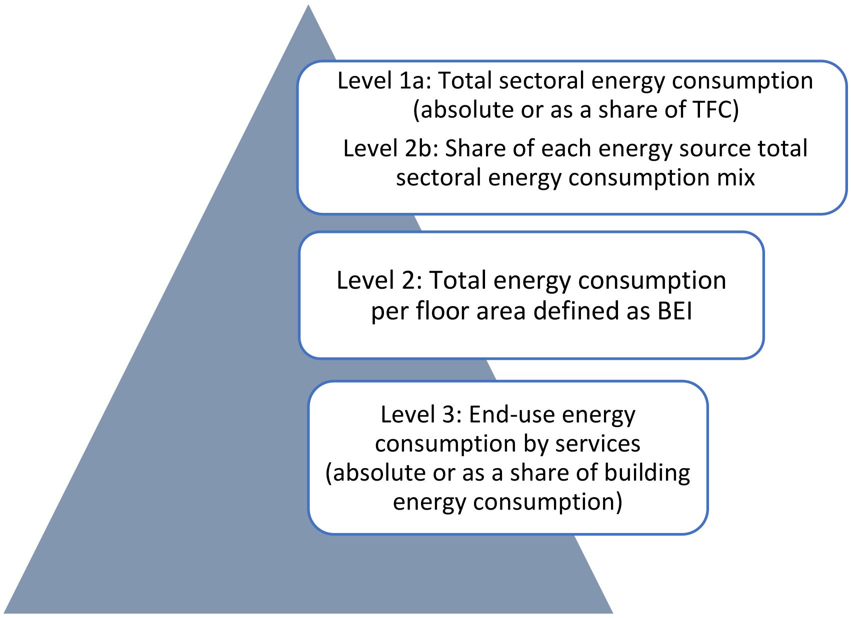
Implementation of the strategies and measures mapped out in this guideline on a voluntary basis would not be effective because it would likely be based on economic justification. Energy savings might not be sufficient to justify the investments in EEC installations due to the low tariff structure in Brunei Darussalam. This guideline provides practical EEC design measures and assessment of procedural process with review criteria as depicted in Figures 1.2**,** 1.7, and 1.8. However, this guideline will remain a reference document without a legal framework or regulatory requirements due to the lack of regulatory power for implementation in the commercial sector.

PBD 12 EEC:2015 Energy Efficiency & Conservation Building Guidelines was launched in May 2015 by the Minister of Development. These guidelines are mandatory for all government buildings but are voluntary only to all commercial buildings. Therefore, to make this Temburong EEC guideline effective, it is necessary to extend the existing mandatory requirements for government buildings to designated buildings in the commercial sector.

2. Labelling of BEIs

BEIs are energy efficiency indicators (EEIs). The concept of EEI is best explained by a pyramid of indicators of the International Energy Agency (IEA, 2014) (Figure 1.3). It explains the various levels of indicators and shows how indicators are organised into a hierarchy. The top of the pyramid in Figure 1.3 shows that the total energy consumption of the commercial sector or share of each energy source of the total commercial sector energy consumption mix is an aggregated indicator. IEA's concept of EEIs is a 'pyramidal approach' starting from the most aggregated level at level 1 to the most disaggregated level at end-use energy consumption by services, e.g. air-conditioning and mechanical ventilation, lighting, lifts and elevators, and escalators, etc. at level 3. The term BEI is used instead of EEI to differentiate the indicators from other sectors, such as the industry sector EEI, which has a different definition.

Figure 1.3: Pyramid of Commercial Sector Indicators



BEI = building energy intensity, TFC = total final consumption.
Source: Produced by the author based on IEA (2014).

2.1. Definition and applications

a) Definition

BEIs are a ratio of yearly energy consumption (measured in energy unit, kWh) to gross floor area (measured in square metre) under level 2 in Figure 1.3. For a meaningful comparison, the BEI values are to be compared with buildings within the same building subsector or category. In other words, the BEIs of office buildings, retail malls, hotels, hospitals, etc. should be compared within the same category or type of buildings because different building categories have different operating functions.

BEIs of buildings are computed at the subsector level and are calculated by the formula given in equation 4 below.[4] BEI is essentially a ratio of yearly energy consumption to gross floor area. However, to provide a more accurate representation of the energy intensity throughout the building, energy use in the car park area, which is usually not air-conditioned, and the data centre, where a high concentration of continuous energy use is expected, is excluded in the computation. Floor vacancy rate is considered only when the BEI is computed for an occupied building after the completion and occupancy of a building. For design submission, the building is usually considered fully occupied. The ratio of average weekly working hours to weighted weekly operating hours is used to make an adjustment to buildings that have different weekly operating hours compared with the national average weekly operating hours, such as office and retail buildings. This adjustment is to ensure a fair comparison of energy performance in different buildings of the same category.

$$BEI = \frac{(TBEC - CPEC - DCEC)}{(GFA - CPA - DCA) - (GLA \; x \; FVR)} \; x \frac{AWH}{WOH} \qquad \text{----------- (4)}$$

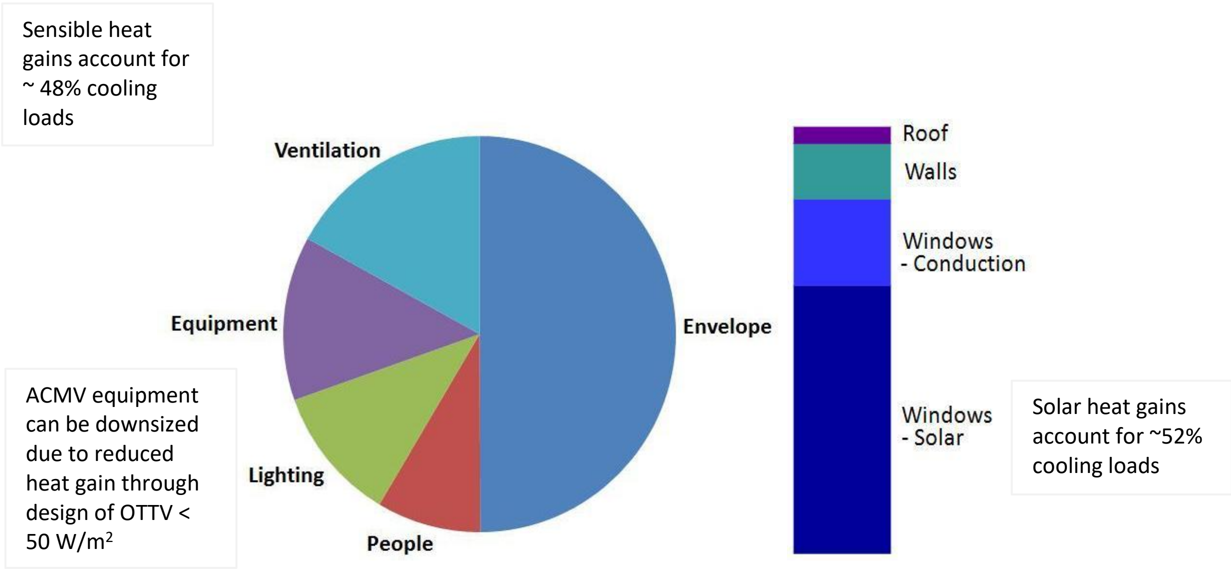
where:

TBEC	= total yearly building energy consumption (kWh/y)
CPEC	= yearly car park energy consumption (kWh/y)
DCEC	= data centre energy consumption (kWh/y)
GFA	= gross floor area (m^2)
CPA	= car park area (m^2)
DCA	= data centre area (m^2)
GLA	= gross lettable area (m^2)
FVR	= floor vacancy rate (%)
AWH	= average weekly operating hours (hours/week)
WHO	= weighted weekly operating hours (hours/week)

The majority share of energy consumption in commercial buildings in a hot and humid climate is energy use by air-conditioning and mechanical ventilation (ACMV) system required to provide thermal comfort in buildings. As reported in the Building Energy Technical Guideline for Passive Design (Public Works Department Malaysia, 2013), the typical energy breakdown in Malaysian office buildings is 50% for air-conditioning, 25% for electrical lighting, and 25% for small power (equipment). Figure 1.4 shows the ACMV system is required to remove solar thermal heat gains through the building envelope, which constitutes more than half of the cooling load. The ACMV system is also necessary to remove sensible heat gains from people, lighting, and other equipment in a building. Therefore, electricity consumption in commercial and public service buildings is energy use distributed throughout the floor areas. In other words, BEI, being total energy consumption over the gross floor area, indicates the efficiency of energy use in a building.

[4] Green Building Index Malaysia, www.greenbuildingindex.org.

Figure 1.4: Typical Breakdowns of Office Cooling Loads in Malaysia



Source: Author, adapted from the Danish International Development Agency study in Malaysia in 2005.

The establishment of the commercial sector EEI focuses on level 2 in the pyramid of commercial indicators. Level 2 focuses on the development of BEIs by building categories such as the following:

1) Office buildings
2) Hotels (one- to three-star rated, and four- to five-star rated)
3) Retail buildings or shopping malls (large, medium, and small)
4) Hospitals (large, medium, and small)

Each building subsector is expected to have different energy level intensities, mainly due to various building functions and operating hours. Hence, they will have different BEI benchmark values. The level of energy intensities in hotels is expected to be different for four- to five-star hotels. The services and amenities available in such hotels are more energy intensive than one- to three-star hotels. Therefore, the hotel category should be further classified under these two categories.

Similarly, retail buildings should be subdivided under low-end and high-end malls. Hospitals should be subdivided under large, medium, and small so that the BEI assessment can be made according to the respective building subsectors.

b) Applications

BEI labelling can be used as a tool to drive the agenda of energy efficiency in buildings. BEI labelling provides a means of measurement or indication of the energy performance of buildings in the same category. Optimising the energy efficiency in a building would involve a combination of passive and active design measures. This guideline is not intended to specify particular design measures because building design should be left to the building owners or developers and the building professionals' creativity to develop their innovative designs within budget allocations. However, BEI labelling can provide a guide with targets and indications of energy efficiency in buildings. The objectives of BEI labelling are summarised as follows:

1) To set minimum requirements of building energy performance for compliance by building owners, developers, and designers to ensure that designated buildings attain the required BEI labelling, which confirms the achievement of minimum energy performance;
2) To set minimum BEI target values for each commercial subsector or building category so that buildings are conscientiously incorporating EE design strategies to improve energy and environmental sustainability and meet the required standard of targeted energy intensity;
3) To be used as a guide and basis for the assessment of building energy performance by the EEC building approving authority;
4) To be used as a tool to recognise energy-efficient buildings, which will enhance the ecotown development of Temburong, and increase the market values of properties in the district.

2.2. Assessment of BEIs and BEI targets

As discussed in Section 2.1.b), BEI indicates energy efficiency in buildings. Various energy-efficient features or measures will be incorporated in a building design to achieve the BEI targets. Such design efforts and achievement of energy reduction are expected to culminate in lower BEI values. Therefore, building energy performance can be assessed by comparing and evaluating BEIs with pre-set BEI targets.

The establishment of BEI targets for various building categories usually requires historical data but such data are not readily available. Under such circumstances, the BEI targets listed in Table 1.2 are based on the entry-level BEI values for green buildings set by the Green Building Index (GBI) Malaysia and are suggested to be adopted as guide. The entry-level BEI values set by the GBI are the minimum requirement to qualify for one GBI point under the energy efficiency criterion. In other words, GBI entry-level BEI values set minimum requirements for EEC buildings. For office buildings in Brunei Darussalam, the minimum BEI required is 175 kWh/m^2. Table 1.2 provides a range of BEI target values from one-star to five-star ratings. The range of BEI target values is based on GBI Malaysia's range of GBI points scoring that begins with green building entry-level value. Table 1.2 shows that a one-star rating corresponds with the green building entry-level BEI. The highest five-star rating corresponds with a much lower BEI target value. Subject to the MOE's decision on the energy efficiency level for developing commercial buildings in Temburong district, the minimum BEI targets are suggested to be set at three-star rating to achieve recognition and acceptability as an ecotown. The concept of deriving the BEI target values was presented to the MOE and other government stakeholders during the second working meeting for Temburong Ecotown Phase 4 study in February 2020. The target values were generally accepted during the meeting.

Table 1.2 shows higher-star ratings, such as four- and five-star ratings, to encourage higher building energy performance, compared with three-star rating if this is chosen to be the minimum requirement for EEC buildings in Temburong. Such certified approval with star rating should clearly state that it is for the EEC building design submission. The actual BEI of a building may be different after the completion and occupancy of the building. Therefore, designated buildings in Temburong are required to submit yearly records of BEI values after building occupancy for the monitoring and compilation of energy statistics. This requirement is one reason Section 1.4 on the assessment and compliance method specifies the EMS provision under the step 3 assessment requirements. The EMS could track and keep records of building energy performance.

Table 1.2: BEI Targets for Commercial and Public Sector Buildings

Building Category	Average BEI Derived from Brunei Commercial Sector Survey	Green Building Entry Level for GBI [a] Malaysia BEI ($kWh/m^2/y$)	Suggested BEI Targets for Temburong ($kWh/m^2/y$)		Remarks
Office buildings	Small: 242 Medium: 227 Large: 275 Overall average: 258	150	5-Star: BEI ≤ 100 4-Star: 100 < BEI ≤ 120 3-Star: 120 < BEI ≤ 135 2-Star: 135 < BEI ≤ 150 1-Star: 150 < BEI ≤ 175		[b] Energy demand estimates based on 120 $kWh/m^2/y$
Retail buildings	Overall average: 308	[c] Low-end outlets: 240 [d] High-end outlets: 350	Low-end 5: 150 4: 180 3: 210 2: 225 1: 240	High-end 5: 250 4: 280 3: 310 2: 330 1: 350	Energy demand estimates based on 280 $kWh/m^2/y$
Hotels	1-3 Star: 177 4-5 Star: 371	3-star & below: 200 4-star & above: 290	≤ 3-star 5: 120 4: 150	≥ 4-star 5: 200 4: 230	Energy demand estimates based on 233 $kWh/m^2/y$

Building Category	Average BEI Derived from Brunei Commercial Sector Survey	Green Building Entry Level for GBI [a] Malaysia BEI (kWh/m²/y)	Suggested BEI Targets for Temburong (kWh/m²/y)		Remarks
			3: 175 2: 190 1: 200	3: 250 2: 270 1: 290	
Hospitals	Overall average: 334	Small-medium: 200 Large: 290	≤ medium 5: 120 4: 150 3: 175 2: 190 1: 200	Large 5: 200 4: 230 3: 250 2: 270 1: 290	Energy demand estimates based on 233 kWh/m²/y
University	N/A	N/A	5-Star: BEI ≤ 100 4-Star: 100 < BEI ≤ 120 3-Star: 120 < BEI ≤ 135 2-Star: 135 < BEI ≤ 150 1-Star: 150 < BEI ≤ 175		Energy demand estimates based on 120 kWh/m²/y
Industrial park	N/A	N/A	5-Star: BEI ≤ 100 4-Star: 100 < BEI ≤ 120 3-Star: 120 < BEI ≤ 135 2-Star: 135 < BEI ≤ 150 1-Star: 150 < BEI ≤ 175		Energy demand estimates based on 140 kWh/m²/y

[a] Green Building Index Malaysia, www.greenbuildingindex.org/faq-green/#1582099483746-93d4e753-6907.
[b] The basis of energy demand estimates was adopted from Kimura (2017).
[c] Low-end outlets are retail outlets having low-energy intensity.
[d] High-end outlets are upmarket or large outlets having high energy intensity.
BEI = building energy intensity.
Source: Author, in consultation with the Sustainable Energy Department, Ministry of Energy.

3. Minimum Energy Performance Standard for Energy-Intensive Equipment

The MEPS specifies performance requirements for an energy-using device, effectively limiting the maximum amount of energy consumed by a product in performing a specified task. It provides details of specific minimum energy efficiency levels to the devices used. MEPS and labelling programmes for electrical appliances and equipment are widely recognised as a highly cost-effective energy efficiency policy measure. Hence, as part of the energy efficiency measures, MEPS and labelling programmes are recommended to be implemented in Temburong ecotown development.

A government energy efficiency body usually requires a MEPS to be either voluntary or mandatory. MEPS may include requirements not directly related to energy. This is to ensure that general performance and user satisfaction are not adversely affected by increasing energy efficiency. For Temburong ecotown development, MEPS is recommended to be mandatory for designated buildings. Besides contributing to achieving improved building energy performance, MEPS will ensure that the importation of electrical appliances and equipment would be regulated such that only appliances and equipment meeting the MEPS requirements are allowed to be imported and sold in Brunei Darussalam.

A MEPS generally requires the use of a particular test procedure specifying how performance is measured. With the MEPS in place, an energy labelling system will be established, and registration of the equipment will be done based on the labelling categories or rating system. This would set an energy benchmark to the appliances and equipment used and purchased by end users.

3.1. Implementation of MEPS

A few common criteria are observed and used in setting up MEPS. The criteria are summarised below and should be considered in preparing the standards:

1) *Scope*
   The standards proposed shall define the products that shall be included. Inclusion or exclusion of products could be based on the product type, power rating, or usage type.

2) *Normative standard*
   The standards set shall have normative reference criteria to refer to any existing performance or international standard – such as the International Electrotechnical Commission (IEC) and American Society of Heating, Refrigerating, and Air-Conditioning Engineers – and reference requirements for the condition, testing method, and performance.

3) *Terms and conditions*
   The specific terms and conditions shall be identified for the appliances. These include the following:

   a) The standards will also depict the parameters to be used to determine performance, such as
      - Fan : coefficient of performance
      - Refrigerator : energy efficiency factor

- Air conditioner : energy efficiency ratio; coefficient of performance; cooling seasonal performance factor (CSPF)
- Television : energy efficiency factor
- Lamp : efficacy

b) MEPS: the required minimum level of energy will be defined.

c) Star-rating requirements

With the MEPS requirements in place, a set of ratings and requirements to define the level of compliance of the energy performance would be established. The common method will be categorising them under star ratings such that the star ratings of one to five would correspond to the lowest to highest energy efficiency ratings. However, some appliances, such as lamps, do not require any star rating.

Another essential element of the MEPS and labelling programme is the testing standards and facilities available to carry out the appliance compliance tests, according to MEPS. Existing laboratory facilities in Brunei that could carry out the various tests to comply with the requirements were reviewed. We also examined the current international and regional laboratories to assist in conformance testing. No accredited testing laboratories exist in Brunei, only electrical product safety certification scheme by third-party testing. Since no certified testing laboratory is available in the country, it is recommended that Brunei jump-start the MEPS and labelling programme by collaborating with some regional test laboratories to carry out the tests accordingly. Or it can embark on a harmonisation programme such that the results of tests conforming to the MEPS requirements of one ASEAN member state may be accepted in Brunei, without having to undertake additional tests. Such a method can save time and resources required for the setting-up of testing procedures and facilities. Also, it would not hold up the implementation of EEC guidelines for designated buildings in Temburong district. Numerous internationally accredited test laboratories are available and registered under the ASEAN Secretariat. This is listed as Testing Laboratories and Certification Bodies under the ASEAN Sectoral Mutual Recognition Agreement for Electrical and Electronic Equipment. Whilst existing labs are available to implement MEPS and the labelling programme immediately, Brunei needs to establish a body that would manage the administrative, approving, and certification processes.

A wide range of electrical appliances and equipment are being used in the market for consumers and the commercial and industry sectors. Targeted appliances and equipment to be selected for labelling, such as lighting, refrigerator, air conditioners, fans, television, water heaters, motors, chiller, Others should be reviewed per their market demand, distribution, and their contributing shares of power consumption vis-à-vis the nation’s final energy consumption.

For Temburong ecotown development, the selection of the targeted appliances and equipment is proposed to focus on intensive energy use and extensive equipment and appliance use as listed below.

3.2. Air-conditioning equipment

Air-conditioning equipment consumes the majority of electricity use in the residential and commercial sectors. Hence, it is essential to ensure that energy use in air-conditioning is efficient. There are two basic types of air conditioning equipment:

1) Unitary air-conditioning system
   In general, unitary air-conditioners are mainly used in the residential sector and in small commercial entities. Energy labelling for unitary air-conditioning equipment is based on a minimum performance criterion. One measurement used in MEPS for air-conditioning equipment is the cooling seasonal performance factor (CSPF). CSPF is the ratio of total annual amount of heat that the equipment can remove from indoor air when operated for cooling to the total annual amount of energy consumed by the equipment during the same period. Table 1.3 provides the unitary air conditioners minimum CSPF requirements as per Malaysian Standard MS:1515.

2) ACMV applied system
   The ACMV applied system is mainly installed in medium to large commercial buildings. It provides, in one or more factory-assembled packages, means for chilling water with controlled temperature for delivery to terminal units serving the conditioned space of the building. The chiller may be centrifugal, rotary, screw, scroll, or reciprocating, electrically driven type, absorption (heat-operated) type, or using other prime movers. The system also includes a system with a condensing unit, which receives its suction refrigerant vapour from a packaged or field assembled combination of cooling coil and fan and delivers the liquid refrigerant to the air-handling units. The electrically operated ACMV applied system performance rating value is suggested to be as per Table 1.4, which depicts the minimum energy performance requirement for chiller energy performance rating per Malaysian Standards 1515. The energy consumed by the external water pumps circulating the chilled water and the heat rejection device, such as cooling tower or heat exchanger, is not included in the coefficient of performance for the ACMV system component unless the manufacturer integrates the device into the package.

Table 1.3: Unitary Air Conditioners Minimum CSPF – Cooling Requirements

Equipment		Size	Minimum CSPF	
			Non-inverter type	Inverter type
Air-cooled condenser (or evaporative cooled)	<14.65 kWr	Single split	3.0	3.0
	≥ 14.65 kWr and <35 kWr	Split/Package/Multiple split (including VRF)	3.1	3.7
	≥ 35 kWr	Split/Package/Multiple split (including VRF)	3.0	3.2
Water-cooled condenser	<19 kWr	Split/Package/Multiple split (including VRF)	3.9	4.7
	≥ 19 kWr and <35 kWr	Split/Package/Multiple split (including VRF)	4.0	4.8
	≥ 35 kWr	Split/Package/Multiple split (including VRF)	4.1	4.9

CSPF = cooling seasonal performance factor, VRF = Variable Refrigerant Flow.
Source: MS1525:2019, Malaysian Standard.

Table 1.4: Water Chilling Packages, Electrically Driven: Chiller Energy Performance Rating

Equipment	Size	[a]COP at 100% Load at Malaysian Test Condition		[c]MPLV at Malaysian Standard Condition		[b]COP at 100% Load at Standard AHRI Test Conditions		IPLV at AHRI Standard Conditions	
		Min COP	Max kWe/RT	Min COP	Max kWe/RT	Min COP	Max kWe/RT	Min COP	Max kWe/RT
Air cooled, with condenser	< 105 kWr (30 RT)	2.93	1.20	3.36	1.05	2.93	1.20	3.84	0.92
	≥ 105 kWr and < 530 kWr (150 RT)	2.93	1.20	3.36	1.05	2.93	1.20	3.84	0.92
	≥ 530 kWr and < 1060 kWr (300 RT)	2.93	1.20	3.52	1.00	2.93	1.20	3.93	0.90
	≥ 1060 kWr (300 RT)	2.93	1.20	3.52	1.00	2.93	1.20	3.93	0.90
Water cooled, positive displacement (reciprocating, scroll, rotary, and screw)	< 260 kWr (75 RT)	4.56	0.77	4.35	0.81	4.74	0.74	5.86	0.60
	≥ 260 kWr and < 530 kWr (150 RT)	4.56	0.77	4.35	0.81	4.74	0.74	5.95	0.59
	≥ 530 kWr and < 1060 kWr (300 RT)	5.20	0.68	4.67	0.75	5.43	0.65	6.36	0.55
	≥ 1060 kWr (300 RT)	5.68	0.62	5.06	0.69	5.95	0.59	6.84	0.51

Water cooled, centrifugal	< 1060 kWr (300 RT)	5.60	0.63	5.27	0.67	5.86	0.60	6.15	0.57
	≥ 1060 kWr and < 2110 kWr (600 RT)	6.15	0.57	5.68	0.62	6.36	0.55	6.71	0.52
	≥ 2110 kWr (600 RT)	6.26	0.56	5.86	0.60	6.48	0.54	6.84	0.51

[a] Tested at Malaysian chilled water and condenser water temperatures.
[b] Tested at AHRI leaving chilled water temperature at 44^{0}F at 2.4 USGPM per tonne and entering water temperature of 85^{0}F at 3 USGPM per tonne.
[c] MPLV denotes Malaysia Part Load Value, which is a single-part load efficiency figure of merit calculated per method described in MS2449 at Malaysian Standard Rating Conditions, where for part-load entering condenser water temperatures (ECWT), the temperature should vary linearly from the selected ECWT at 100% load to 26.67^{0}C (80^{0}F) at 50% load and fixed at 26.67^{0}C for 50% to 0%.
AHRI = Air-conditioning, Heating, and Refrigeration Institute, COP = coefficient of performance , MPLV = Malaysia Part Load Value , IPLV = International Part Load Value.
Source: MS1525:2019, Malaysian Standard.

3.3. High-efficiency motors

Roughly 30 million new electric motors are sold yearly for industrial purposes; some 300 million motors are used in industry, infrastructure, and large buildings. The electric motors system includes controls such as contactor, soft-starters, variable speed drives, coupling accessories such as gear, belt and pulley, clutch and break, and the applications they drive such as pumps, conveyors, fans, and compressors. They are the single largest user of electricity, consuming more than 2.5 times as much as lighting. These electric motors are responsible for 40% of global electricity used to drive pumps, fans, compressors, and other mechanical traction equipment.

The technology of electric motors has also evolved tremendously in the last few decades. Through a selection of efficient motors, the efficiency of the motors will be improved compared to conventional motor systems. It is also notable that the country manufacturing them has also released numerous standards of electric motors.

Many different types of motors are being used globally. Three-phase a.c. induction motors constitute the large majority of motors over 0.75 kW sold worldwide. Therefore, MEPS and voluntary agreements worldwide have focused on this type of motor technology. Although smaller motors (below 0.75 kW or 1 HP) also present significant energy saving potential, they are mostly customised designs, generally incorporated into appliances and equipment, such as refrigerators, air conditioners, and air-handling units whose minimum efficiency performance can be regulated by addressing the whole appliance.

The International Electrotechnical Commission (IEC) has released a global-friendly standard on motors, IEC 60034: Rotating electrical machines. This standard of IEC classification intends to harmonise regional and national standards used in motors so far. This is a positive trend for motor users as it makes it much easier to compare efficiency levels between manufacturers and enables global customers to use the same motor designs.

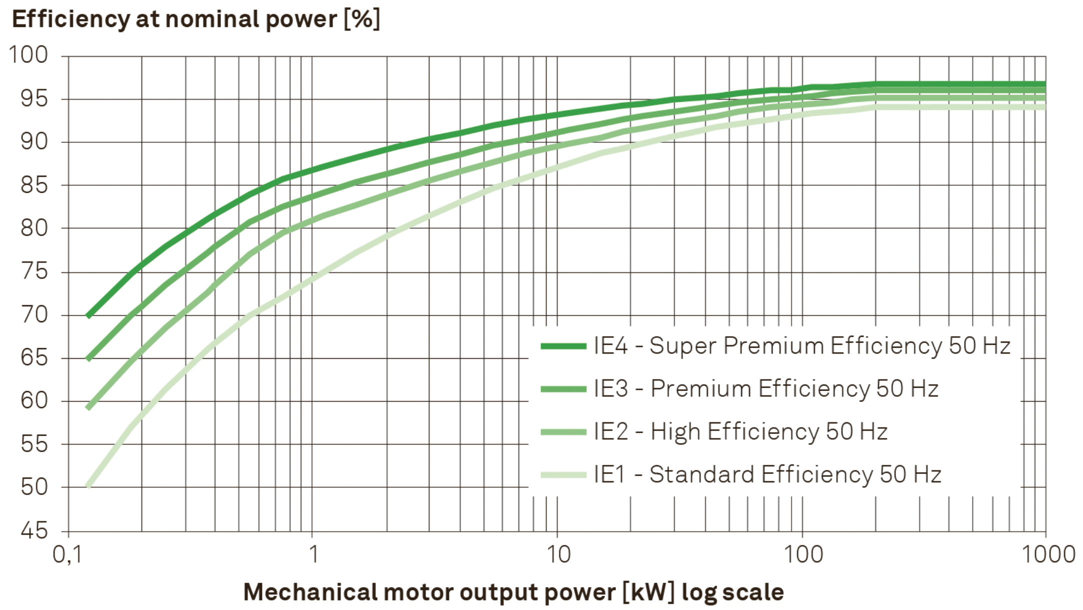
IEC 60034-1 states all the necessary rating plate information. Motors of the covered type always include a permanently attached durable nameplate. This nameplate includes the necessary information to install and operate the motor correctly. This information may consist of connections, horsepower or kW, design code, power supply, amps, and nominal motor efficiency expressed as a percentage of 100% at full load.

IEC 60034-2-1:2014 is published and defines the standard methods for determining losses and efficiencies from tests. This standard applies to d.c. machines and to a.c. synchronous and induction machines of all sizes within the scope of IEC 60034-1.

IEC 60034-30:2014 defines the efficiency classes for the motors. This IEC standard is concerned with the global harmonisation of energy efficiency classes for electric motors. The latest standard significantly expands the range of products covered with eight-pole motors and introduces IE4 efficiency performance class for electric motors. The standard defines four international efficiency (IE) classes for single-speed electric motors rated according to IEC 60034-1 or IEC 60079-0 (explosive atmospheres) and designed for operation on sinusoidal voltage. The four classes are (i) super-premium efficiency (IE4), (ii) premium efficiency (IE3), (iii) high efficiency (IE2), and (iv) standard efficiency (IE1).

Figure 1.5 shows a graphical presentation of this type of motor.

Figure 1.5: Efficiency (%) vs Mechanical Motor Output Power (KW) as per IEC 60034-30:2014 Classes



Source: IEC 60034-30:2014.

The new standard covers a broader scope of products. The power range has been expanded to cover motors from 120 W to 1,000 kW. All technical constructions of electric motors are covered as long as they are rated for direct online operation. The coverage of the new standard includes the following:

- Single-speed electric motors (single- and three-phase power supply), 50 and 60 Hz;
- Two, four, six, or eight poles;
- Rated output nominal power from 0.12 kW to 1,000 kW;
- Rated voltage nominal voltage above 50 V up to 1 kV;
- Motors capable of continuous operation at their rated power with a temperature rise within the specified insulation temperature class;
- Motors marked with any ambient temperature within the range of -20 °C to +60 °C; and
- Motors marked with an altitude up to 4,000 m above sea level.

The following motors are excluded from IEC 60034-30-1:

- Single-speed motors with 10 or more poles or multi-speed motors;
- Motors completely integrated into a machine (for example, pump, fan, or compressor) that cannot be tested separately from the machine; and
- Brake motors when the brake cannot be dismantled or separately fed.

However, most of the national MEPS only apply to general purpose motors. This is because motor efficiency is sometimes compromised by design restrictions imposed by special working requirements, such as motor specifically designed for special requirements of the driven machine like heavy starting duty, special torque stiffness and/or breakdown torque characteristics, large number of start and stop cycles, and very low rotor inertia.

All motors shall be tested according to IEC 60034-2-1:2014 or IEEE 112:2004.

Test reports from the following laboratories are accepted:

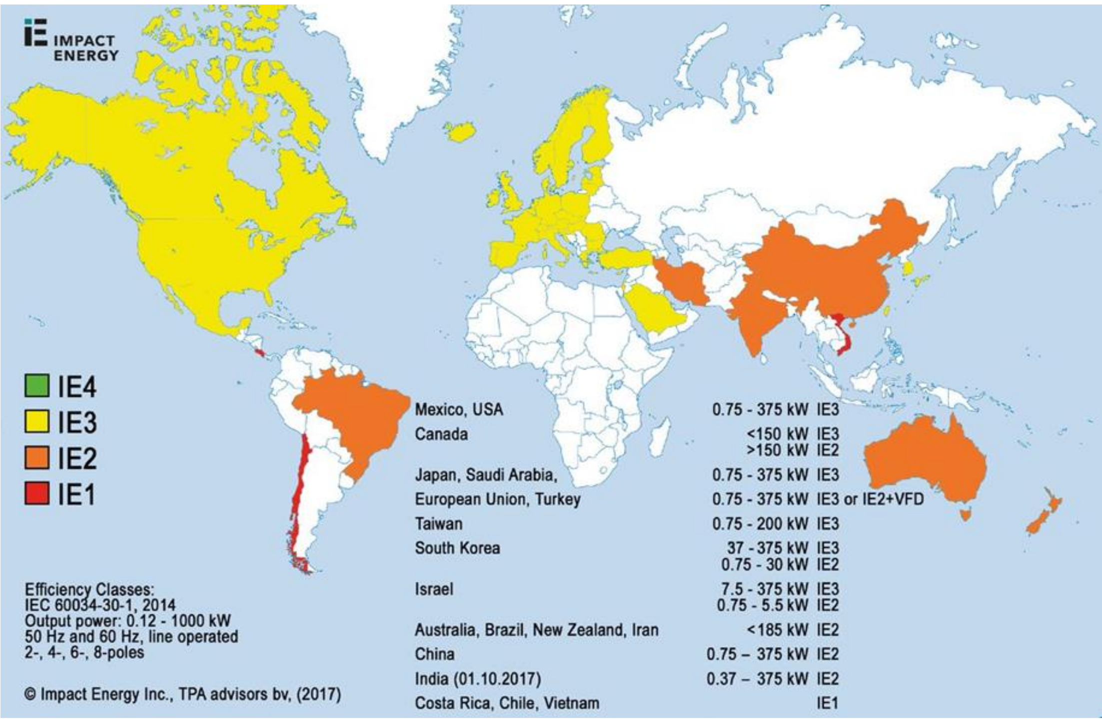
1) manufacturers' in-house test laboratories, and
2) test laboratories that have been accredited to carry out the test under the applicable test.

The demand and awareness of the high-energy efficiency motors are still at the infant stage. A study by Impact Energy Group 2017 showed that a small portion of the countries have made motors achieving IE2 and above standards mandatory. In general, most countries have not adopted the IEC efficiency classes as a benchmark for motors. Figure 1.6 depicts the overall global IEC efficiency classes in relation to the IEC efficiency classes.

Some concerns in implementing the minimum energy performance requirement for motors are listed below:

1) Currently, most of the motors used in the market are IE 1 motors.
2) Most of the installed motors are in operation for more than 15 years.
3) Operators are not concerned with motor efficiency and life cycle costs.

Figure 1.6: Global MEPS Mapping Based on Classification of IEC IE Efficiency



IE = internal efficiency.
Source: UNEP (2017).

3.4. Lighting

As outlined in Appendix 1: Fundamentals of Energy Efficiency in Buildings, the share of lighting energy in an office building could be as much as 27%, which is the second-largest proportion of energy consumption besides the ACMV system. Therefore, it is prudent to prioritise lighting to be listed in the MEPS and labelling programme.

Selection of inefficient light fittings and inefficient lighting design will cause unnecessary higher lighting power. It will also increase the cooling load because higher lighting energy will end up as heat in buildings. In other words, the ACMV capacity will need to be increased due to the increased cooling load. This will result in higher equipment and operating costs due to the higher air-conditioning load.

Luminous efficacy is an indicator of the efficiency of lamps. The higher efficacy values indicate higher efficiency, producing more light for the same energy used. It is defined as:

$$Efficacy = \frac{Lumen}{Watt}$$

Hence, the MEPS commonly used will be the measured efficacy of the lamp in lumen/watt, which shall be determined under the relevant standards set. Table 1.5 outlines the efficacy of various types of lamps in the Malaysian Standard; MS 2598:2014 Minimum Energy Performance Standards for Lamps.

3.5. Summary of MEPS

Given the advancement of product technology and more vigorous energy-saving initiatives globally, MEPS and labelling programme are evolving product requirements. Therefore, its periodic review is imperative to ensure the programme keeps up with advances in technology. As a result, new or revised MEPS or labelling requirements may be introduced, especially for regulated products, from time to time. Also, subject to the development of energy-efficient products, MEPS and labelling requirements should be reviewed and updated from time to time for new products and improved energy performance of products.

It is recommended that the MOE embark on a harmonisation programme to expedite the implementation of MEPS and the labelling programme to be ready for the adoption of EEC guidelines in Temburong ecotown development. The programme is based on selected member state/s in the ASEAN region, without setting up testing facilities soon. However, for long-term planning, Brunei Darussalam may want to consider setting up testing facilities. Nevertheless, for Temburong development, the adoption of MEPS should become a mandatory requirement for designated buildings in selecting appliances and equipment, which are listed in the MEPS and labelling programme.

Table 1.5: Minimum Efficacy (lm/w) for Various Types of Lamps and Ratings

Type of Lamp	**Self-ballasted Single-capped Lamps [Compact Fluorescent Lamps (CFL)] for General Lighting Services**
Lamp rating (W)	**Minimum efficacy (lm/W)**
< 9	46
≥ 9 to < 15	52
≥ 15 to < 25	55
≥ 25	62
Type of Lamp	**Single-capped fluorescent lamps (non-integrated compact fluorescent lamps) and circular fluorescent lamps for general lighting services**
Lamp rating (W)	**Minimum efficacy (lm/W)**
< 10	46
≥ 10 to < 19	55
≥ 19 to < 52	59
≥ 27	70
Type of Lamp	**Self-ballasted Light Emitting Diode (LED) lamps for general lighting services**
Lamp cap type (as in MS IEC 60061-1)	**Minimum efficacy (lm/W)**
G13	75
GU10	50
E27 or B22d	60
E14	60

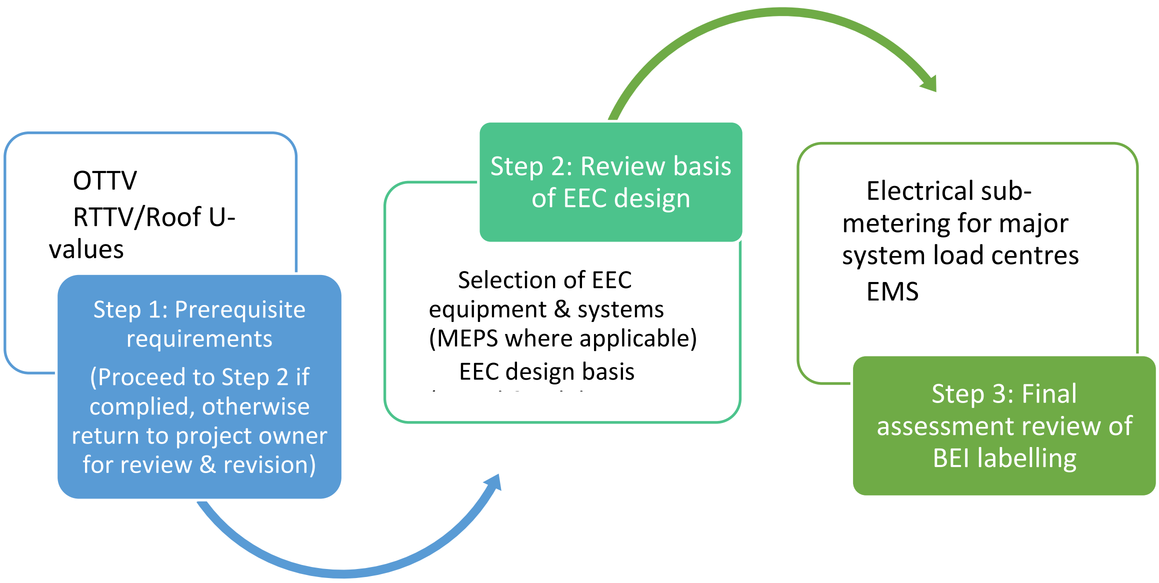
Source: MS 2598:2014.

4. Assessment and Compliance Method

The achievement of energy-efficient buildings does not just rely on one EEC measure or method but on a combination of passive and active EEC design measures, as highlighted in Section 1.3 and Appendices 1 and 2. Passive design measures must be incorporated first before the active systems in a building are designed (Figure 1.2). Accordingly, the EEC section of the building development (or EEC building design) submission should be first assessed for compliance with the passive design requirements, which are minimum EE performance, before assessing other aspects of EEC building design. Hence, basic passive design measures are prerequisite requirements (Figure 1.7).

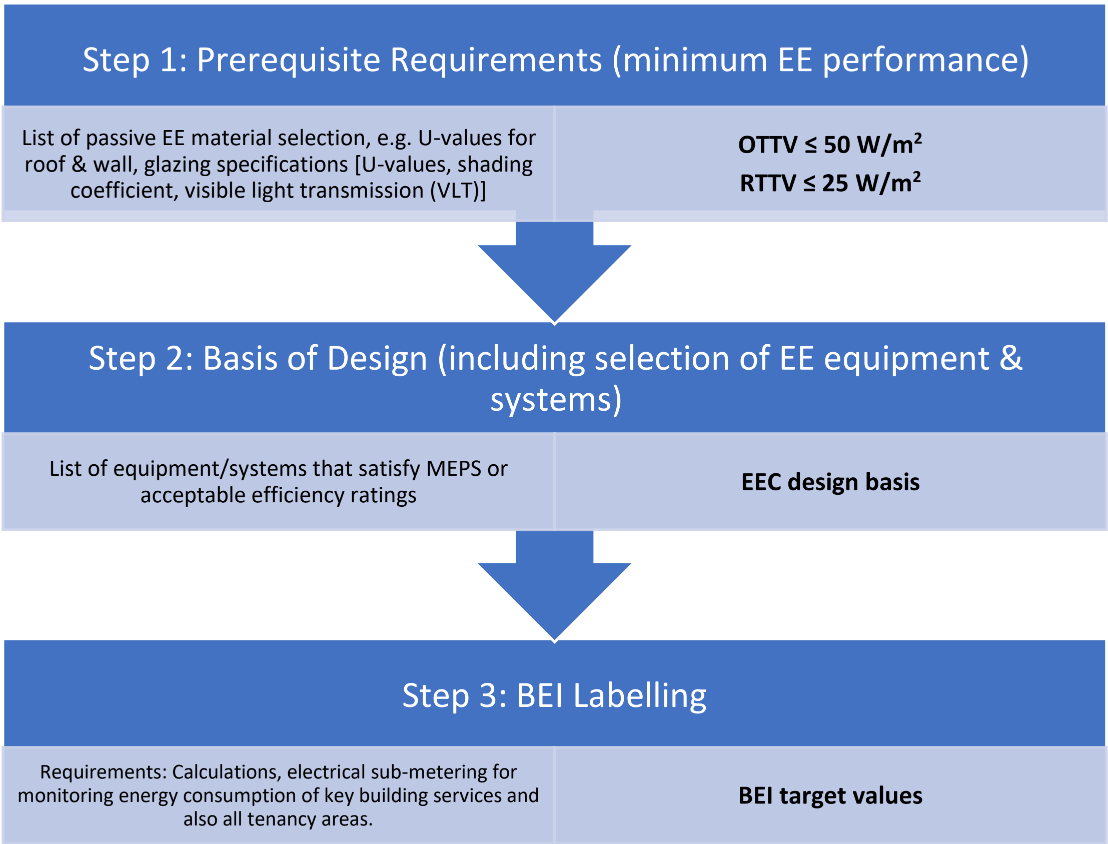
The EEC building design submission should be assessed for compliance in three areas: (i) passive design requirements, (ii) basis of design (BoD) (which includes a selection of equipment/system based on MEPS), and (iii) BEI labelling comprising target values. The basis and sequence of assessment are summarised in Figure 1.8, which shows the steps and methodology to be used as an EEC building design approval procedure. Therefore, Figures 1.7 and 1.8 show the flow of EEC building assessment activities. This aspect of the guideline on the assessment and compliance method is recommended to the MOE for review and adoption in establishing EEC buildings in Temburong.

Figure 1.7: Overview of Procedures for EEC Building Design Assessment



BEI = building energy intensity, EEC = energy efficiency and conservation, EMS = energy management system, OTTV = overall thermal transfer value, RTTV = roof thermal transfer value
Source: Author.

Figure 1.8: EEC Building Design Assessment Criteria and Flowchart



BEI = building energy intensity, EE = energy efficiency, EEC = energy efficiency and conservation, MEPS = minimum energy performance standard.
Source: Author.

Figure 1.8 shows the three steps of EEC building design assessment: (i) prerequisite requirements, (ii) BoD, and (iii) BEI labelling checks. The intents of these assessment steps are explained as follows:

1) Step 1: Prerequisite requirements

- The prerequisite requirements intend to establish the minimum energy performance, which is the first step in establishing the EEC building design. Meeting the prerequisite requirements is mandatory (refer to Table 1.6 for details of compliance checks). Therefore, further assessment of the EEC design submission will not proceed if these requirements are not satisfied, i.e. such submission will need to be queried, clarified or reviewed, revised, and resubmitted if the initial submission failed to meet the requirements.

2) Step 2: Basis of design (BoD)

- The BoD aims to ensure that building designers are knowledgeable on EEC design and have paid attention to sound BoD on EEC design criteria (refer to Section 4.2 for details).
- Step 2 will allow the assessment team to examine the basis of EEC design, which includes selecting appliances, equipment, and systems following the MEPS, where

applicable. Building designers must also declare other BoDs in EEC building design submission, as detailed in Section 4.2. This is an essential step of the assessment because information on BoD will provide bases or clues for the eventual compliance of the step 3 assessment on BEI labelling. For example, if BEI calculation shows good BEI value but the information given in the BoD does not correlate with the BEI calculation, more detailed checks and queries, including clarifications, will need to be carried out.

3) Step 3: BEI labelling

- BEI labelling intends to ensure that the energy efficiency performance of designated buildings in Temburong exceeds the SED's baseline BEI values.
- The step 3 assessment is the final EEC building assessment step, a design assessment based on the design estimation of BEI values. It does not cover the completion and verification assessment upon building completion and occupancy.
- The records of BEI values are recommended to be submitted to SED yearly during the designated buildings' operation for subsequent monitoring purposes to ensure sustainability in building energy performance of designated buildings.

4.1. Minimum energy efficiency performance

Minimum energy efficiency performance is recommended to be the prerequisite requirements before any further assessment is made. The minimum EE performance requirements are based on the details given in Section 3.1. Assessment is made based on building envelope calculations on the criteria listed in Table 1.6.

Table 1.6: Prerequisite Energy Efficiency Performance Requirements

	Prerequisite Requirements	Remarks
Overall Thermal Transfer Value (OTTV)	OTTV ≤ 50 W/m^2	Calculations based on PBD 12 EEC:2015 Energy Efficiency & Conservation Building Guidelines Plans and elevations marking out walls and apertures used for the calculation to be in blue; walls and apertures not used for the calculation to be in red. Preferred scale of plans: 1:200.
Roof Thermal Transfer Value (RTTV)	RTTV ≤ 25 W/m^2 (Applicable if building roof is provided with skylight and the entire enclosure below is fully air-conditioned, e.g. atrium.)	Calculations based on PBD 12 EEC:2015 Energy Efficiency & Conservation Building Guidelines
Maximum U-value for roof	Lightweight (Non-concrete roof construction): ≤ 04(W/m^2 K) Heavyweight (concrete roof construction): ≤ 0.6 (W/m^2 K)	The roof shall not have a thermal transmittance (U-value) greater than these values.

Source: MS1525:2019, PBD12 EEC:2015.

4.2. Basis of design (BoD)

Information based on EEC building design, including the selection of appliances, equipment, and systems in compliance with MEPS, where applicable, is required to be included in the EEC building design submission for assessment purposes. This is one way of ensuring that the sound basis of EEC building design is adopted in the design of designated buildings in Temburong. By providing such information, the SED assessment team has another avenue to review the extent of EEC design considerations that allow the BEI baseline values to be achieved.

4.2.1. Selection of Energy Efficiency Equipment and Systems

In addition to the air-conditioning system (in terms of high coefficient of performance or low kW/RT), the use of other electrical appliances and equipment, collectively referred to as plug load, should not be overlooked as both contribute significantly to energy consumption in buildings. Where applicable, appliances and equipment meeting the MEPS requirements are recommended to be used. The use of energy-efficient plug load equipment provides twofold benefits. Firstly, energy-efficient plug load equipment consumes less electricity. Secondly, equipment consuming less energy will produce less heat in a space, which means that such equipment will help reduce the cooling load in the building. Therefore, the selection of energy-efficient equipment and systems can be taken as helping achieve the BEI target in EEC building design. The review of the plug load equipment should be based on the guidelines in MEPS, where available; otherwise, MEPS from other countries may be used for reference. In general, equipment and systems having energy efficiency ratings should be used.

4.2.2. EEC BoD

Other contributing factors towards reducing energy consumption and lowering BEI values are avoiding overdesign in areas such as lighting, air-conditioning and mechanical ventilation, temperature control, electric power and distribution, lifts, and escalators. The objective of EEC BoD is to ensure that the design computation of BEIs for the step 3 assessment is based on sound and valid EEC criteria. For the details of design criteria of various services, refer to PBD 12 EEC:2015 Guidelines (or MS1525:2019 for updated reference). Therefore, for assessment purposes, EEC building design submission must provide information on BoD concerning EEC. The following are examples of EEC BoD.

a) Lighting[5]

– Specify average illuminance levels in design, examples:
  - o Lighting for infrequently used area
    - ▪ Interior walkways and car parks: 100 Lux
    - ▪ Hotel bedrooms: 100 Lux
    - ▪ Corridors, passageways, stairs: 100 Lux
  - o Lighting for working interiors
    - ▪ General offices, shops and stores, and writing: 300–400 Lux
    - ▪ Restrooms, bathrooms: 150 Lux

[5] PBD 12 EEC:2015 Energy Efficiency & Conservation Building Guidelines (& MS1525:2019 for updated reference).

  - Restaurants, canteens, cafeterias: 200 Lux
  - Shops/supermarkets/department stores: 200–750 Lux
  - Classrooms, libraries: 300–500 Lux
- Interior building lighting power density, examples are given in Table 1.7.

Table 1.7: Interior Lighting Power Density (including Ballast Loss) Allowance for Typical Building Area

Type of Usage	Maximum Lighting Power Density (W/m^2)
a) Lighting for infrequently used areas:	
– Minimum service illuminance	3
– Interiors	5
– Lift interiors	5
– Corridors, passageways, stairs	5
– Escalators, travellators	6
– Entrance halls, lobbies, waiting rooms	5
– Inquiry desks	11
– Guard houses	8
b) Lighting for working interiors	
– Infrequent reading and writing	8
– General offices, shops and stores, reading and writing	12
– Restrooms	6
– Restaurants, canteens, cafeterias	8
– Kitchens	11
– Lounges	6
– Bathrooms	6
– Toilets	5
– Bedrooms	5
– Classrooms, libraries, reading areas	15
– Retail stores	24
– Museums and galleries	11
– Proofreading	18

Source: MS1525:2019.

Table 1.8: Maximum Lighting Power Intensity Allowance of Building Exteriors

Building Exteriors	Maximum Lighting Power Intensity
Uncovered parking areas	2
Uncovered driveways	2
Pedestrian malls	5
Landscape areas	5

Source: MS1525:2019.

b) *Air-conditioning hydronic system*

– In addition to selecting energy-efficient chillers for chilled water system, it is important to design the water pumping system with a system power exceeding 7.5 kW and operating for more than 750 hours a year, following the system efficiency listed in Table 1.9. For further design details, refer to MS1525:2019.

Table 1.9: Maximum Power Consumption for Pumping System

Type of Pumping System	Maximum Power Consumption $[W/(m^3/h)]$
Condenser water pump	84
Chilled water pump	97

Source: MS1525:2019.

4.3. BEI labelling

BEI labelling, assessment step 3, is the final step in the EEC building assessment. It evaluates building energy performance based on the design for designated buildings in Temburong with respect to the baseline BEI values set by SED. Reference values are shown in Table 1.2. BEI values would be evaluated according to the target values of the same building subsector or building category. In other words, the BEIs of office buildings, retail malls, hotels, hospitals, etc. are compared with the respective target value of the same category or type of building.

Although the assessment is based on BEI calculations in EEC building design submission, it is necessary to ensure that the design includes facilities that will monitor and verify information or data to confirm the BEI performance. This will also help the building owner/operator continuously review and monitor the building's sustainable energy performance. Thus, the following facilities should be included in the design:

a) Electrical sub-metering to provide electricity consumption data for main load centres or significant energy users such as the air-conditioning system including auxiliary equipment like cooling towers, pumps, air-handling units, fan coil units, lighting, lifts and escalators, major water pumping system, plug loads, and any additional item whose energy use ≥ 100 kVA

b) Building energy management system (BEMS)
   1. BEMS requirements shall comply with PBD12 EEC:2015, Brunei.
   2. Up-to-date BEI information and BEI trending graphs to show historical average monthly BEI values for tracking and reporting, which can be used for analysis and energy audit purposes.
   3. The average BEI value computation is required to consider building occupancy rates and operating hours.
   4. BEMS software that monitors energy should be able to do real-time reporting and can compare data against historical data.

Table 1.10 shows the checklist for step 3 assessment.

Table 1.10: Checklist for Step 3 Assessment of EEC Building Design Submission

Assessment Item	Requirements	Remarks
1. Major load centre sub-metering	To check electrical sub-metering load centres: a. Air-conditioning systems incl. auxiliaries b. Lighting c. Lifts and escalators d. Major water pumping systems e. Plug loads f. Tenancy areas, if applicable g. Others (to specify)	To check sub-metering compliance
2. BEMS	To check the provision of BEMS functions: a. Compliance with PBD12 EEC:2015, Brunei b. Computation and monitoring of BEI with tracking and reporting capability for analysis and energy audit purposes.	BEMS will facilitate continuous EEC building operations. Building management and/or owners must submit yearly records of BEI values after building occupancy to monitor and compile energy statistics.
3. BEI labelling	Computed BEI value: a. BEI value to be declared b. BEI calculations to be included	Design BEI value to comply with the target value listed in Table 2.1. If this final item complies with Table 2.1 besides complying with items 1 and 2 of this table, and the requirements in Sections 4.2.1 and 4.2.2 are met after complying with 4.1, the EEC design will be approved.

BEI = building energy intensity, BEMS = building energy management system, EEC = energy efficiency and conservation.
Source: Author.

5. Conclusions

The anticipated Temburong development will offer Bruneians an opportunity to incorporate energy efficiency in developing an ecotown. This opportunity, if seized early and coordinated well, can be translated into several benefits, such as energy and environmental sustainability of an ecotown, showcase of efficient demand-side management in the commercial sector, showcase of greenhouse gas (GHG) reduction, and promotion of ecotourism. If proven successful, the EEC strategies and measures mapped out in this guideline can be implemented for nationwide adoption of EEC practices, contributing to Brunei's energy and environmental sustainability goals. However, the successful implementation of EEC strategies and measures recommended in this guideline will depend on whether the existing regulatory requirements are adequate or whether specific EEC regulations will be introduced. This is because implementation on a voluntary basis would not be effective.

This guideline is intended to assist the MOE, Brunei Darussalam in formulating a plan and a guide for incorporating EEC measures in developing Temburong ecotown. This guideline aims to establish the requirements for EEC practices, minimum building energy performance, and assessment procedure and criteria for the approval of EEC building design submission, which is part of the overall building development plan submission aimed at developing the Temburong ecotown.

This guideline refers to PBD 12 EEC:2015 and MS1525:2019, the established design reference guidelines and standards. The similarities between these documents and this Temburong EEC guideline are the passive and active design methods and measures. However, this guideline focuses on methodology to map out an EEC assessment procedure (complete with compliance criteria), which comprises three steps (as detailed in Section 4) as follows:

Step 1: Prerequisite requirements (mandatory passive design compliance)
Step 2: BoD (including MEPS and other EEC active design bases)
Step 3: BEI labelling (to determine whether the EEC building design submission meets the requirements that include incorporation of BEMS and BEI compliance)

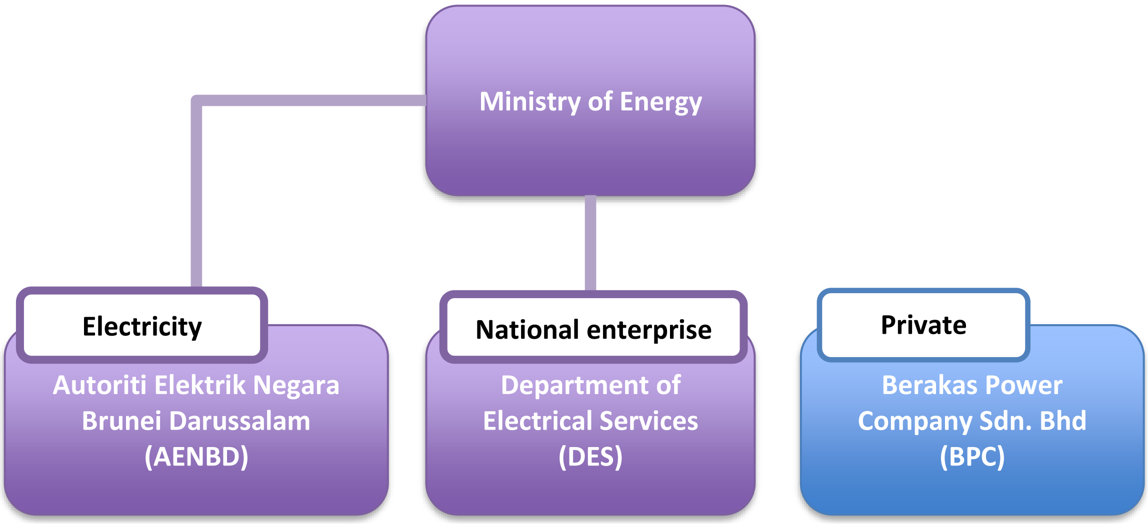
The assessment procedure mentioned provides an avenue for SED to check the steps and basis taken by building designers in their EEC design submissions. As a measure of ensuring sustainability in building energy performance, this guideline recommends that designated premises submit their annual building energy consumption reports, which include actual BEI values recorded in BEMS for continual tracking and verification purposes.

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.

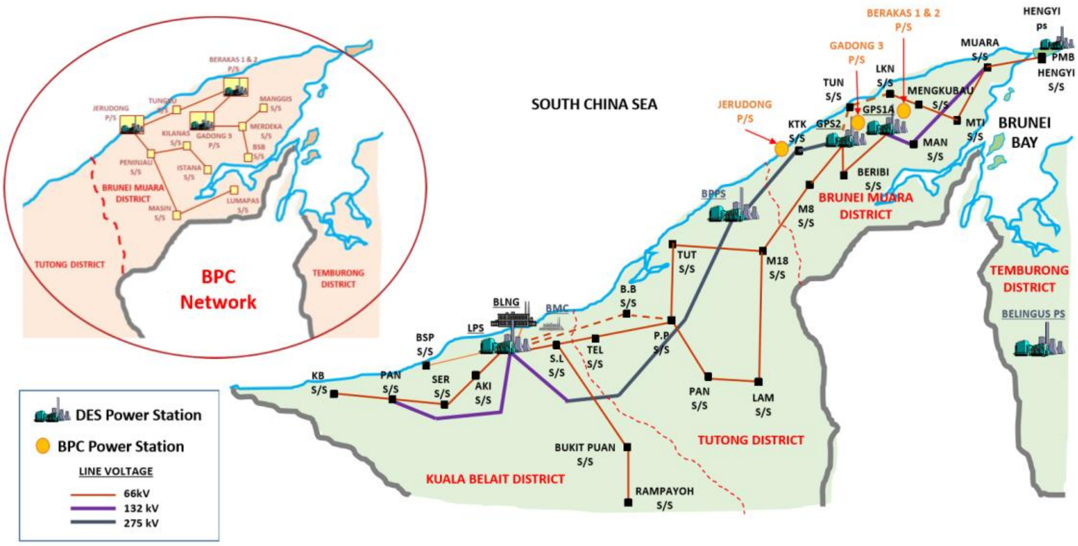
Temburong district is currently an off-grid system, and one diesel power station is operational. There is a plan to synchronise the main grid and the Temburong grid in the future. The interconnection plan with Temburong district will be described later.

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.

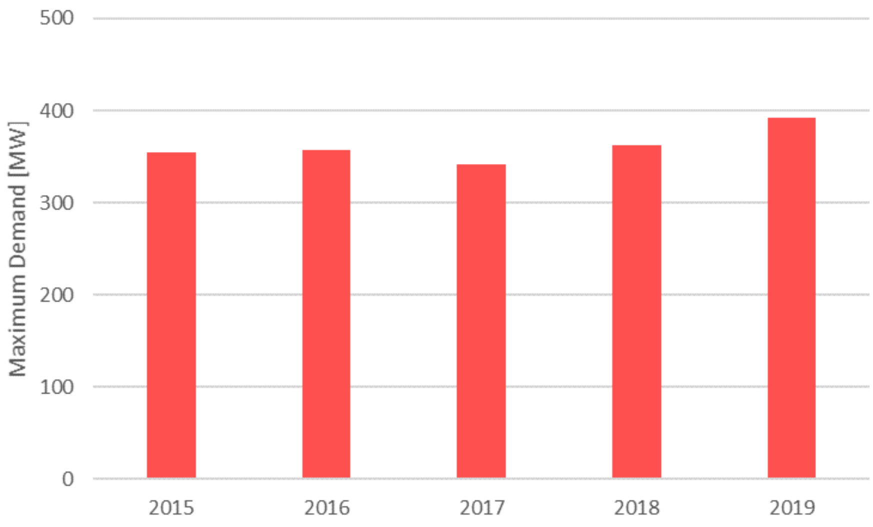
2.2. Power demand

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.

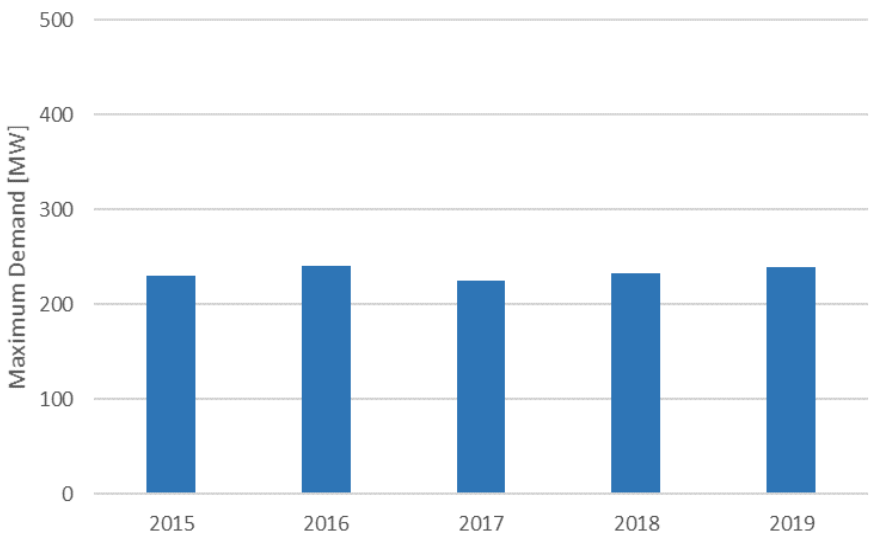
The demand curve in Brunei Darussalam starts to increase gradually in the morning with the start of industries and offices and reaches the daytime peak around 14:00 to 15:00 due to air conditioning. Then it dips around 17:00 with the end of work in some industries and offices and increases again. The 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)



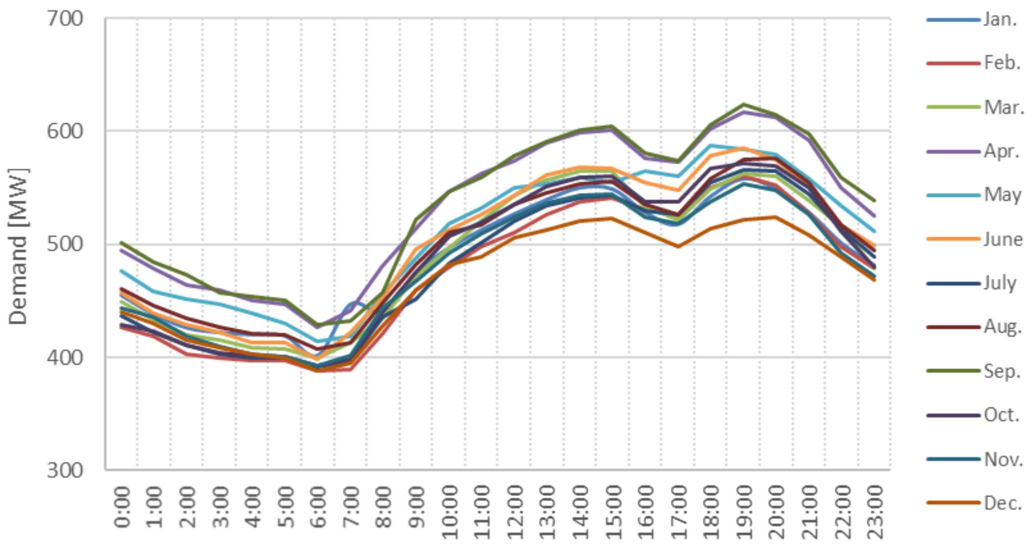
Source: DES data, modified by the author.

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)

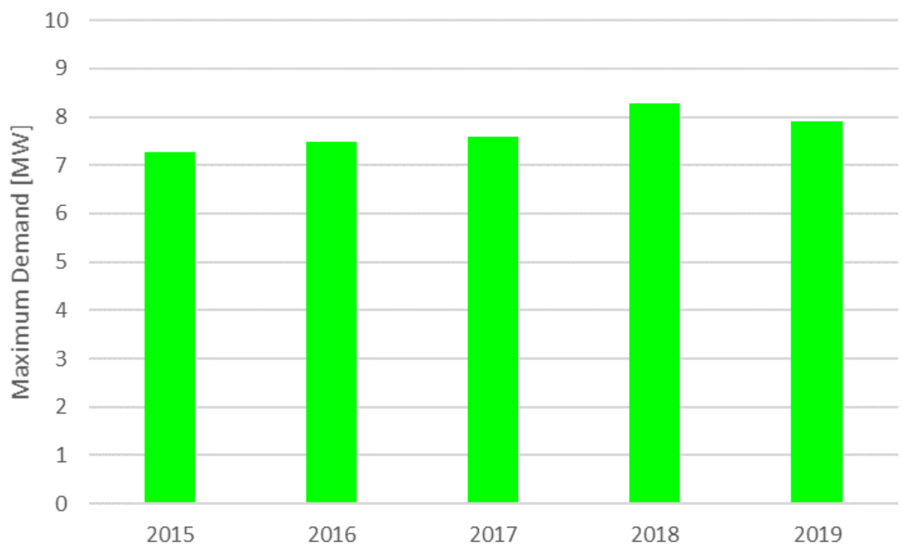


Source: DES and BPC data, modified by the author.

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%.

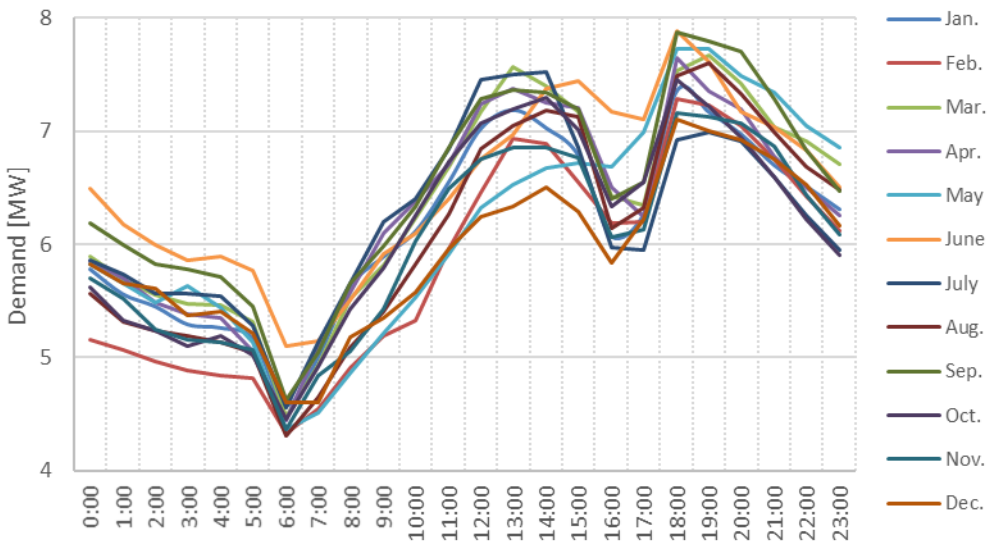
Figure 2.6: Changes in Maximum Demand in Temburong District



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

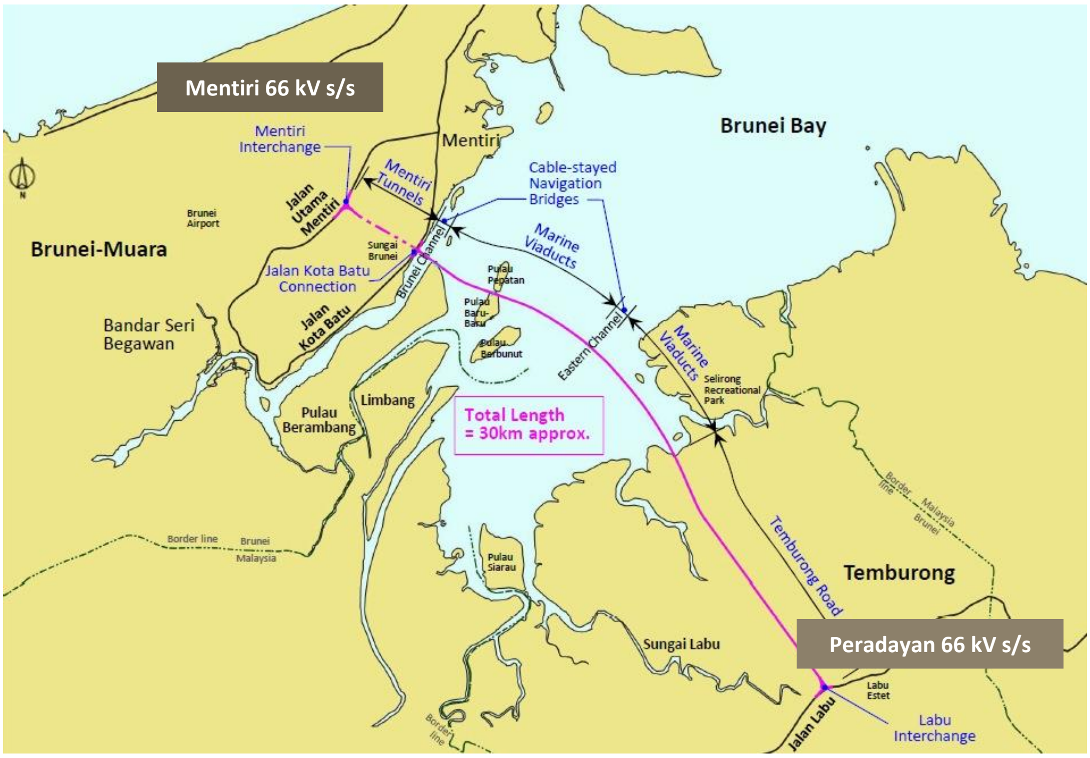
Temburong district is an off-grid system. Electricity is supplied to customers by diesel generators at the Belingus power station. In 2020, the completion of the Temburong Bridge connecting Muara and Temburong districts made it possible to travel between the mainland and Temburong by land.

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



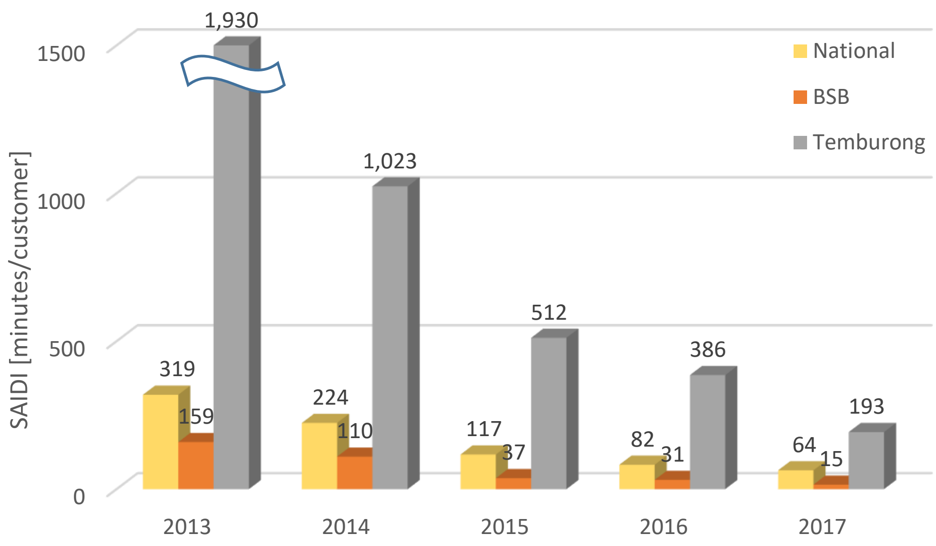
Source: DES.

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.

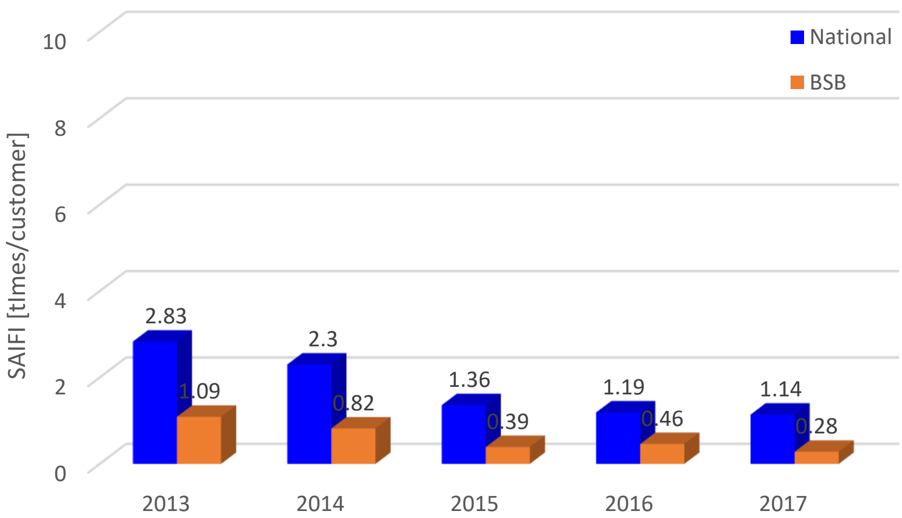
Figures 2.9 and 2.10 show SAIDI in Brunei Darussalam. Table 2.1 shows the power outage over 1 hour in Temburong district instead of its SAIFI. The national, BSB, and Temburong SAIDIs decreased from 2015 to 2019. The national SAIDI improved to about one fifth and that of BSB and Temburong dramatically 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

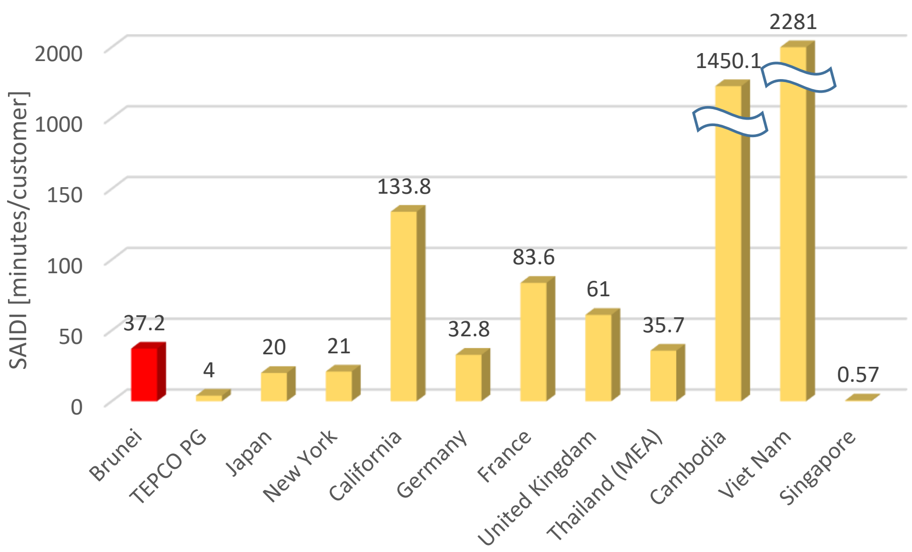
	2013	2014	2015	2016	2017
Temburong district power outage > 1 hour	38	19	17	8	5

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.

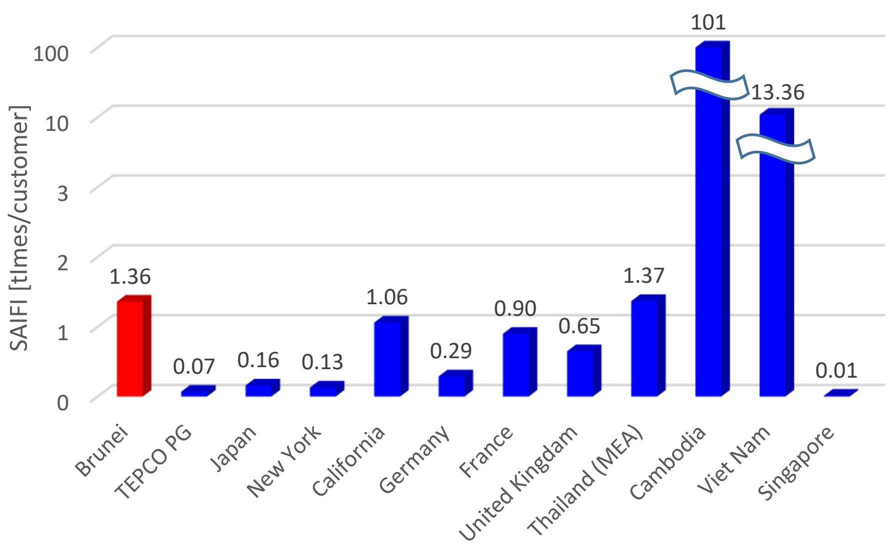
However, the power system reliability of the Temburong district is still low. Therefore, as mentioned, the Temburong transmission line plan is expected to improve further the power system reliability of the Temburong district.

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



Source: Authors.

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



Source: Authors.

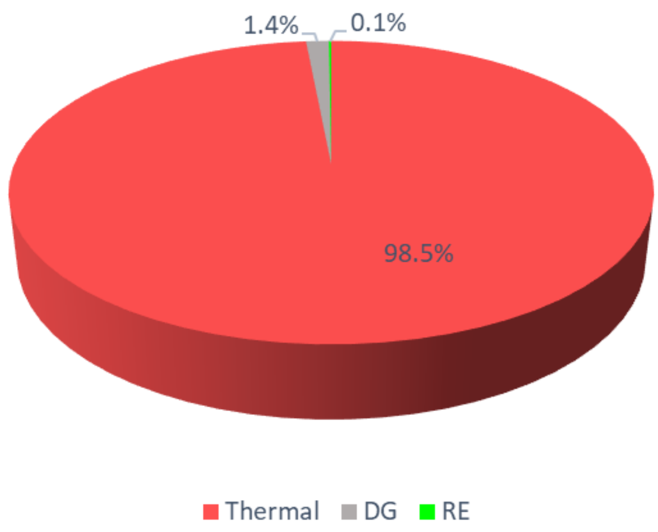
3. Renewable Energy

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.

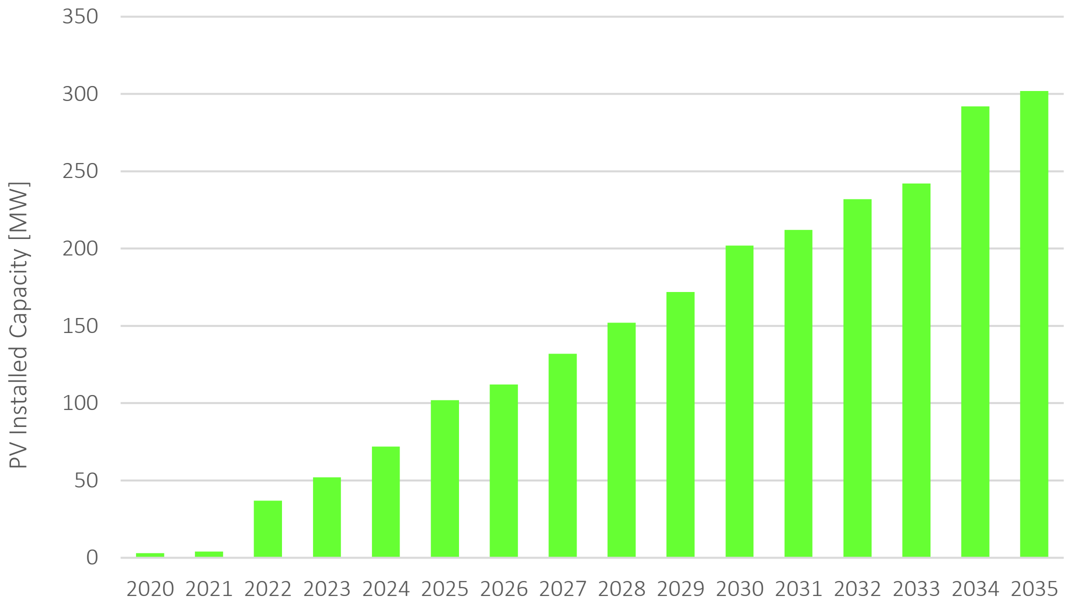
3.2. Renewable energy installation target

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



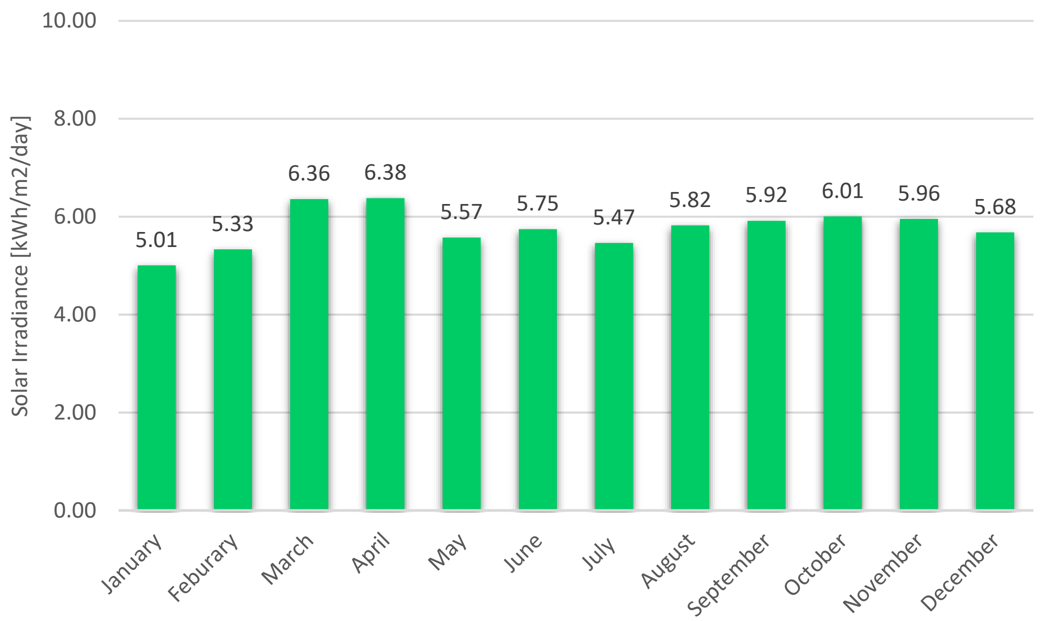
Source: MOE data, modified by the author.

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

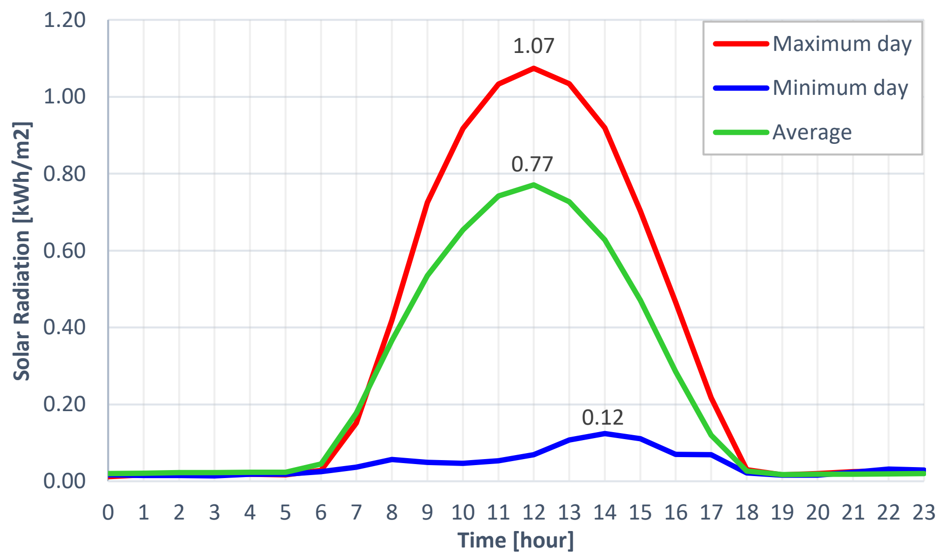


Source: MOE data, modified by the author.

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

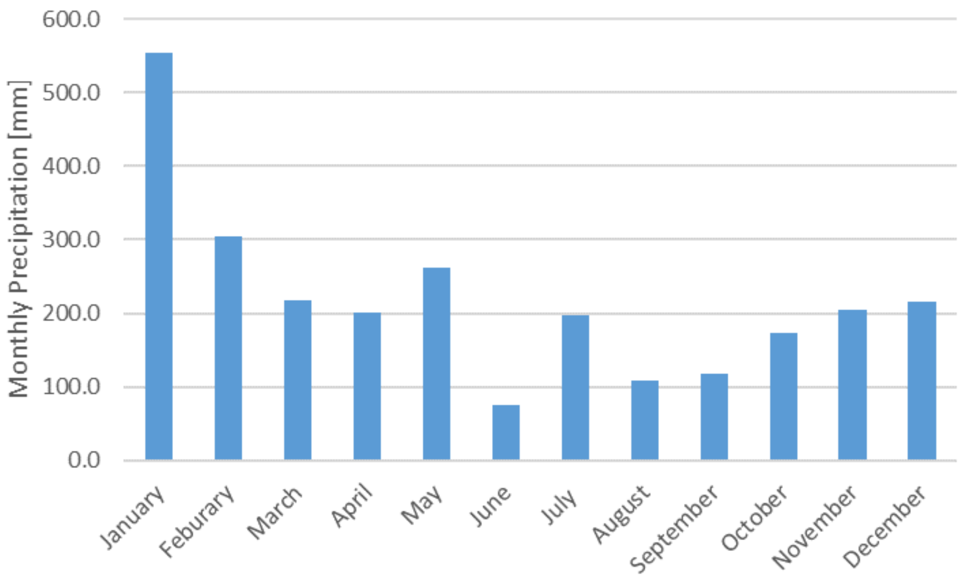


Source: MOE data, modified by the author.

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.

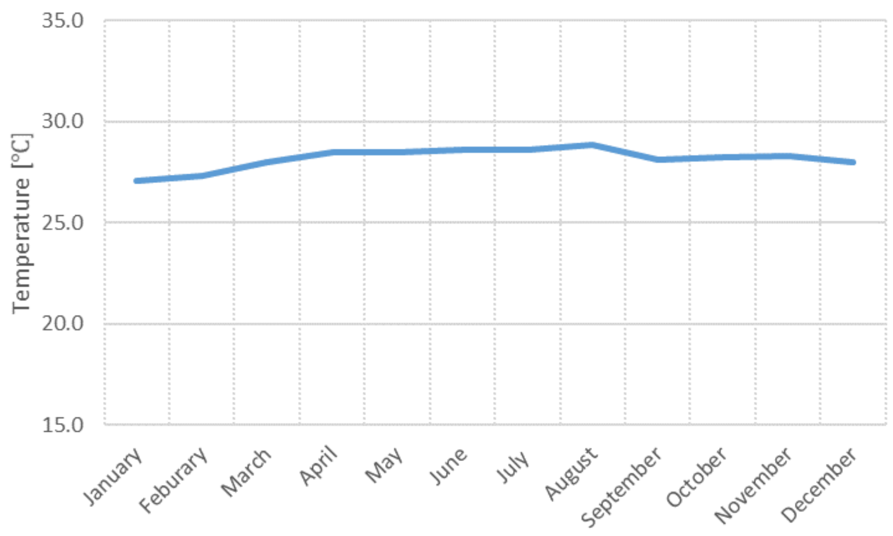
Figure 2.17: Precipitation at Tenaga Suria Brunei Power Station in 2018



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

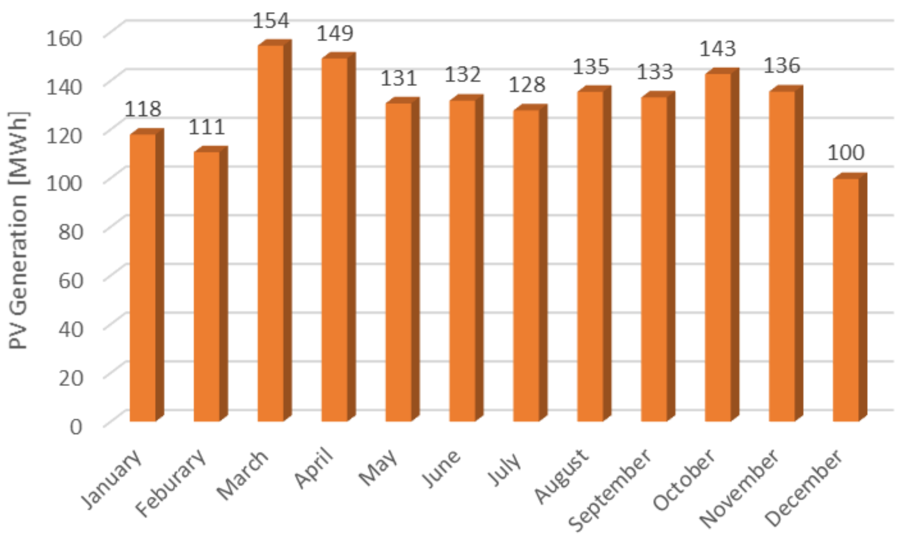


Source: MOE data, modified by the author.

3.4. PV generation at TSB power station

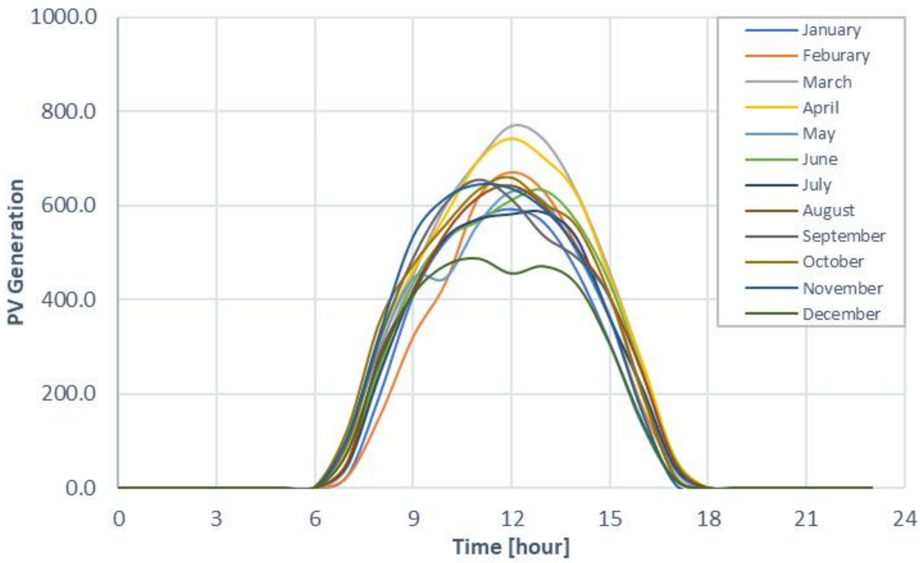
The MOE provides the PV generation data. Figures 2.19 and 2.20 show the monthly PV generation and monthly average hourly PV generation at the TSB power station in 2018, respectively. PV generation was highest in March and April, at 154 MWh and 149 MWh, respectively. The increase in PV generation could 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.

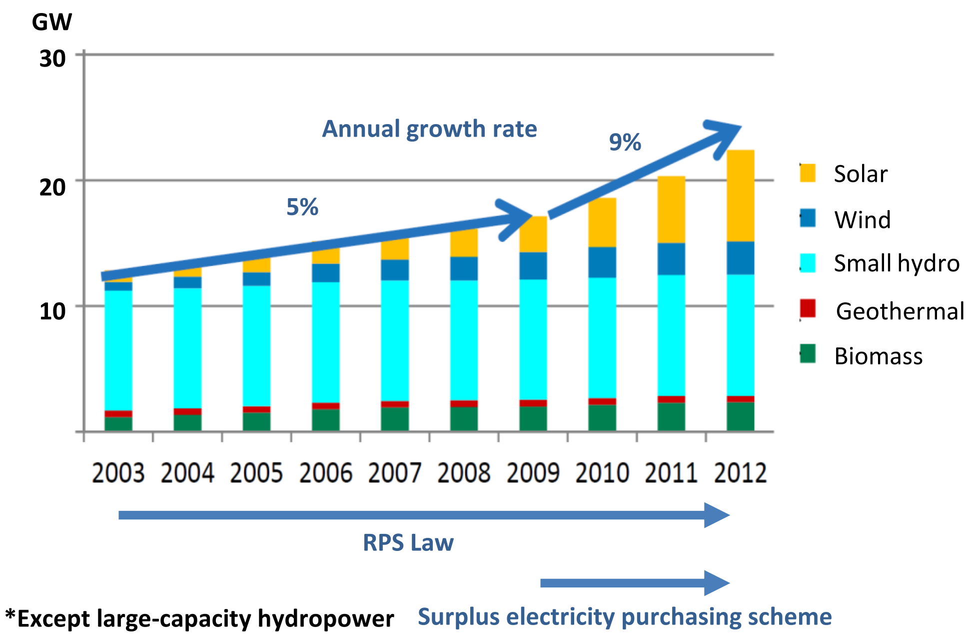
3.6. Promotion of the introduction of renewable energy in Japan

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



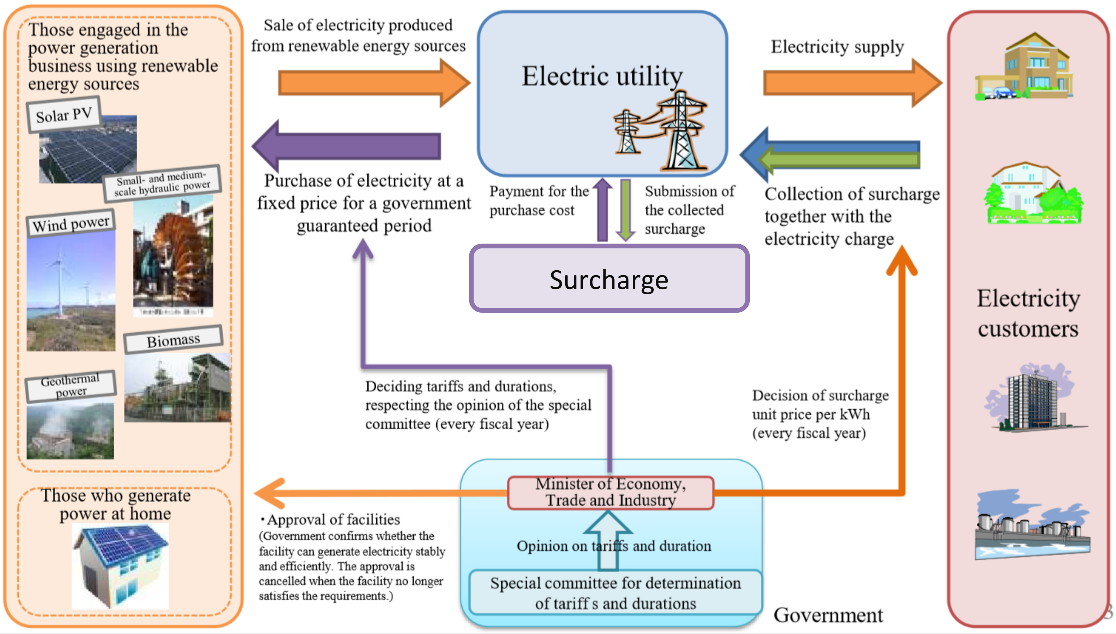
Source: METI (2011).

[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.

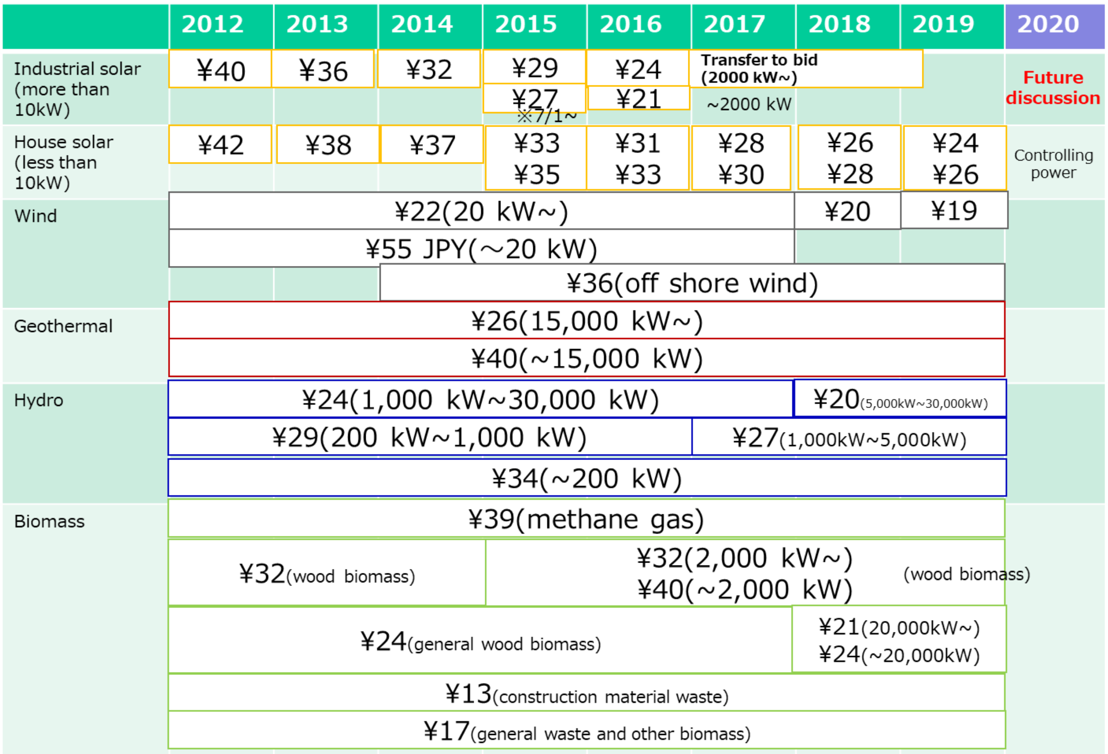
The RPS mandates the vRE generation targets for electric power utilities. FIT mandates them to connect vRE generation, unless there are no grid constraints, and purchase electricity from vRE generation before other generations, except nuclear power, at a fixed price for a long-term period guaranteed 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

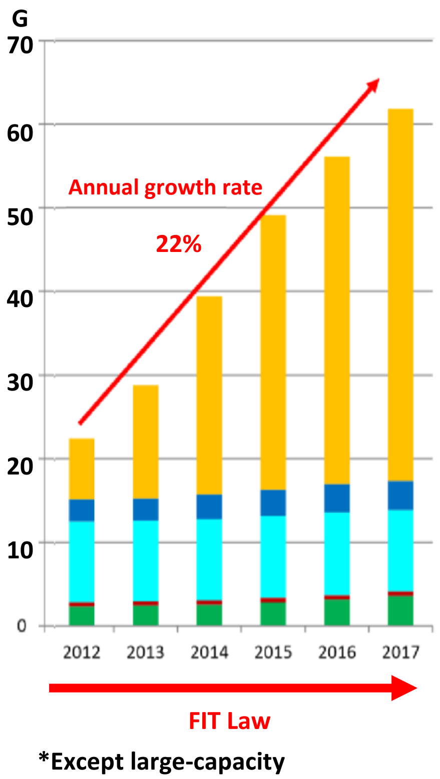


Source: METI (2017).

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).

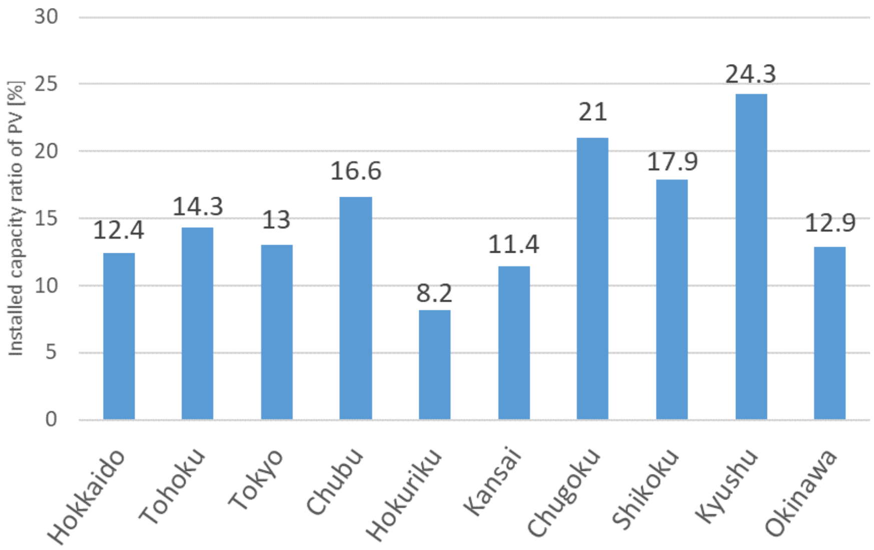
Figure 2.25 shows that the installed capacity ratio of PV in the Kyushu and Chugoku regions has already exceeded 20% of the total power generation capacity. With a large amount of PV introduced, surplus PV power generation has been more serious, especially in the Kyushu region.

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).

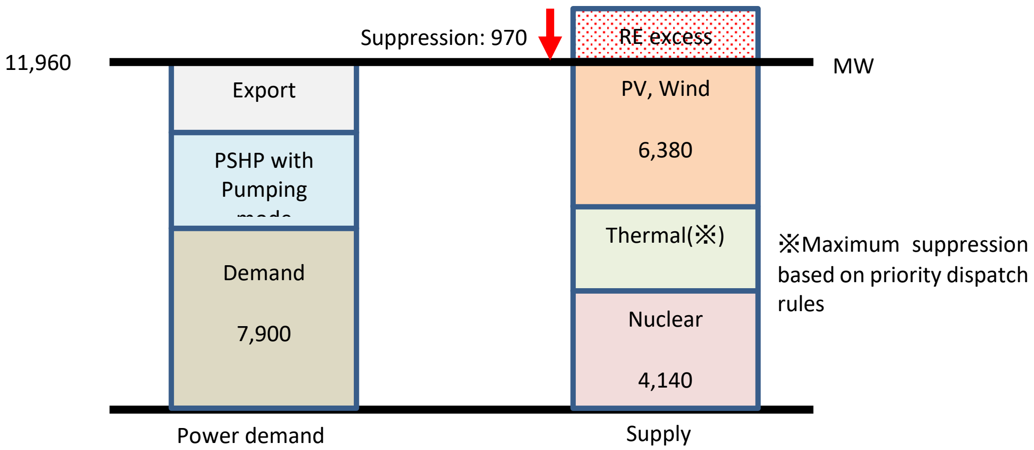
In addition to the Kyushu region are an increasing number of regions where PV generation must be suppressed. To overcome this problem, each electric power utility calculates an appropriate amount of vRE capacity that can be connected to each area under the initiative of the Ministry of Economy, Trade 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



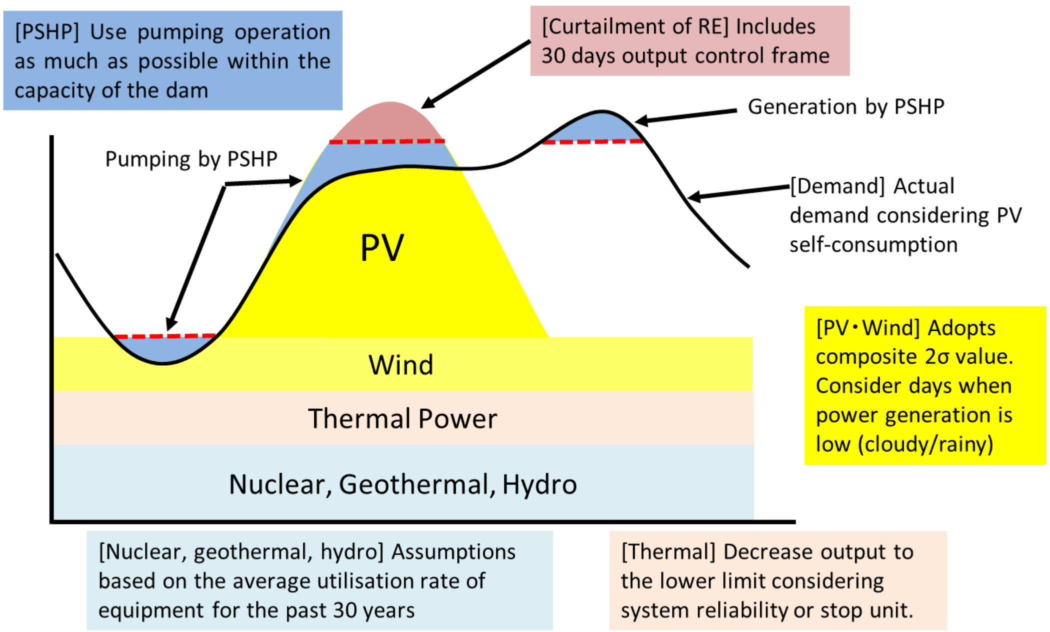
PSHP = pumped storage hydropower, PV = photovoltaic.
Source: Authors.

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

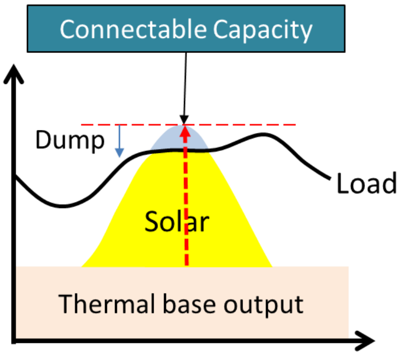


PSHP = pumped storage hydropower, PV = photovoltaic, vRE = variable renewable energy.
Source: Authors.

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.

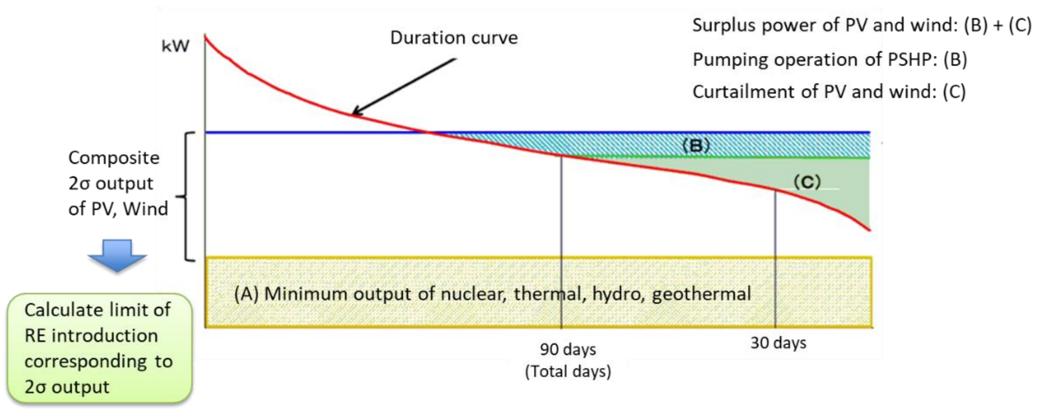
Figure 2.28: Definition of Connectable Capacity

Output-curtailment–acceptable type



Source: Authors.

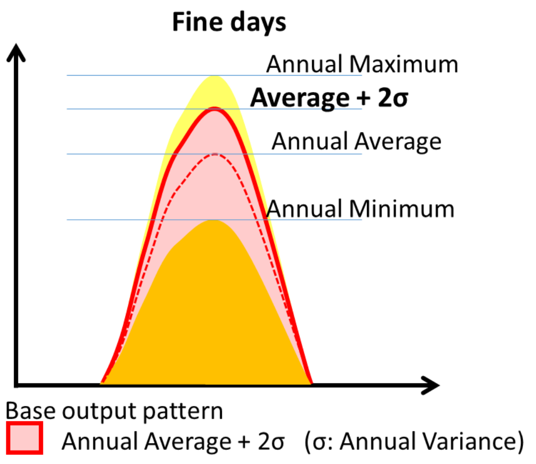
Figure 2.29: Conceptual Figure of Calculation Method for Connectable Capacity of vRE in Japan



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.

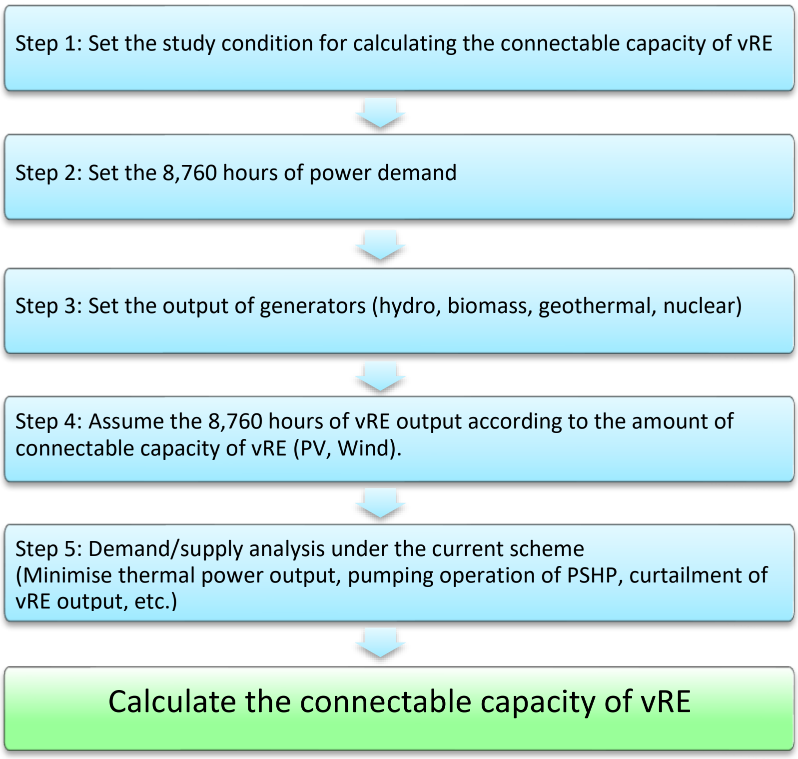
Figure 2.30: Conceptual Figures of Output Pattern of vRE for Connectable Capacity Calculation



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.

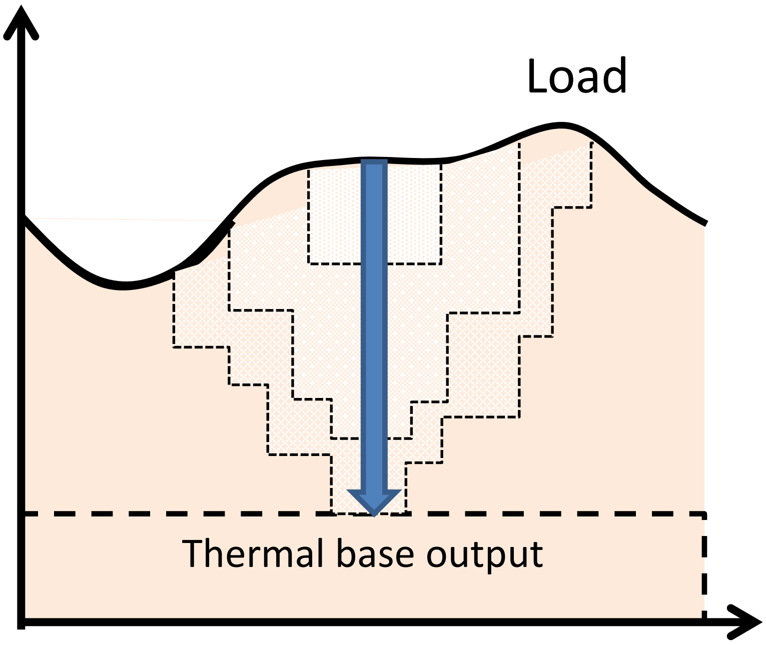
a) Power demand

- ❖ 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**

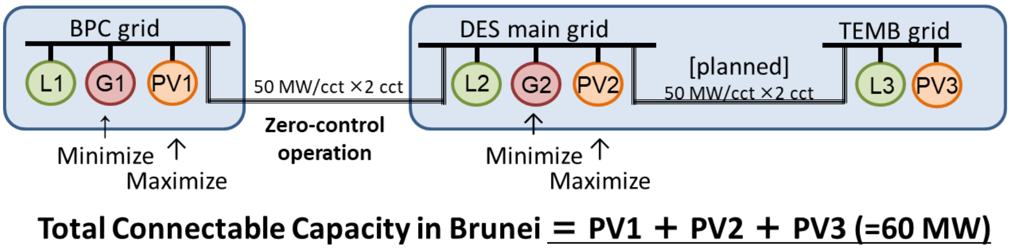
❖ Since this study's main objective is to make the Temburong district an ecotown, we assumed that PV will be introduced preferentially in said district. However, environmental issues, such as land use for PV introduction, were not considered.

❖ 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

3		Details
Demand	Base curve	▪ Actual records (8,760 points in 2019) in DES, BPC, and TEMBURONG
	How to increase	▪ In DES & TEMBURONG: Base curve x Increase rate ▪ In BPC: fixed to the Base curve
Thermal Power Generators	Set the 34 units' status to the 'Thermal base output'	
	Rated output	▪ 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
	Minimum output	
	Minimum output under LFC	
	Secured reserves for LFC	
	Efficiency	
	Must-run p/s	▪ Select the power plants considering the constraints of power stations
PVs	Base output pattern	▪ Actual records (8,760 points in 2019) of existing mega-solar farm
	How to increase	▪ 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]
Capacity of tie-line		▪ 50 MW, considering N-1 constraint (1-circuit trip)
Reserves for LFC		▪ 2% of electricity demand in each area

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]

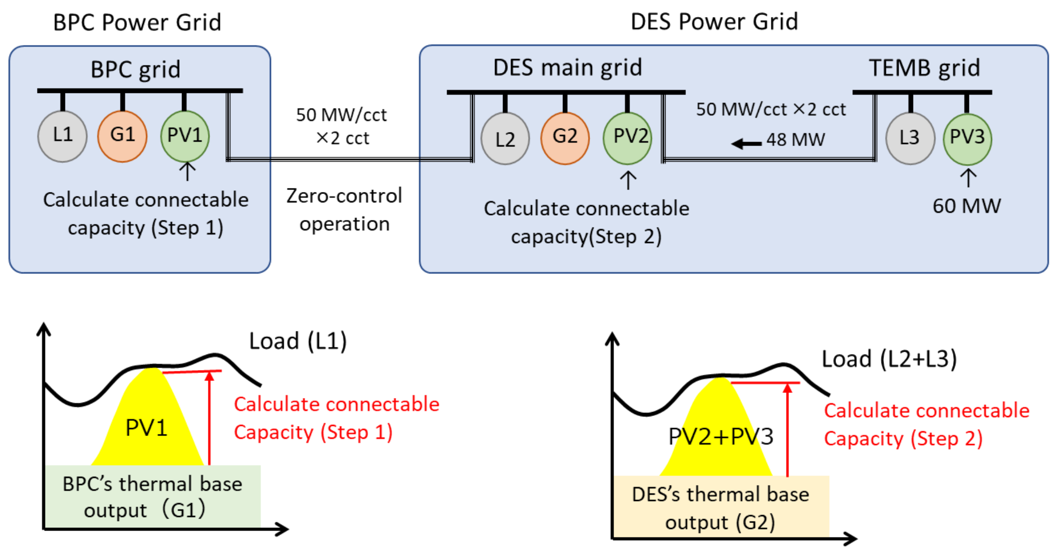
Step 9: Assume the 8,760 hours of PV output according to the amount of connectable capacity of PV in DES

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.

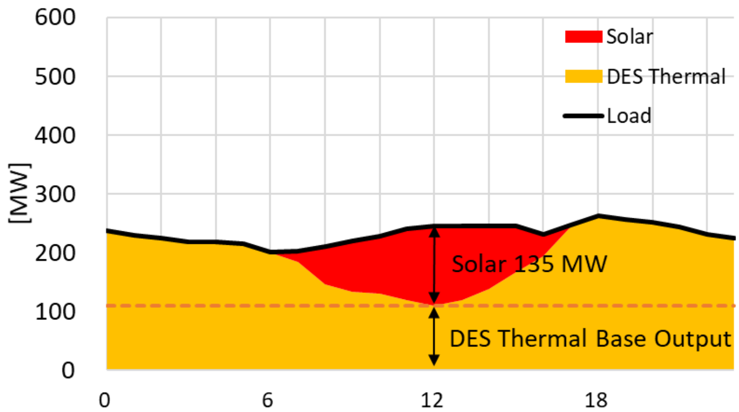
As a result of analysing the connectable capacity of 8,760 hours using the provided data, the point where DES's connectable capacity became the minimum during the year was 12:00 p.m. on 9 November. The demand–supply balance in each case on 9 November is shown in Tables 2.6, 2.7, 2.8, 2.9, and Figures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



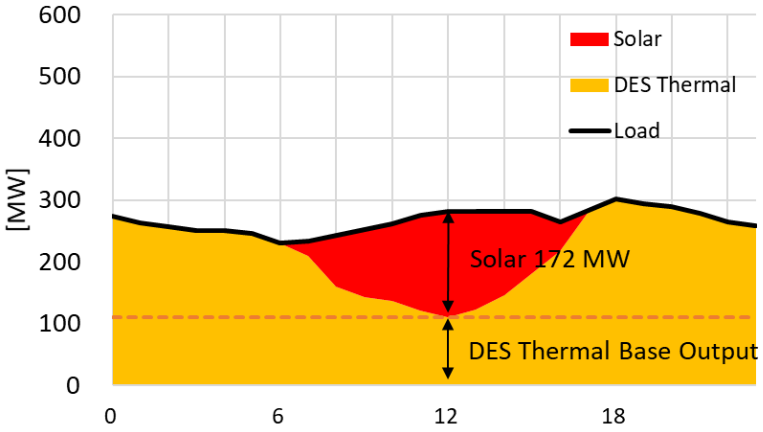
DES = Department of Electrical Services.
Source: Authors.

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



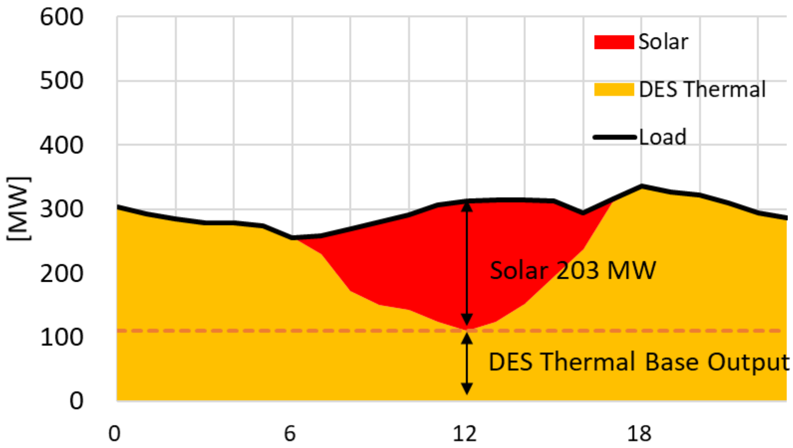
DES = Department of Electrical Services.
Source: Authors.

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



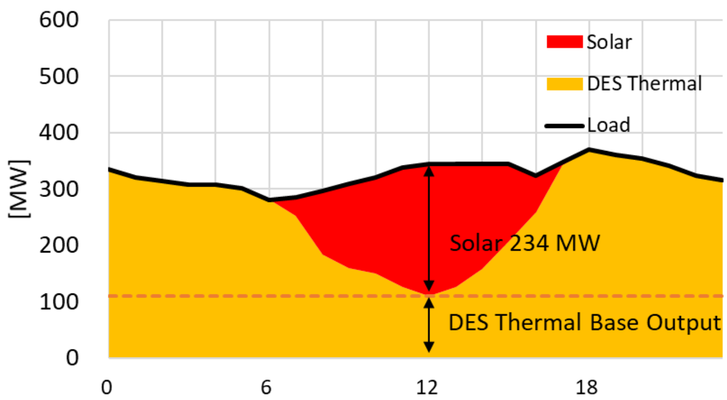
DES = Department of Electrical Services.
Source: Authors.

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

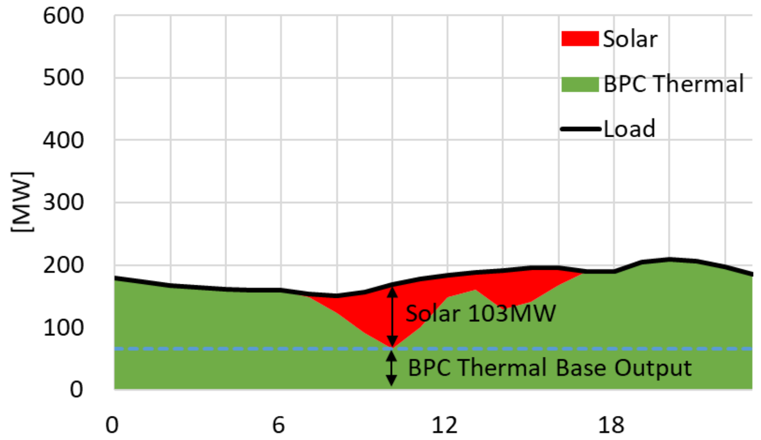
BPC's connectable capacity under the current demand level (case 1-1) was calculated at 132 MW. This result was about 33% of the total generation capacity of BPC. As a result of analysing the connectable capacity of 8,760 hours using the provided data, the point where BPC's connectable capacity became 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

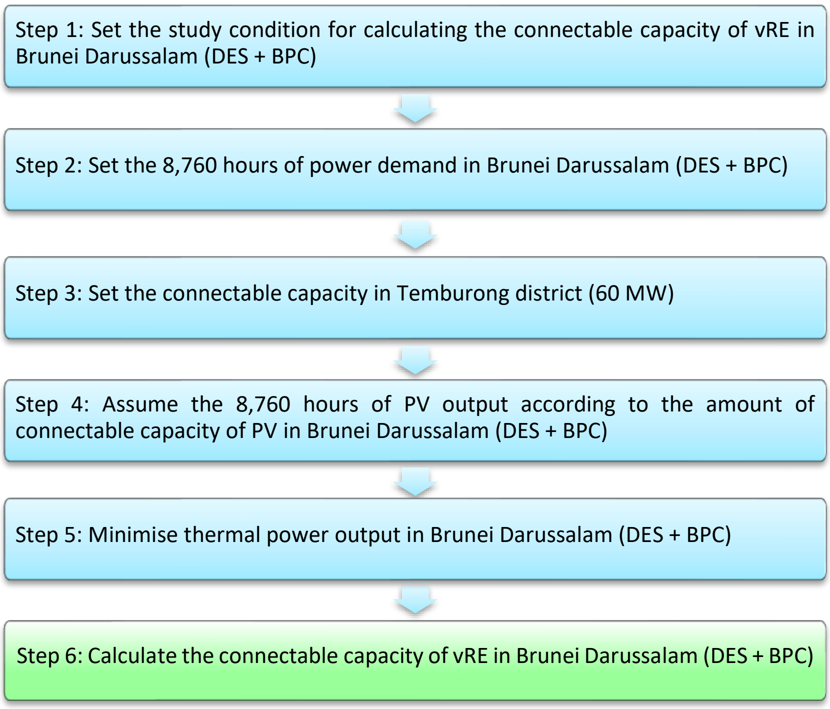
Case	Yearly Energy Consumption [GWh]				Yearly Energy Output from PVs [GWh]			
	DES	BPC	TEMB	TOTAL	DES	BPC	TEMB	TOTAL
1-1	2,399	1,608	49	4,056	166	173	78	417
1-2	2,755		56	4,419	231			482
1-3	3,061		63	4,732	288			539
1-4	3,367		69	5,044	344			595

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

4.5. Calculation method for Case 2

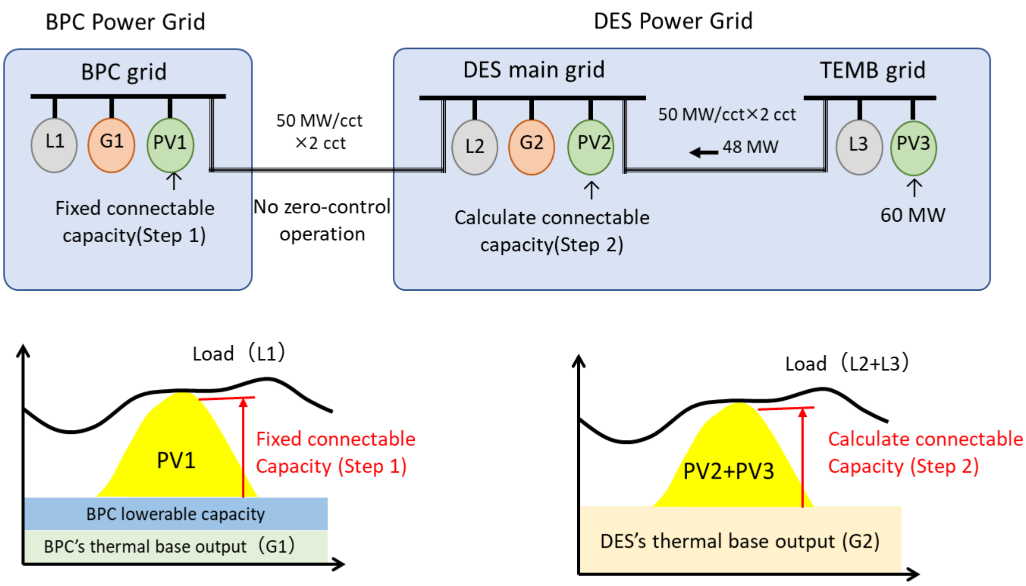
Since the zero-control operation between DES and the BPC was not adopted in case 2, the connectable capacities of DES and the BPC were calculated as one value. Figure 2.41 shows the flow of the calculation method for case 2.

Figure 2.41: Flow of the Calculation Method for Case 2



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

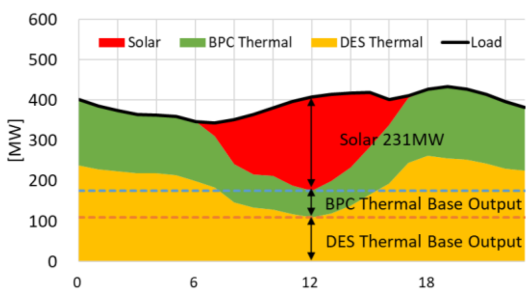
With Zero-control Operation

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

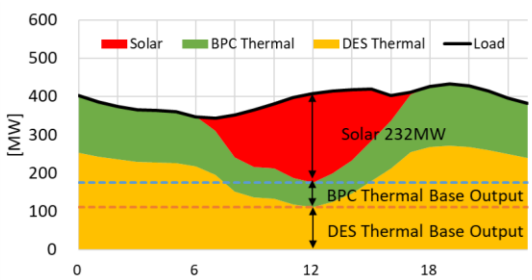
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

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

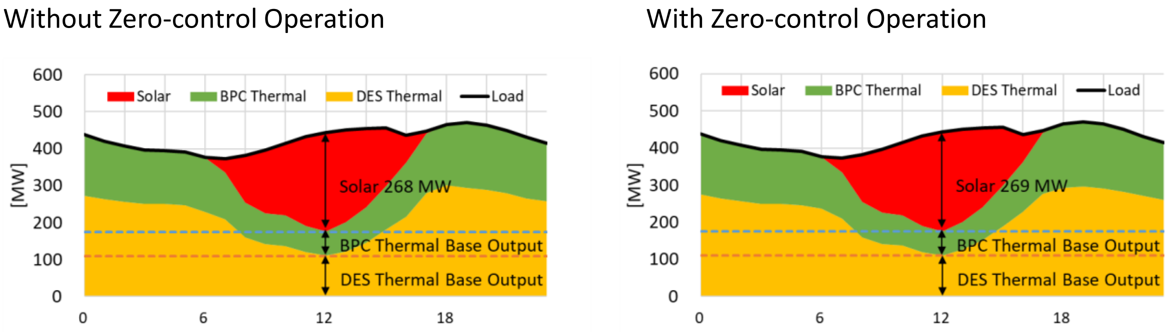
	Load	Solar	Thermal [Lowerable Capacity]	Thermal Base Output
DES	282	172	None	110
BPC	162	96	1	65
	444	268	1	175

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



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

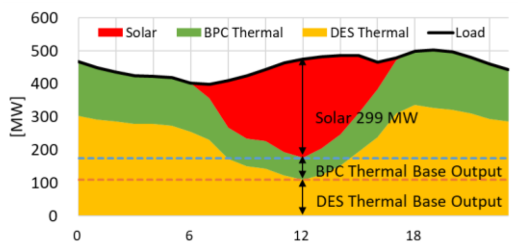
With Zero-control Operation

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

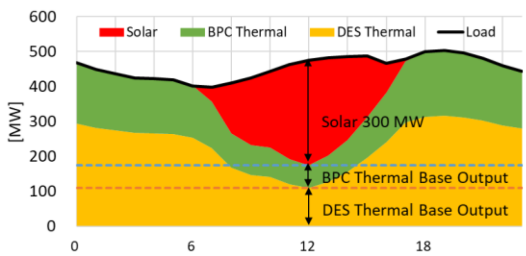
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services
Source: Authors.

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

Without Zero-control Operation



With Zero-control Operation



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

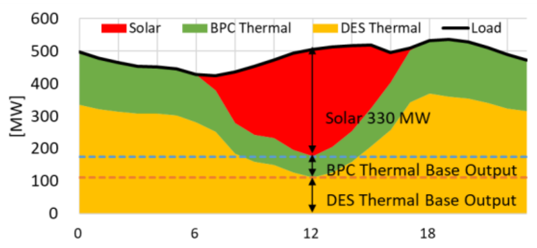
With Zero-control Operation

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

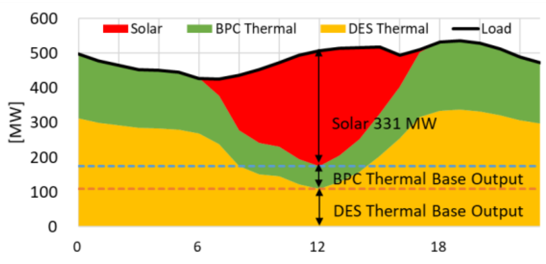
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

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

Without Zero-control Operation



With Zero-control Operation



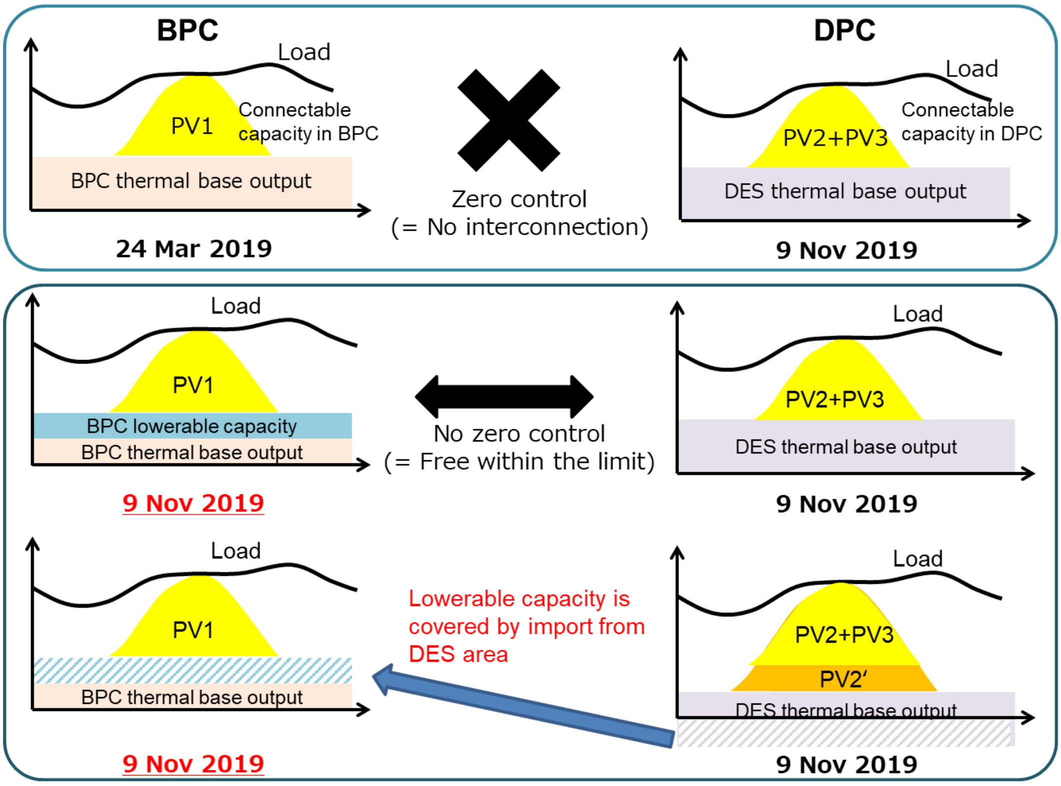
BPC = Berakas Power Company Sdn Bhd, DES = Department of Electrical Services.
Source: Authors.

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.

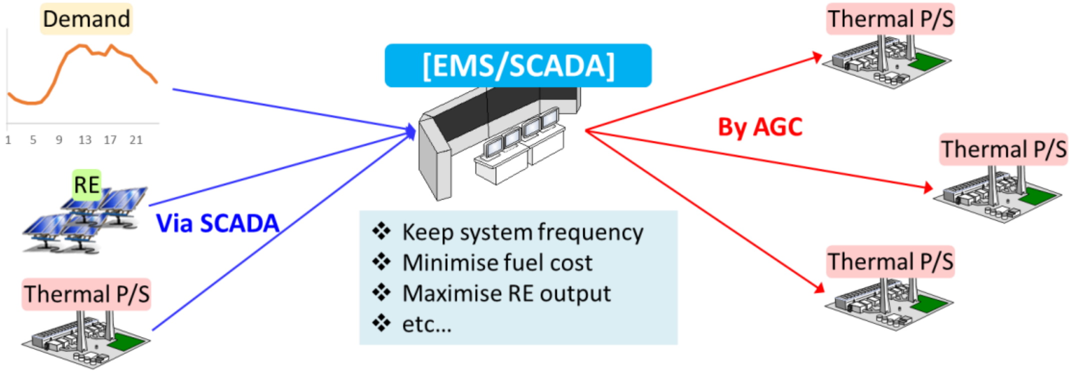
On the other hand, the DES control centre has the SCADA system only. Therefore, the DES power stations supervise their system frequency and manually control the generator outputs to keep their frequency at 50 Hz. However, according to interviews with DES, its control centre plans to install an EMS system, 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.

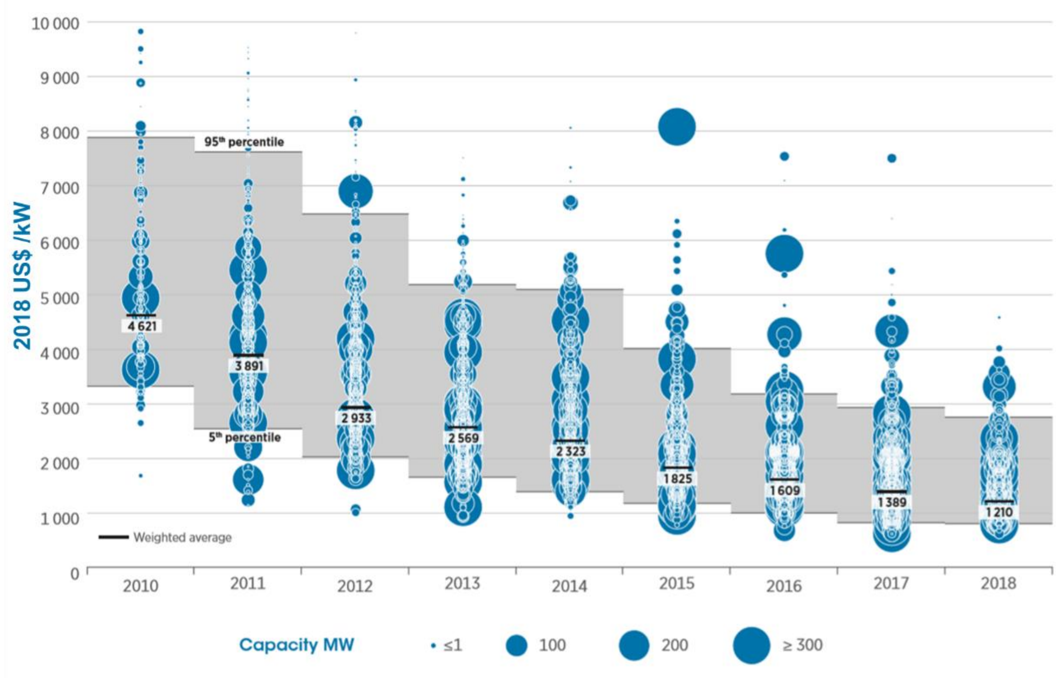
When we asked the MOE experts about this result during the Third Working Group meeting, we obtained the following answers. The experts thought they could unlikely get 300–600 acres of the land use for Temburong district. Furthermore, the MOE has made it clear not to cut down trees. At present, they have 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.

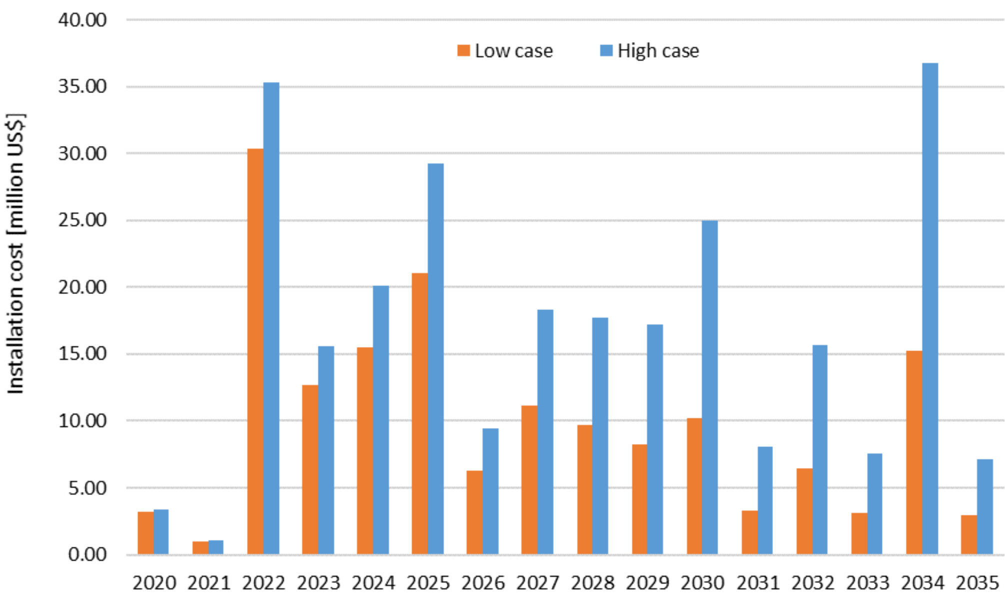
According to IRENA (2019a), the global weighted average total installed cost of utility-scale solar PV has fallen by 74% between 2010 and 2018. Installed costs also converged closer to the average, with the 5th and 95th percentile ranges dropping from the US$3,300–US$7,900/kW range in 2010 to US$800–US$2,700/kW 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

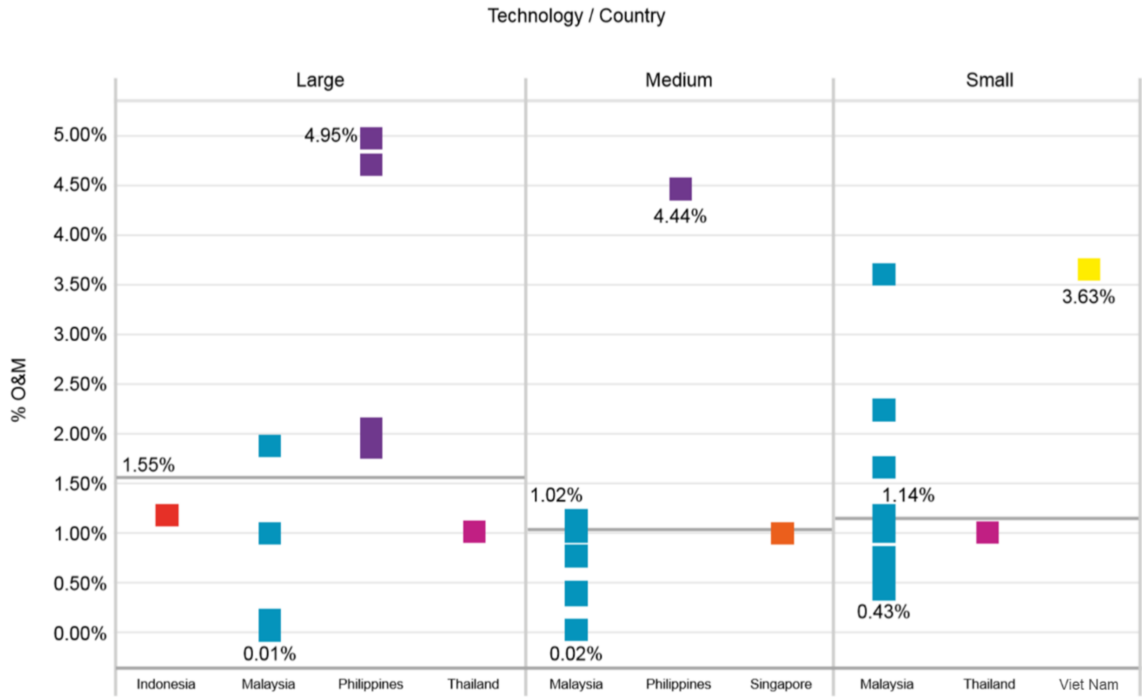


Source: Authors.

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.

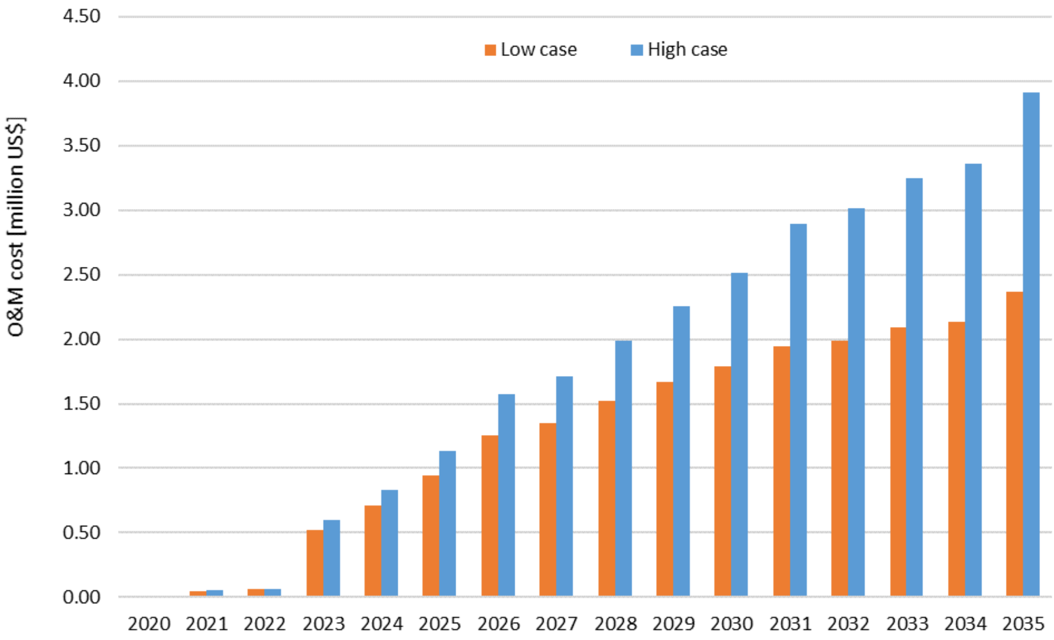
O&M costs are major costs incurred in the operation of power plants. According to ACE (2019), the O&M costs ranged from about 0.23% to 3.63%, 0.02% to 4.44%, and 0.01% to 4.95% of capital expenses (CAPEX) for the small (less than 100 kW)- , medium (100–1,000 kW)-, and large-scale (1,000 kW or more) projects, 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.

Chapter 3

Low-Carbon Vehicles and Traffic System: Temburong Ecotown Phase 4 Study

1. Introduction

The transport sector in ASEAN countries accounts for 40%–60% of the total energy demand. The sector is dominated by oil (gasoline and diesel), imports of which have been increasing rapidly in parallel to the slowing down of domestic production, which affects the security of supply (Kutani, 2013). Increased combustion of oil products has worsened the air quality, which potentially has significant socio-economic impacts.

In many cases, there has been an inadequate development in infrastructure for public transport, walking, and cycling due to overbuilt roadways that accelerate more use of private vehicles. The public transport system is inadequate and unreliable there is often the urge to own a private vehicle or a motorised two-wheel vehicle. This also, in turn, makes walking and cycling redundant, mainly due to unfavourable and not-public-friendly walking and cycling pathways. The US Energy Information Administration (2017) pointed out that in 2017, non-OECD Asian countries, including China and India, accounted for more than 70% of the increase in transport fuel consumption in non-OECD countries due to an increase in personal mobility.

Two principal ways can improve the delivery of efficient and sustainable transport infrastructure, which is essential for a town, city, or urban area aspiring to be energy-efficient and environment-friendly. These ways are the use of information and communications technology (ICT) and the electrification of mobility.

The use of ICT to support better transport infrastructure is called intelligent transport system (ITS). UNESCAP (2014) defined ITS as combinations of technologies for increasing efficiency in vehicular traffic. Their most frequent applications are in the road transport sector, such as electronic sensors, geo-positioning navigation systems, video surveillance devices, vehicle probes, and wireless communications. These applications enable data to be accumulated, analysed, and communicated in real-time, or near real-time, in ways that can greatly improve traffic efficiency and safety.

This study for developing a low-carbon transport system in Temburong shall focus on the use of more efficient vehicle technology, propulsion, and energy. Therefore, it shall analyse the electrification of mobility, the second principal way. Nowadays, we are witnessing electro-mobility as a fast-growing technological and social trend, which has become one of the main opportunities and challenges for smart cities. The opportunity lies in the fact that penetration of electric vehicles (EVs) would help shift oil consumption to electricity, reducing on-street greenhouse gas (GHG) emissions and air pollution and reaching a higher energy efficiency in mobility. On the other hand, however, smart cities need to build smart infrastructure for the EVs' electric charging (Xu et al., 2016; Wagner et al., 2014).

Often considered within the category of EVs are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), full battery electric vehicles (BEVs), and fuel-cell hydrogen-electric vehicles (FCEVs). Electricity produced in these four EV types is different. In the HEVs, electricity is produced by the braking mechanism; in PHEVs and BEVs, electricity is produced in the grid system and fed into the vehicle's battery unit during charging. In FCEVs, electricity is produced by electrochemical oxidation of hydrogen in the vehicle's fuel cell unit that is equipped with hydrogen storage.

This report proposes two levels of analysis. In section 3.2, we analysed the possibility of having low-carbon vehicles, i.e. battery electric cars or hydrogen-powered fuel cell cars in Brunei Darussalam in the horizon of 2050. In that section, we analysed the impacts of each new car technology on energy use and carbon dioxide (CO_2) emissions at the national level. In section 3.3, we proposed a low-carbon traffic system for Temburong district concerning the possible technological options for passenger cars proposed at the national level (section 3.2).

Through this approach, this report should provide a technological framework that contains options for policymakers to develop a low-carbon road transport sector, especially in terms of passenger cars. It should also provide a policy framework containing mobility-related policy options that should support developing Temburong into an ecotown.

2. Perspective of Low-Carbon Vehicles for Brunei Darussalam

2.1. Trends, policies, and possibilities

Electromobility is developing rapidly. The global electric car fleet is estimated to exceed 5.1 million, which is 2.0 million more than in the previous year and almost double the earlier sales of new electric cars (IEA, 2019). The number of EVs nearly tripled globally since 2005 (Raposo and Cuiffo, 2019).

China is the world's largest market for electric cars, with nearly 1.1 million sold in 2018. With 2.3 million units, it accounts for almost half of the global electric car stock, followed by Europe (1.2 million) and the United States (US) (1.1 million) (IEA, 2019). China started in 2009 with the '10 cities, 10,000 vehicles' business model to promote plug-in electric vehicle (PEV) development. However, it established targets only in June 2012: 500,000 vehicles by 2015 and 5 million by 2020. China aims to reach new EV sales shares of 7%–10% by 2020, 15%–20% by 2025, and 40%–50% by 2030 (Marklines, 2019).

In Japan, a leading EV market, government support for BEV development started in the early '70s. Strong government commitment to promoting EVs is reflected in a heavy emphasis on research and development of vehicle and component technologies, infrastructure, and market support for EV users. The Ministry of Economy, Trade and Industry (METI) funded the Clean Energy Vehicle Introduction Project, which provided subsidies and tax discounts for purchasing EVs (Loveday, 2013).

In 2017, Japan's EV production ranked fourth in the world at around 8%, after China (50%), Europe (21%), and the US (17%) (Lutsey et al., 2018). The government works with industry stakeholders to reduce by 80% GHG emissions from domestically produced vehicles (by 90% for passenger vehicles), including exported vehicles, by 2050, with a combination of HEVs, BEVs, PHEVs, and FCEVs. Under the new policy scenario, Japan targets increasing EV sale share of all modes (excluding two- and three-wheelers) by 21% and scaling up to 37% market share under the EV30@30 scenario in 2030. To provide more charging stations throughout Japan, in 2018, the government set the goal of having fast chargers every 9.3 miles (15 km) or within every 19-mile (30 km) radius (Kane, 2018a). Japan's success in the EV market is due to government commitment, strong support from the automotive industry, and user-friendly infrastructure.

The Government of India, in 2013, established the National Electric Mobility Mission Plan 2020 and, in 2015, enacted Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India or FAME India. The government announced its intention to move towards all-EV sales in 2025–2040 and, through EV30@30 programme, to ensure that EVs will account for at least 30% of all vehicle sales by 2030 (Lutsey et al., 2018; IEA, 2019). All vehicles, including two-wheelers, are targeted for electrification. EVs have penetrated the vans and urban bus markets, accounting for 14% of all passenger cars and light commercial vehicles (LCVs) and 11% of all bus sales (IEA, 2019). As a member of the Electric Vehicle Initiative, India is dedicated to accelerating the deployment of EVs.

Only two ASEAN countries produce and commercialise PEVs – Thailand and Malaysia. Thailand's first PEV development road map – the Electric Vehicle Promotion Plan – was approved by the government in March 2015. In 2017, the Board of Investment approved incentives for manufacturers of BEVs, HEVs, and PHEVs, mostly in the form of corporate tax exemptions for 5 to 8 years. The project to develop next-generation automotive vehicles, focusing on PEVs, was included in the Eastern Economic Corridor, approved in February 2018, to spur investment. In March 2019, the Board of Investment agreed to renew the investment package for HEVs to attract more investment in PEV production. Investors must apply to produce HEVs in 2019 and assemble BEVs within 3 years. HEV and PHEV sales rose by 24.7% in 2017 to 11,945 units whilst BEV sales reached 165 units (Nicholls et al., 2018). Vehicles sold in that year totalled 870,748 units. By 2036, Thailand targets having 1.2 million electric cars on its streets and setting up 690 charging stations.

On 8 August 2019, the Government of Indonesia issued Presidential Decree No. 55/2019 which laid the general framework to accelerate the penetration of (plug-in) battery-based electric vehicles in the country. Before that decree, the Ministry of Industry told a newspaper that the government would target sales of 400,000 EVs by 2025 to reduce GHG emissions by 29% in 2030 (Akhyar, 2019). One source mentioned that 400,000 PEVs would be produced domestically by then. Other sources estimate that around 2 million electric-powered two-wheelers would be sold by 2025. Jakarta has around 1,000 charging stations, built by the PLN (State Electricity Company) (Aji, 2017). On 23 October 2019, the government issued Regulation (PP) no. 73/2019 concerning luxury sale tax of private cars that gives advantage to low CO_2-emitting cars, including the different classes and types of EVs.

FCEVs, on the other hand, are much less developed. The use of hydrogen for FCEV could contribute to decarbonising the road transport sector. FCEVs have zero direct CO_2 emissions when used; they only release water from the tailpipe. Energy use and CO_2 emissions take place then in the phases of hydrogen production and vehicle infrastructure.

2.2. Methodology and scenarios

In this study, we modelled Brunei's national energy systems on the Long-Range Energy Alternatives Planning System (LEAP) software during the Working Group of ERIA's Energy Outlook and Energy Saving Potential Project organised in Jakarta, 3–7 February 2020. Historical data of Brunei's energy consumption from the different sectors and the energy supply system were used to develop the model that contains the relationship between energy demand and supply and the different socio-economic and demographic assumptions, which allow long-term forecasting.

Based on this model, we developed a business-as-usual scenario (BAU) of the road transport, i.e. passenger car transport sector in Brunei to the horizon of 2050 as a benchmark scenario to assess the impacts of penetration of new technologies in the passenger car fleet.

We define BAU as the scenario where the country's passenger car fleet would develop to the horizon of 2050 without any penetration of battery electric or fuel-cell hydrogen cars. This scenario means that up to 2050, there will be only two kinds of passenger cars based on fuel types: gasoline- and diesel-fuelled passenger cars.

The first new technology we analysed is the EV. We elaborated three EV scenarios representing certain penetration levels of full BEVs in the country's road passenger car fleet in 2017–2050.

The level of penetration is represented by the exogenously defined percentages of shares of BEV in the total number of passenger cars in Brunei in 2050. We assumed that there was no electric vehicle in the base year in all scenarios, i.e. 2017.

The three EV scenarios in Brunei are:

- EV20 – a scenario where battery electric cars would make 20% share of the total road passenger car fleet in 2050
- EV40 – a scenario where battery electric cars would make 40% share of the total road passenger car fleet in 2050
- EV60 – a scenario where battery electric cars would make 60% share of the total road passenger car fleet in 2050.

The second technology is the hydrogen-powered fuel cell (FC) vehicle. Three FC scenarios were elaborated to represent certain penetration levels of hydrogen-powered FC cars in the country's road passenger car fleet in 2017– 2050.

The same as the EV scenarios, the level of penetration is represented by the exogenously defined percentages of shares of FCs in the total number of road passenger cars in Brunei in 2050. In all scenarios, we assumed that there is no FC in 2017, the base year.

The three main FC scenarios in Brunei are:

- FC10 – a scenario where FC hydrogen cars would make 10% share of the total road passenger car in 2050
- FC20 – a scenario where FC hydrogen cars would make 20% share of the total road passenger car fleet in 2050
- FC30 – a scenario where FC hydrogen cars would make 30% share of the total road passenger car fleet in 2050.

To compare with the production of hydrogen from natural gas steam reforming without carbon capture and sequestration (CCS) – considered the most mature technology pathway of hydrogen production in Brunei – we also simulated two other variants: hydrogen production from natural gas steam reforming with CCS and from electrolysis.

2.3. Assumptions of the study

2.3.1. Population, GDP, and Power Generation Energy Mix

The population is expected to grow at 1.5% per year during the whole observation period. We used the projection of the International Monetary Fund (IMF, 2019) as our main source for GDP growth (Table 3.1). The annual growth rate decreases from 4.7% in 2017–2020, the base year's period, to around 2.1% in 2023–2050.

Table 3.1: Assumptions on GDP growth

Period	Annual Growth Rate, %
Up to 2020	4.7
2020 to 2021	3.6
2021 to 2022	3.5
2022 to 2023	2.4
2023 and beyond	2.1

Source: IMF (2019).

We assumed that natural gas–fired plants comprise 99% of the total electricity generation during the whole simulation period. The remaining 1% is composed of diesel-fired power plants and a negligible solar photovoltaic (PV) portion.

2.3.2. Hydrogen Production

Hydrogen can be produced from fossil-based options and renewable sources. Fossil-based options can include steam reforming of natural gas and coal gasification. These are thermochemical processes where the feedstock is processed at high temperatures in a gasification medium, such as air, oxygen, and/or steam to produce syngas. Those two options are mature technologies, but the implementation of carbon capture and storage (CCS) systems might be required reduce CO_2 emissions of both options.

Hydrogen can also be produced from renewable sources, such as wind power water electrolysis, steam reforming of biofuels, and biomass gasification.

Water electrolysis involves a process in which electricity is converted into chemical energy in the form of hydrogen with oxygen as a by-product. When using grid electricity, Brunei's electricity production mix becomes a crucial aspect. The possibility of using the electricity surplus from renewable power generation facilities, such as PV or hydropower plants to produce hydrogen through water electrolysis, should be pursued.

Hydrogen in Brunei is assumed to be uniquely produced from steam reforming based on the gas generated by Brunei LNG (liquefied natural gas's plant). The process is currently without CCS.

Citing various sources – Collodi et al. (2017), Keipi et al., (2018), Mondal and Chandran, (2014), Navas-Anguita et al. (2020) – we summarised the steam reforming process as follows: during the steam reforming of natural gas or renewable feedstock, steam and hydrocarbons are heated up to 800–1,000 °C to produce synthetic gas. Afterwards, the syngas stream undergoes a water gas shift process to increase the hydrogen content. In a subsequent step, hydrogen is separated and purified, e.g. through a pressure swing adsorption unit.

Navas-Anguita et al. (2020) estimated energy efficiency rates in various hydrogen production pathways. We extracted and analysed three pathways in this report (Table 3.2), i.e. steam reforming of natural gas with and without CCS and electrolysis with grid electricity.

Table 3.2: Energy Efficiency in Hydrogen Production

Study	2017–2020	2021–2029	2030–2050
Steam reforming of natural gas without CCS	76%	Interpolation	85%
Steam reforming of natural gas with CCS	65%	Interpolation	70%
Electrolysis	67%	Interpolation	85%

CCS = carbon capture and sequestration.
Source: Navas-Anguita et al. (2020).

2.3.3. Passenger Car Transport

The total number of passenger cars in the future is a key assumption that would determine energy consumption and the transport sector's profile. Forecasting the future number of passenger cars can estimated using Brunei's future car ownership rate, given the number of cars per 1,000 inhabitants. A usual method in estimating the car ownership rate is using the car ownership model developed, for example, by Dargay et al. (2007). This model employs an S-shaped function, i.e. the Gompertz function, to estimate the relationship between vehicle ownership and per-capita GDP.

$$V_{year} = \gamma . e^{\alpha . e^{\beta . GDPCAP_{year}}}$$ Equation (1)…

where

V_{year} = long-run equilibrium of car ownership rate (cars per 1,000 inhabitants at purchasing power parity)
γ = saturation level (cars per 1,000 inhabitants)
$GDPCAP_{year}$ = GDP per capita (expressed in constant local current unit (LCU) of 2018)
α, β = parameters defining the shape, or curvature, of the function

However, the GDP per capita of Brunei had been decreasing from 2008 to 2018 by an average annual rate of 1.3%, whilst the car ownership rate had been increasing from around 542 vehicles per 1,000 inhabitants in 2008 to around 658 vehicles per 1,000 inhabitants, i.e. an average annual growth rate of around 2.1%.

The GDP per capita cannot be used as the only dependent variable to estimate the car ownership rate. We incorporated time, i.e. year, as another dependent variable, which signifies the inclusion of other factors not explicitly described by the equation, i.e. lifestyle, urbanisation, road infrastructure development, etc. The equation is given as follows, where δ is the additional parameter that defines the function's shape or curvature.

$$V_{year} = \frac{\gamma}{1+\alpha . e^{\beta * year} . GDPCAP_{year}{}^{\delta}}$$ Equation (2)…

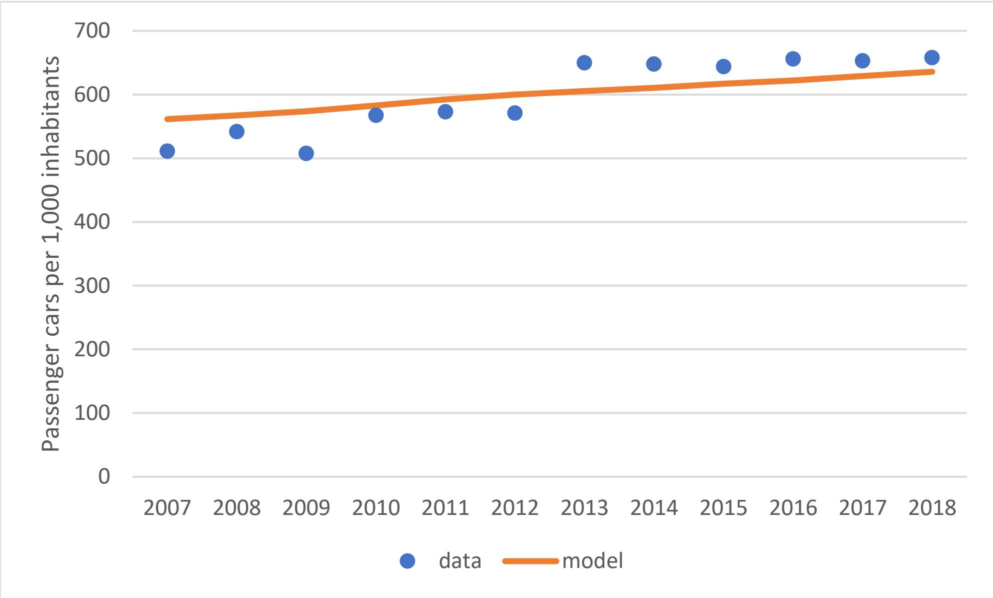
Using car ownership, GDP, and population data from 2007 to 2018, we estimated the parameters of equation (2) with the coefficient of determination (r2) of 0.602 in Table 3.3.

Table 3.3: Estimated Parameters of Equation (2)

Parameters	Estimated Value
γ	844
Ln(α)	93.96
β	-0.045
δ	-0.4

Source: Authors' calculation.

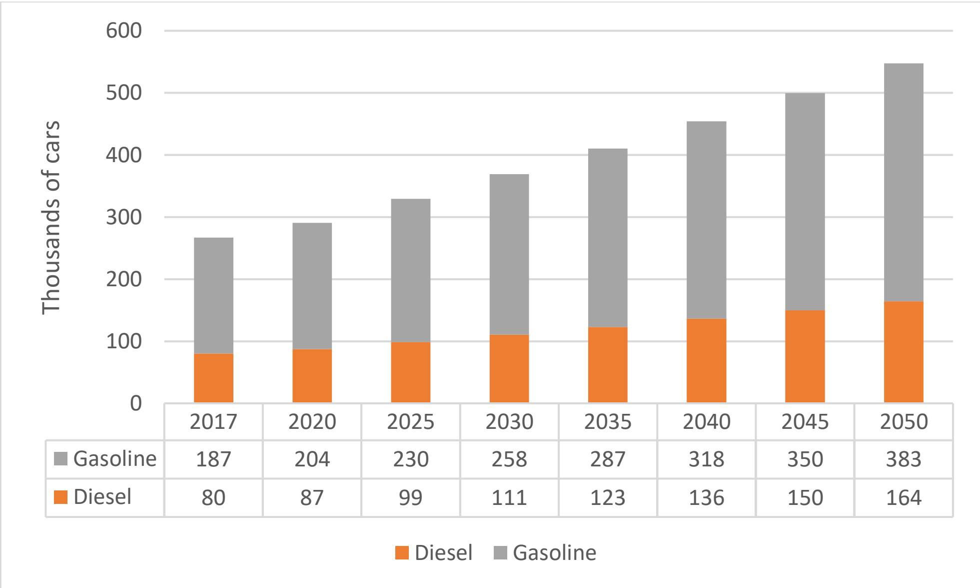
Figure 3.1: Data and Modelled Car Ownership Rate



Source: Authors' calculation.

Combined with Brunei's estimated future population, we obtained the estimated number of cars in use (Figure 3.2). We expected the number of cars in use or active would grow from 270,000 to 370,000 by 2030, 455 (2040), and 550 (2050).

Figure 3.2: Estimated Number of Passenger Cars in Use



	2017	2020	2025	2030	2035	2040	2045	2050
Gasoline	187	204	230	258	287	318	350	383
Diesel	80	87	99	111	123	136	150	164

Source: Authors' calculation.

Tables 3.4 and 3.5 show our assumptions in the electric car and hydrogen-powered FC scenarios. We assume the fuel-cell efficiency of FCEVs of 1.1 MJ/km or 3.27 km/kWh. This is in line with the specification of the compact hydrogen-powered fuel cell Toyota Mirai passenger car model FCA110 of the year 2015 whose specification is given by Toyota Europe (2015).

Table 3.4: Passenger Car–Related Assumptions for Electric Car Scenarios

Variable	Description	Unit	2017	2018–2049	2050	Source
TOTCAR	Total number of cars	million cars	0.29	See equation (2) and Table 3.3		Authors' estimate
DSLCAR	ICE- diesel cars	million cars	0.09	$(TOTCAR_{year} - ELECAR_{year}).0.7$		Authors' estimate
GSLCAR	ICE - gasoline cars	million cars	0.2	$(TOTCAR_{year} - ELECAR_{year}).0.3$		Authors' estimate
EVCARSH	Share of BEV based on scenarios	%	0	$\frac{x.(year - 2017)}{(2050 - 2017)}$	x	Authors' assumption
ELECAR	Number of BEVs	million cars	0	$TOTCAR_{year}.EVCARSH_{year}$		Authors' estimate
FE	Fuel economy of ICE cars	km/l	12.7			Authors' estimate
BATEFF	BEV battery efficiency	km/kWh	5			Authors' estimate
KMYEAR	Average distance travelled (km/ year)	km	24000			Authors' estimate

ICE = internal combustion engine.
Source: Author.

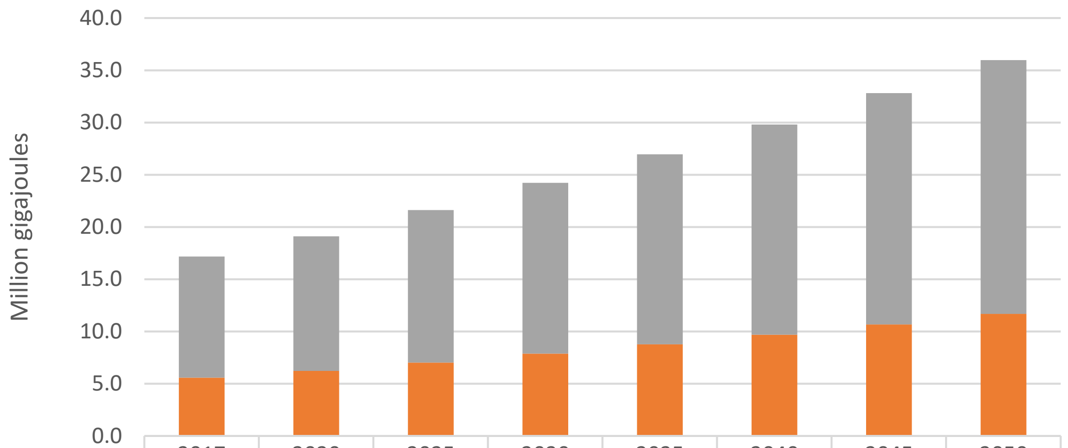
Table 3.5: Passenger Car–Related Assumptions for Hydrogen-Powered Fuel Cell Car Scenarios

Variable	Description	Unit	2017	2018–2049	2050	Source
TOTCAR	Total number of cars	million cars	0.29	See equation (2) and Table 3.4		Authors' estimate
DSLCAR	ICE- diesel cars	million cars	0.09	$(TOTCAR_{year} - FCEVCAR_{year}).0.7$		Authors' estimate
GSLCAR	ICE-gasoline cars	million cars	0.2	$(TOTCAR_{year} - FCEVCAR_{year}).0.3$		Authors' estimate
FCEVCARSH	Share of FCEV based on scenarios	%	0	$\frac{x.(year - 2017)}{(2050 - 2017)}$	x	Authors' assumption
FCEVCAR	Number of FCEVs	million cars	0	$TOTCAR_{year}.FCEVCARSH_{year}$		
FE	Fuel economy of ICE cars	km/l	12.7			Authors' estimate
FCEFF	Fuel cell efficiency	km/kWh	3.27			Toyota Motor Europe (2015)
KMYEAR	Average distance travelled (km/year)	km	24000			Authors' estimate

ICE = internal combustion engine.
Source: Author.

We can expect that in BAU, between 2017 and 2050, energy demand from passenger car transport in Brunei would increase by around 12% per year from about 17 million gigajoules (GJ) in 2017 to approximately 36 million GJ in 2050, an increase of around 11% annually. Gasoline–diesel consumption ratio would be around 2:1, and full BEVs are assumed to enter the road passenger car fleet during the whole simulation period.

Figure 3.3: Energy Consumption of Passenger Cars – Business-As-Usual Scenario



	2017	2020	2025	2030	2035	2040	2045	2050
Gasoline	11.6	12.9	14.6	16.3	18.2	20.1	22.1	24.3
Diesel	5.6	6.2	7.0	7.9	8.8	9.7	10.7	11.7
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: LEAP model running results (2020).

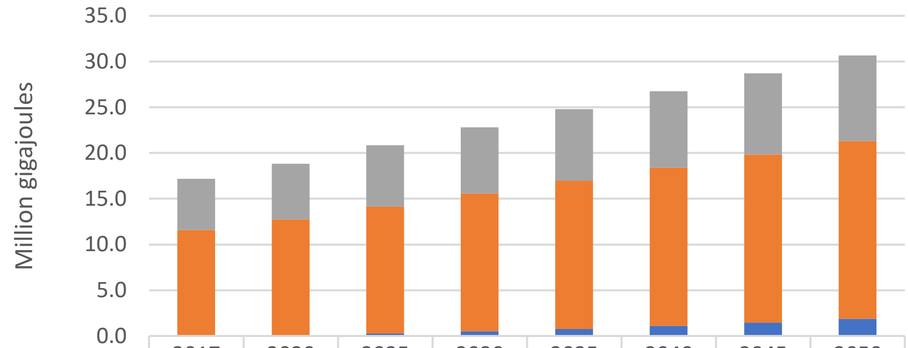
2.4. Results

The following subsections discuss the LEAP model running results of the EV and FCEV scenarios where hydrogen is produced from natural gas steam reforming without CCS and where hydrogen is produced from other pathways, i.e. natural gas reforming with CCS and electrolysis.

2.4.1. Electric Car (EV) Scenarios

Figure 3.4 shows that having BEVs composing 20% of the passenger car fleet by 2050 would reduce the total energy consumption in 2050 by around 5 million GJ compared to BAU. The yearly growth rate of total energy consumption would be reduced from 11% in BAU to about 8.5%.

Figure 3.4: Energy Consumption of Passenger Cars – EV20 Scenario



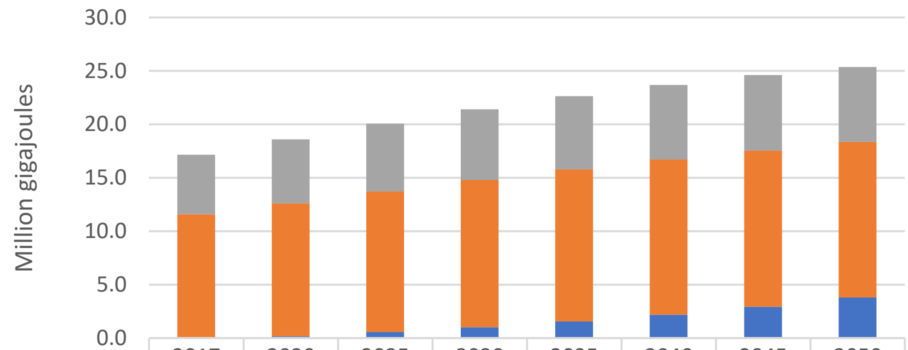
	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	6.1	6.7	7.3	7.8	8.3	8.9	9.4
Gasoline	11.6	12.6	13.9	15.1	16.2	17.3	18.4	19.4
Electricity	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.9

Electricity Gasoline Diesel

Source: LEAP model running results (2020).

Having full BEVs comprising 40% of the total passenger cars (Figure 3.5) should reduce the total energy demand by 2050 to about 25 million GJ. The yearly growth rate of energy demand is around 5.3%. It is interesting to note that starting at around the year 2045, gasoline and diesel fuel demand should reach stagnation.

Figure 3.5: Energy Consumption of Passenger Cars – EV40 Scenario



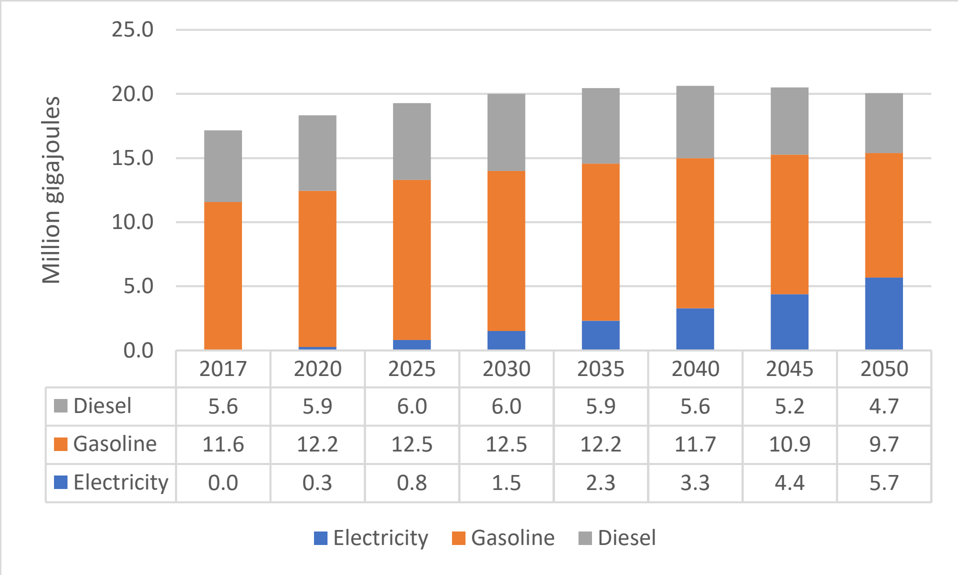
	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	6.0	6.4	6.6	6.9	7.0	7.1	7.0
Gasoline	11.6	12.4	13.2	13.8	14.2	14.5	14.6	14.6
Electricity	0.0	0.2	0.6	1.0	1.5	2.2	2.9	3.8

Electricity Gasoline Diesel

Source: LEAP model running results (2020).

Finally, having 60% BEVs amongst the passenger car fleet in 2050 would reduce the total energy demand to around 20 million MJ in 2050 (Figure 3.6). Total energy demand would reach its peak at about 21 million MJ somewhere between 2035 and 2040. Beyond that period, total energy demand would be decreasing.

Figure 3.6: Consumption of Passenger Cars – EV60 Scenario

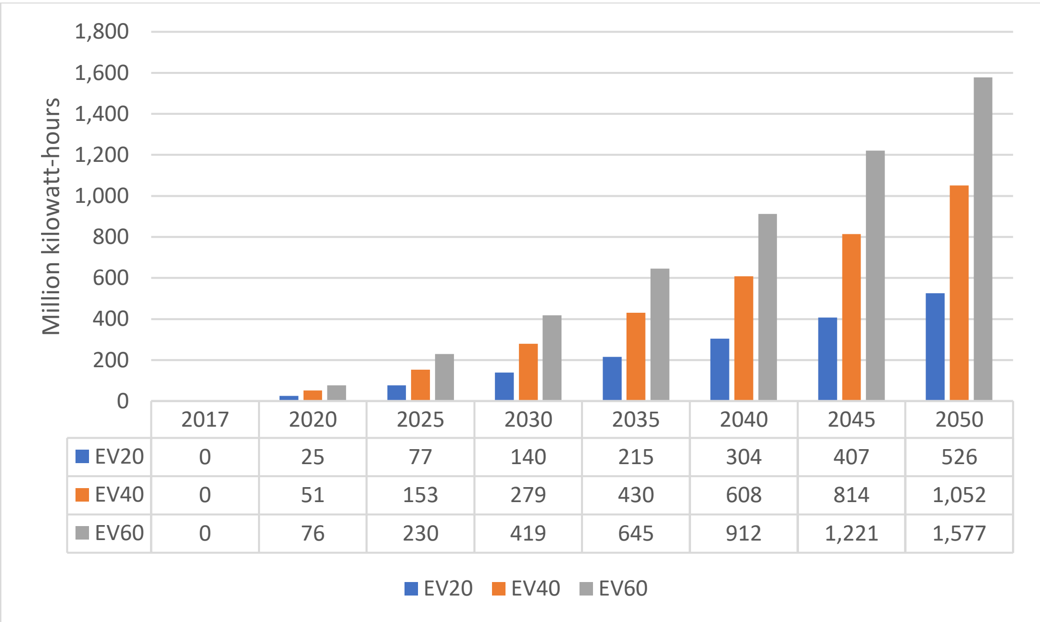


	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	5.9	6.0	6.0	5.9	5.6	5.2	4.7
Gasoline	11.6	12.2	12.5	12.5	12.2	11.7	10.9	9.7
Electricity	0.0	0.3	0.8	1.5	2.3	3.3	4.4	5.7

Source: LEAP model running results (2020).

Compared to BAU, in 2050, EV scenarios would consume approximately 526, 1,052, and 1,577 million kWh of additional generated electricity, respectively, in EV20, EV40, and EV60 scenarios (Figure 3.7). If the total generated electricity in Brunei Darussalam in BAU grows from 3,700 million kWh in 2017 to 5,600 million kWh in 2050, the electric demand of EV scenarios in 2050 would correspond to an additional increase of consecutively 9%, 19%, and 28% compared to BAU.

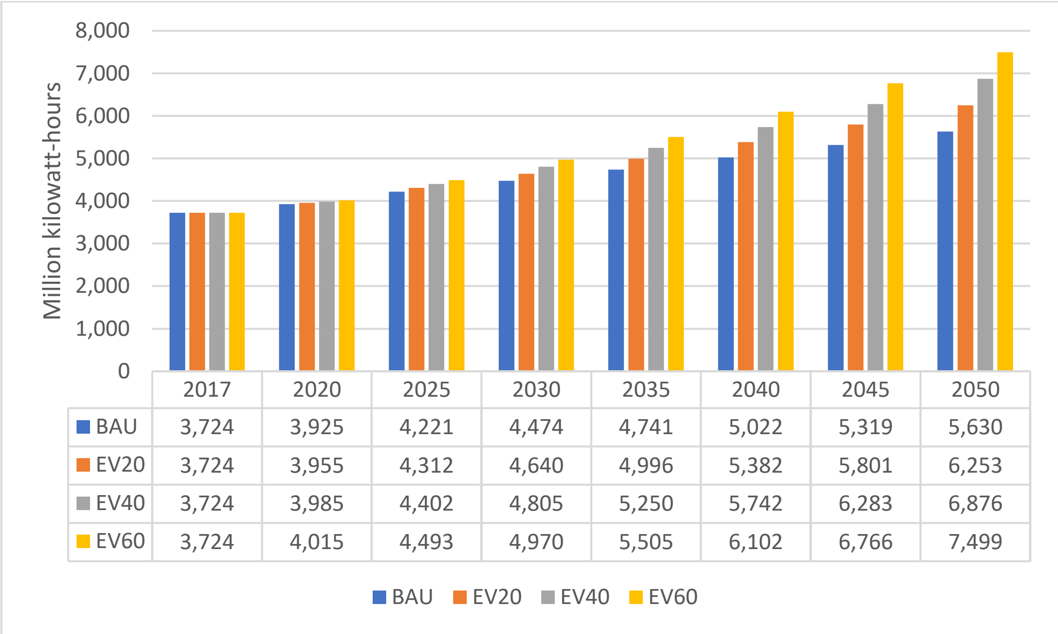
Figure 3.7: Electric Energy Needed in Electric Car Scenarios



	2017	2020	2025	2030	2035	2040	2045	2050
EV20	0	25	77	140	215	304	407	526
EV40	0	51	153	279	430	608	814	1,052
EV60	0	76	230	419	645	912	1,221	1,577

Source: LEAP model running results (2020).

Figure 3.8: Generated Electricity – Electric Cars Scenarios

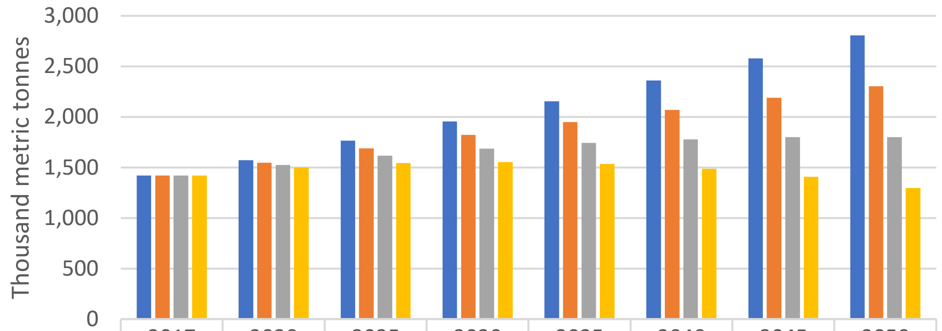


Source: LEAP model running results (2020).

The penetration of BEVs should affect CO_2 emissions in two sectors: passenger car transport and power generation. In the passenger car transport sector, the penetration of BEVs means shifting from conventional fuels – gasoline and diesel – to electricity, which should reduce CO_2 emitted by passenger cars.

We can expect CO_2 emissions from road passenger cars in Brunei in BAU to double from around 1.4 million tonnes of CO_2 in 2017 to about 2.8 million tonnes in 2050, a 33-year period. Compared to BAU, the three electric-car scenarios – EV20, EV40, and EV60 – should reduce CO_2 emissions from passenger cars by 2050 by 18%, 36%, and 54%, respectively. The effect of EV60 scenario would be significant as it would cause CO_2 emission from passenger cars to peak somewhere between 2040 and 2045.

Figure 3.9: CO_2 Emissions from Passenger Cars – Electric Cars Scenarios

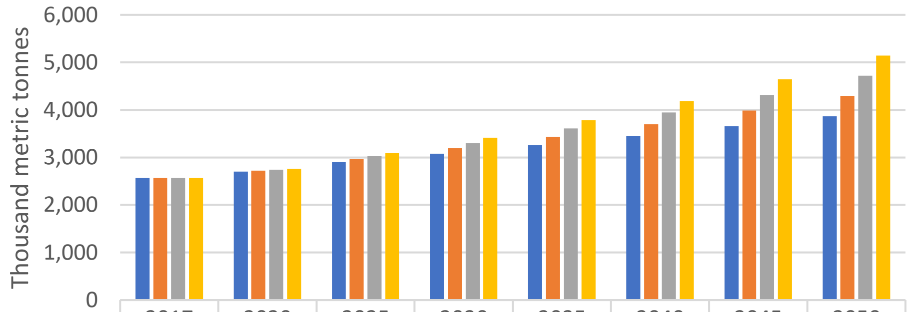


	2017	2020	2025	2030	2035	2040	2045	2050
BAU	1,421	1,572	1,764	1,955	2,154	2,362	2,580	2,809
EV20	1,421	1,548	1,691	1,821	1,948	2,071	2,190	2,304
EV40	1,421	1,524	1,618	1,688	1,742	1,779	1,799	1,800
EV60	1,421	1,499	1,544	1,554	1,536	1,488	1,409	1,296

Source: LEAP model running results (2020).

Having BEVs in the passenger car fleet also means that additional electric power needs to be generated. Assuming that Brunei's electricity would be produced almost uniquely in the gas-fired power plants, this additional generated power would mean an increase in CO_2 emissions. Figure 3.10 shows that the higher the number of BEVs in the scenarios, the higher the CO_2 emitted in the power plants. In BAU, we expect that CO_2 emissions would increase from 2.6 million tonnes CO_2 in 2017 to reach 3.9 million tonnes CO_2 in 2050. Compared to BAU, the EV20, EV40, and EV60 scenarios should increase the CO_2 emission in 2050 by 11%, 22%, and 33%, respectively. In EV60, we can expect that CO_2 emission from power generation would double from 2,600 million tonnes CO_2 in 2017 to 5,200 million tonnes CO_2 in 2050.

Figure 3.10: CO_2 Emissions from Electricity Generation – Electric Cars Scenarios

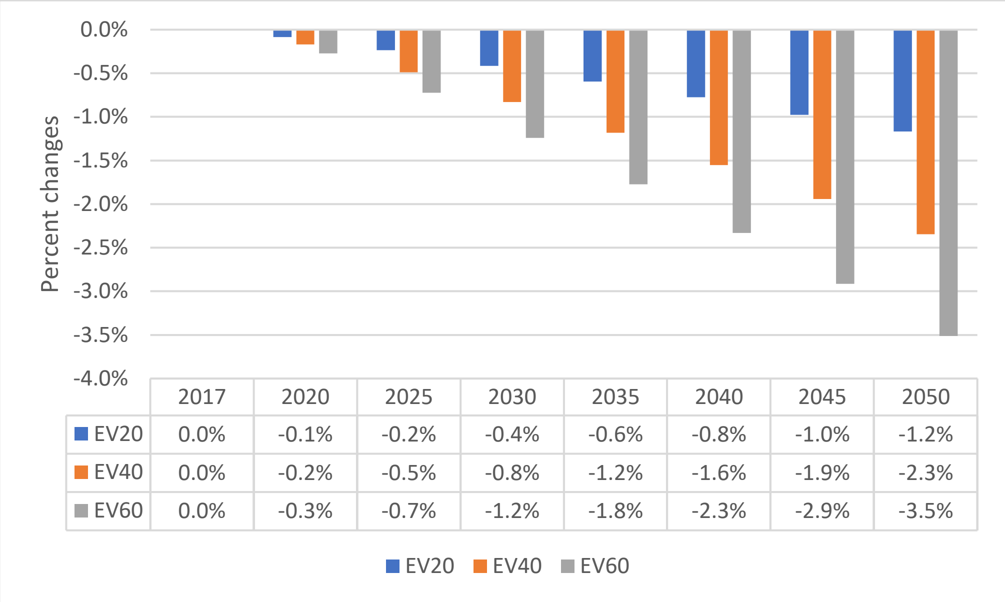


	2017	2020	2025	2030	2035	2040	2045	2050
BAU	2,568	2,702	2,904	3,078	3,260	3,452	3,656	3,867
EV20	2,568	2,723	2,966	3,191	3,434	3,699	3,985	4,294
EV40	2,568	2,743	3,028	3,304	3,609	3,945	4,315	4,719
EV60	2,568	2,763	3,091	3,417	3,783	4,191	4,645	5,146

Source: LEAP model running results (2020).

Considering the passenger car and power generation sectors, BEVs in Brunei Darussalam should contribute to reducing CO_2 emissions. The EV60 scenario should reduce CO_2 the most, i.e. we can expect that in 2050 it would reduce the total CO_2 emission by 3.5% whilst EV20 and EV40 would reduce emissions by 1.2% and 2.3%, respectively (Figure 3.11). As shown previously in the discussion related to Figure 3.10, these limited impacts on CO_2 reduction by BEV penetration are caused mainly by the energy mix in Brunei's power generation, which is based almost solely on natural gas.

Figure 3.11: Changes in Total CO_2 Emissions in Electric Cars Scenarios Relative to BAU (%)



	2017	2020	2025	2030	2035	2040	2045	2050
EV20	0.0%	-0.1%	-0.2%	-0.4%	-0.6%	-0.8%	-1.0%	-1.2%
EV40	0.0%	-0.2%	-0.5%	-0.8%	-1.2%	-1.6%	-1.9%	-2.3%
EV60	0.0%	-0.3%	-0.7%	-1.2%	-1.8%	-2.3%	-2.9%	-3.5%

Source: LEAP model running results (2020).

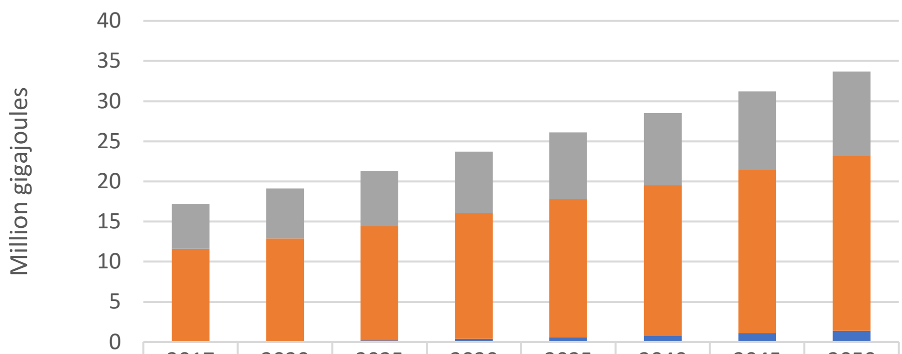
2.4.2. Hydrogen-Powered Fuel Cell Car Scenarios

a) Hydrogen production: steam reforming without CCS

Currently, natural gas steam reforming without CCS is the most feasible pathway of producing hydrogen in Brunei. In this section, we discuss the results of the different scenarios of having FCs in the country's passenger car fleet.

With 10% FCs comprising the total passenger cars by 2050, the FC10 scenario should reduce total energy demand from passenger car fleet by 6%, i.e. a reduction from 36 million GJ in BAU to 33.8 million GJ in the FC10 scenario (Figure 3.12). The reduction in total energy demand from the passenger car fleet would decrease with the increasing rate of FC penetration, i.e. the FC20 and FC30 scenarios should reduce the energy demand of the total passenger car fleet in 2050 by around 12% (Figure 3.13) and 18% (Figure 3.14) consecutively.

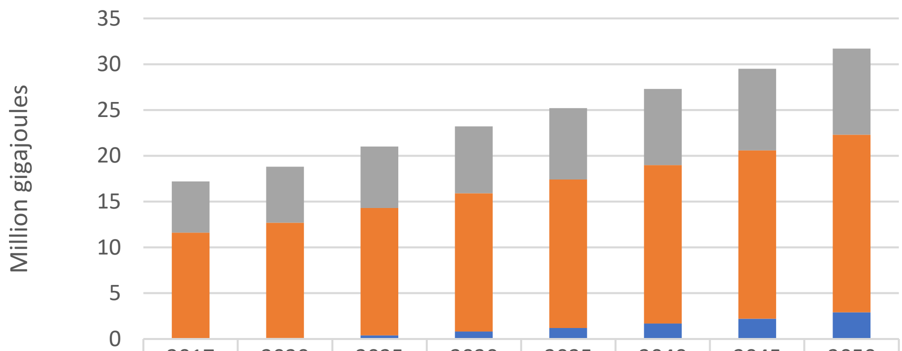
Figure 3.12: Energy Consumption of Passenger Cars – FC10 Scenario



	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	6.2	6.9	7.6	8.3	9	9.8	10.5
Gasoline	11.6	12.8	14.2	15.7	17.2	18.7	20.3	21.8
Hydrogen	0	0.1	0.2	0.4	0.6	0.8	1.1	1.4

Source: LEAP model running results (2020).

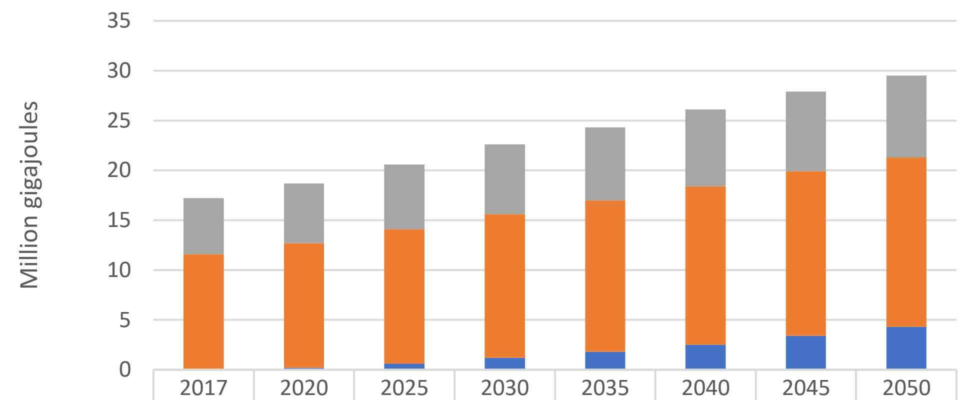
Figure 3.13: Energy Consumption of Passenger Cars – FC20 Scenario



	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	6.1	6.7	7.3	7.8	8.3	8.9	9.4
Gasoline	11.6	12.6	13.9	15.1	16.2	17.3	18.4	19.4
Hydrogen	0	0.1	0.4	0.8	1.2	1.7	2.2	2.9

Source: LEAP model running results (2020).

Figure 3.14: Energy Consumption of Passenger Cars – FC30 Scenario

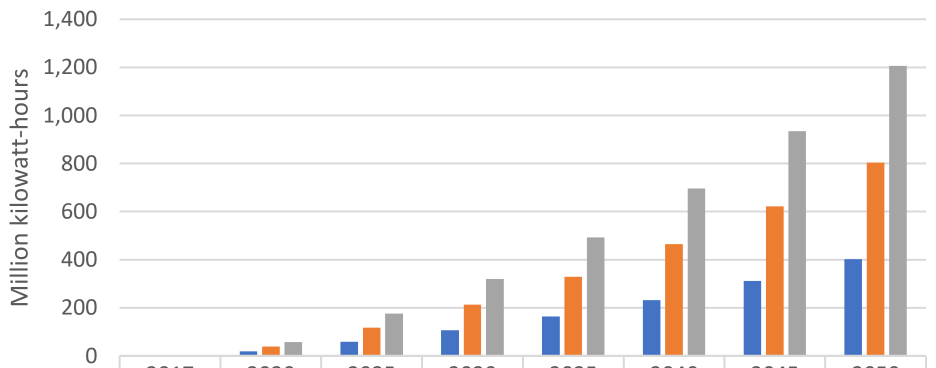


	2017	2020	2025	2030	2035	2040	2045	2050
Diesel	5.6	6	6.5	7	7.3	7.7	8	8.2
Gasoline	11.6	12.5	13.5	14.4	15.2	15.9	16.5	17
Hydrogen	0	0.2	0.6	1.2	1.8	2.5	3.4	4.3

Source: LEAP model running results (2020).

Figure 3.15 shows the hydrogen that needs to be produced in the country to meet the hydrogen demand in FC scenarios. In 2050, the FC10 scenario would need about 400 GWh of hydrogen; FC20, about 800 GWh; and FC30, about 1,200 GWh of hydrogen.

Figure 3.15: Produced Hydrogen – Fuel-Cell Hydrogen Scenarios

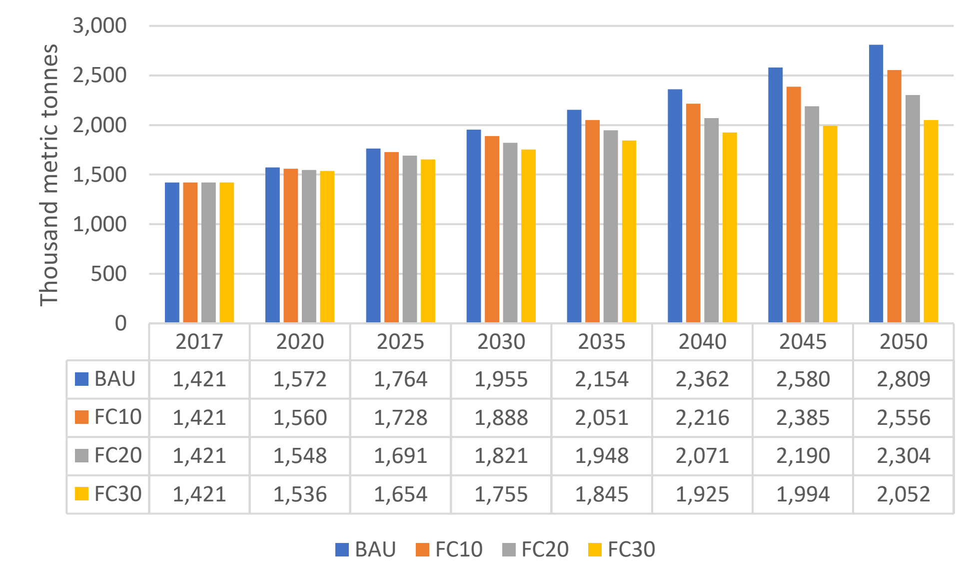


	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	19	59	107	164	232	311	402
FC20	0	39	117	213	329	465	622	804
FC30	0	58	176	320	493	697	934	1,206

Source: LEAP model running results (2020).

Shifting from gasoline- and diesel-fuelled passenger cars to fuel-cell passenger cars would reduce CO_2 emission of the total fleet of passenger cars. In 2050, the reductions from the three scenarios compared to BAU would be 9%, 18%, and 27%, respectively, from the FC10, FC20, and FC30 scenarios (Figure 3.16).

Figure 3.16: CO_2 Emissions of Passenger Car Transport – Fuel-Cell Hydrogen Cars Scenarios

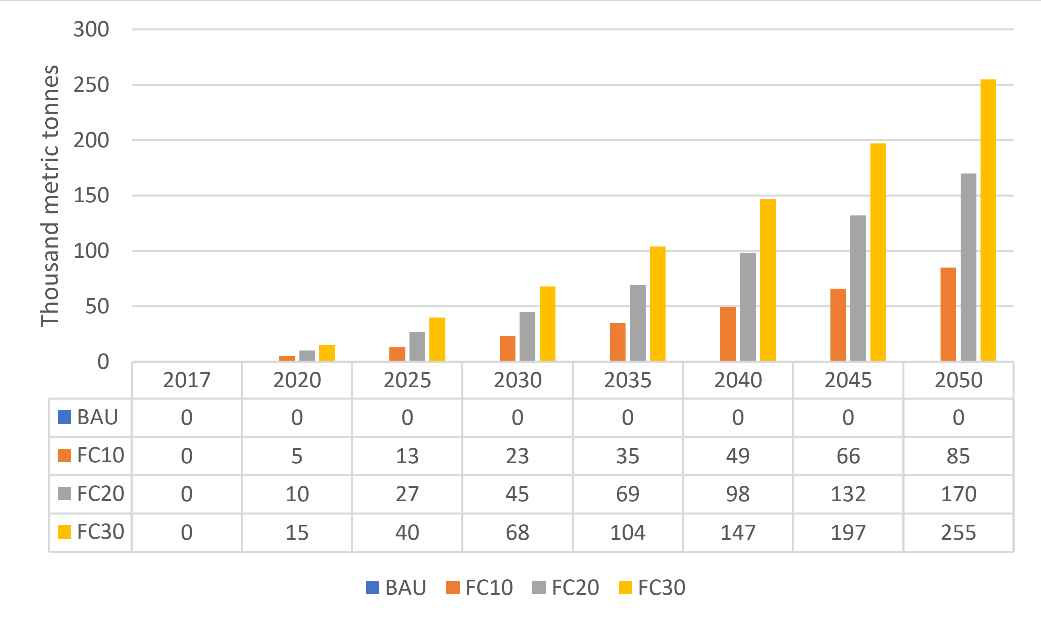


	2017	2020	2025	2030	2035	2040	2045	2050
BAU	1,421	1,572	1,764	1,955	2,154	2,362	2,580	2,809
FC10	1,421	1,560	1,728	1,888	2,051	2,216	2,385	2,556
FC20	1,421	1,548	1,691	1,821	1,948	2,071	2,190	2,304
FC30	1,421	1,536	1,654	1,755	1,845	1,925	1,994	2,052

Source: LEAP model running results (2020).

At the same time, producing hydrogen from natural gas steam reforming without CCS would emit CO_2. In 2050, for example, we can expect that this hydrogen production would bring 85 thousand, 170 thousand, and 255 thousand metric tonnes CO_2 from the FC10, F20, and FC30 scenarios, respectively (Figure 3.17).

Figure 3.17: CO_2 Emissions from Hydrogen Production – Natural Gas Steam Reforming without CCS – Hydrogen-Powered Fuel-Cell Car Scenarios

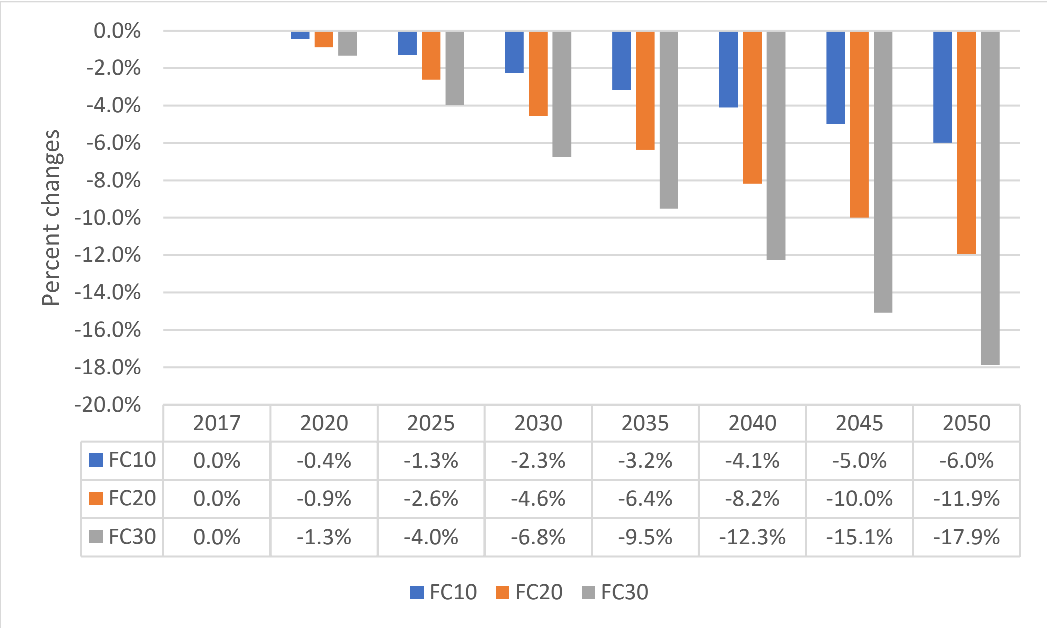


	2017	2020	2025	2030	2035	2040	2045	2050
BAU	0	0	0	0	0	0	0	0
FC10	0	5	13	23	35	49	66	85
FC20	0	10	27	45	69	98	132	170
FC30	0	15	40	68	104	147	197	255

Source: LEAP model running results (2020).

FC penetration in the passenger car fleet in Brunei should overall reduce CO_2 emissions. In 2050, we can expect that, compared to BAU, the reduction rate would be around 6%, 12%, and 18% from the FC10, F20, and FC30 scenarios, respectively. These CO_2 emission reduction effects are higher than those from the BEV scenarios presented in Section 3.2.4.1.

Figure 3.18: Changes (%) in Total CO_2 Emissions in Hydrogen-Powered Fuel-Cell Car Scenarios vis-à-vis BAU – Hydrogen Produced from Natural Gas Steam Reforming without CCS



	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0.0%	-0.4%	-1.3%	-2.3%	-3.2%	-4.1%	-5.0%	-6.0%
FC20	0.0%	-0.9%	-2.6%	-4.6%	-6.4%	-8.2%	-10.0%	-11.9%
FC30	0.0%	-1.3%	-4.0%	-6.8%	-9.5%	-12.3%	-15.1%	-17.9%

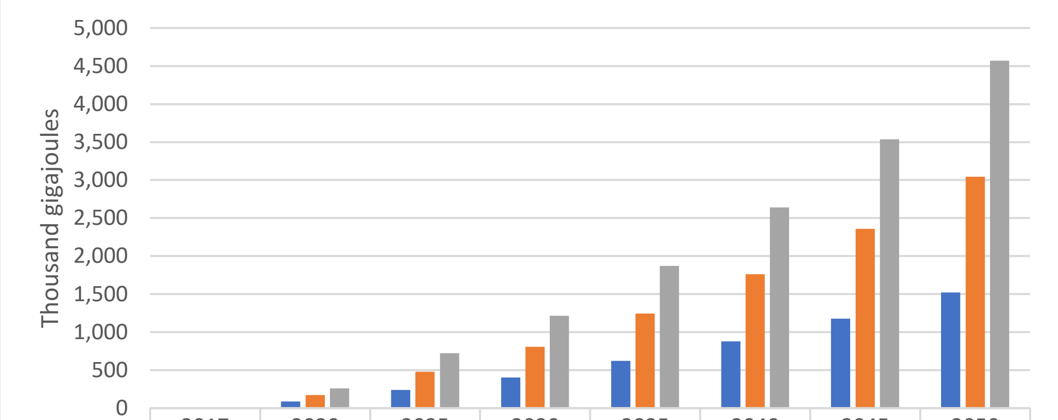
Source: LEAP model running results (2020).

b) **Other pathways of hydrogen production: steam reforming with CCS and electrolysis**

Apart from producing hydrogen from natural gas steam reforming without CCS, we also analysed the impacts of producing hydrogen using other pathways, i.e. natural gas steam reforming with CCS and electrolysis. This section discussed the energy needed to produce hydrogen and CO_2 emissions from the different hydrogen production pathways.

Figures 3.19 and 3.20 show the total energy input needed to produce hydrogen from steam reforming of natural gas consecutively without and with CCS. Hydrogen production via steam reforming with CCS needs more natural gas than without CCS, following the assumption on efficiency as explained in Section 1.8.5. That is, the process with CCS needed 20% more natural gas in 2017 than that without CCS and around 27% more in 2030 onwards.

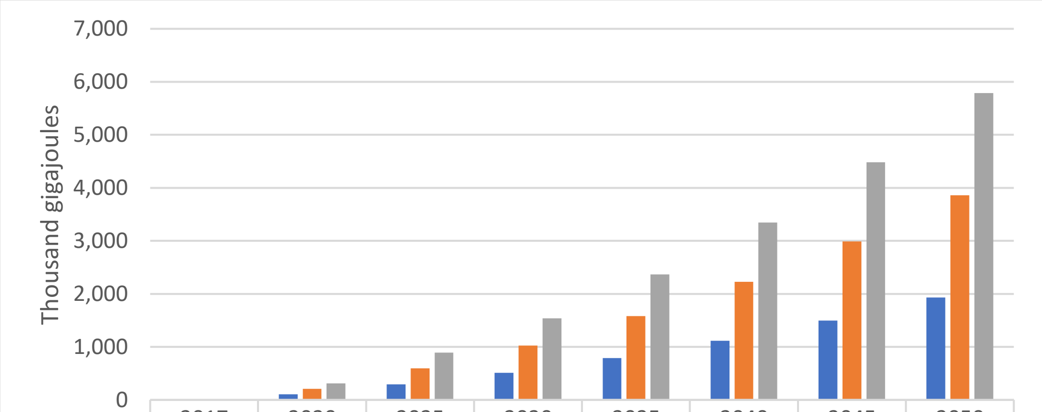
Figure 3.19: Natural Gas Input to Produce Hydrogen from Natural Gas Steam Reforming without CCS



	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	87	240	404	623	880	1,179	1,523
FC20	0	174	481	808	1,246	1,761	2,359	3,046
FC30	0	261	721	1,213	1,869	2,641	3,538	4,570

CCS = carbon capture and sequestration.
Source: LEAP model running results (2020).

Figure 3.20: Natural Gas Input to Produce Hydrogen from Natural Gas Steam Reforming with CCS

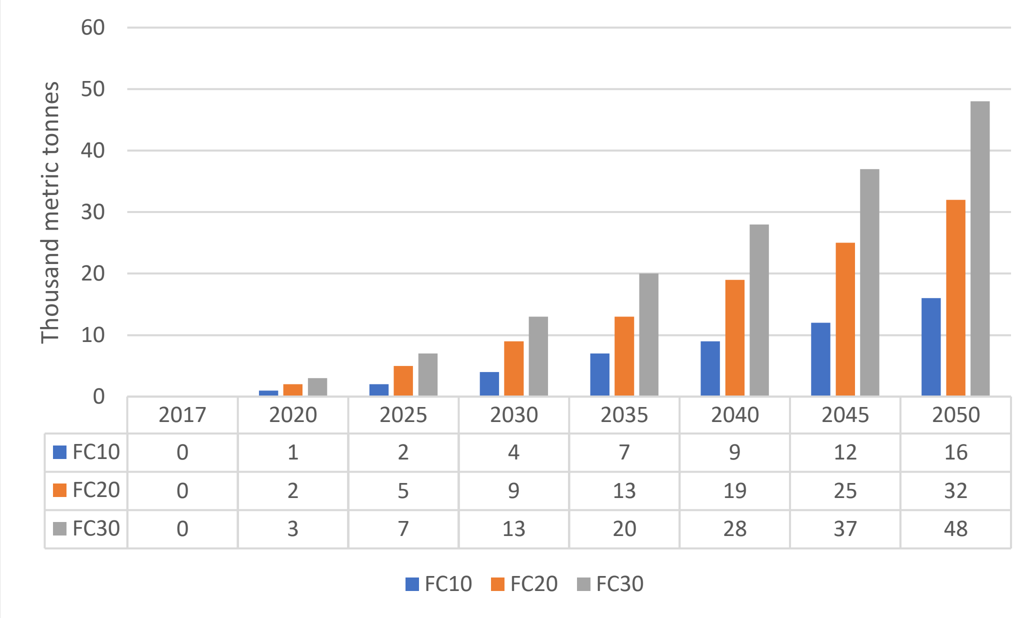


	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	104	296	512	789	1,115	1,494	1,929
FC20	0	208	593	1,024	1,578	2,230	2,988	3,859
FC30	0	311	889	1,536	2,367	3,345	4,481	5,788

CCS = carbon capture and sequestration.
Source: LEAP model running results (2020).

Whilst it needs more natural gas feedstock, hydrogen production from natural gas steam reforming with CCS emits significantly lower CO_2 (Figure 3.21). In FC 30, the most advanced FC scenario, we can expect this hydrogen production pathway to emit not more than 48 thousand metric tonnes CO_2 in 2050. This is less than one-fifth (or 255 thousand metric tonnes) of CO_2 emission from hydrogen production from natural gas reforming with CCS (Figure 3.17).

Figure 3.21: CO_2 Emission from Hydrogen Production from Methane Steam Reforming with CCS – Fuel-Cell Car Scenarios



	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	1	2	4	7	9	12	16
FC20	0	2	5	9	13	19	25	32
FC30	0	3	7	13	20	28	37	48

CCS = carbon capture and sequestration.
Source: LEAP model running results (2020).

Hydrogen can also be produced by water electrolysis, i.e. splitting water into hydrogen and oxygen using electric energy. We can usually differentiate this pathway into two methods based on the electricity sources used in the process. The first is from renewable energy, such as wind and solar, and the second is from grid power.

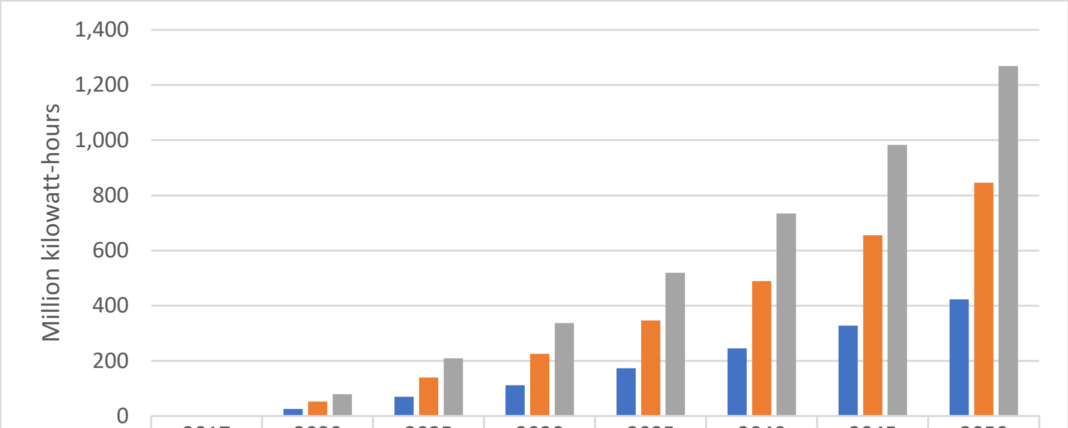
Producing hydrogen from electrolysis emits practically no CO_2. However, as the installed capacity of solar and wind power plants is limited in Brunei, this pathway is currently not feasible.

Figure 3.22 shows the additional grid electricity needed to produce hydrogen to meet the needs of FC scenarios. As electrolysis has low efficiency (see Section 3.2.3), FC scenarios would require more electricity than EV scenarios. For example, the FC20 scenario would need at least 60% more electricity than EV20 (see Figure 3.7).

The grid electricity–based electrolysis pathway also emits more CO_2 than the other hydrogen production pathways. As Figure 3.23 shows, in 2050, CO_2 emission from hydrogen production using grid electricity–based electrolysis is four times higher than that of steam reforming without CCS.

Considering both electricity needs and CO_2 emission, we can consider hydrogen production from grid electricity–based electrolysis a non-reasonable pathway of hydrogen production.

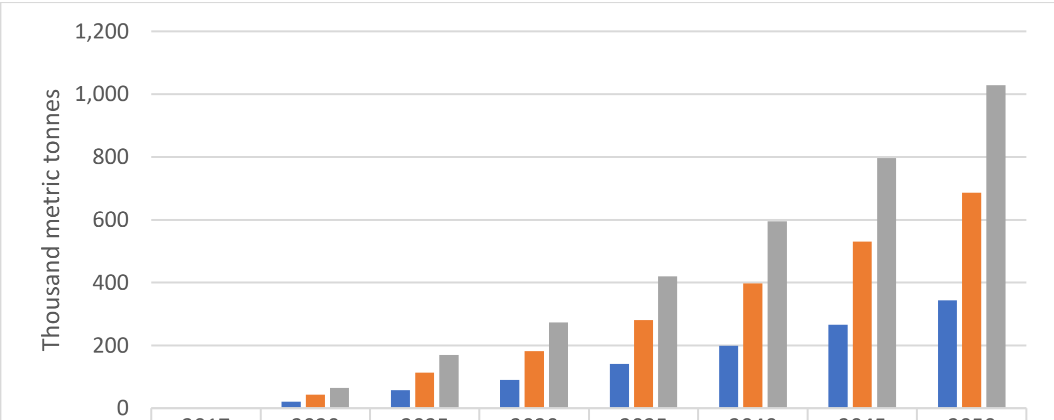
Figure 3.22: Grid Electricity Needed to Produce Hydrogen by Electrolysis



	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	26	70	112	173	245	328	423
FC20	0	53	139	225	346	489	655	846
FC30	0	79	209	337	519	734	983	1,269

Source: LEAP model running results.

Figure 3.23: CO_2 Emission from Hydrogen Production from Grid Electricity–Based Electrolysis – Fuel-Cell Car Scenarios



	2017	2020	2025	2030	2035	2040	2045	2050
FC10	0	21	57	90	141	199	266	343
FC20	0	43	113	182	280	397	531	686
FC30	0	64	169	273	420	595	796	1,029

Source: LEAP model running results.

2.5. Elements of conclusion

Both electric- and hydrogen-powered FCs are more energy efficient than conventional internal combustion engine cars. Both technologies should reduce CO_2 emissions in the transport and power generation sectors and hydrogen production.

The effects of the penetration of hydrogen-powered FCs on CO_2 emissions depend on how hydrogen is produced. Using natural gas steam reforming–based hydrogen, with or without CCS, to feed FCs can potentially reduce the total CO_2 emissions more than the penetration of electric cars. The best effect of hydrogen-powered FC penetration on CO_2 emissions would be obtained when the hydrogen is produced by water electrolysis with renewable energy source–based electric power. The effect would be negative if hydrogen is produced by electrolysis with electric power coming from the grid.

A massive implementation of hydrogen-powered FCs will imply changes in the development of hydrogen production technologies according to the techno-economic and environmental features, which must be implemented in the model.

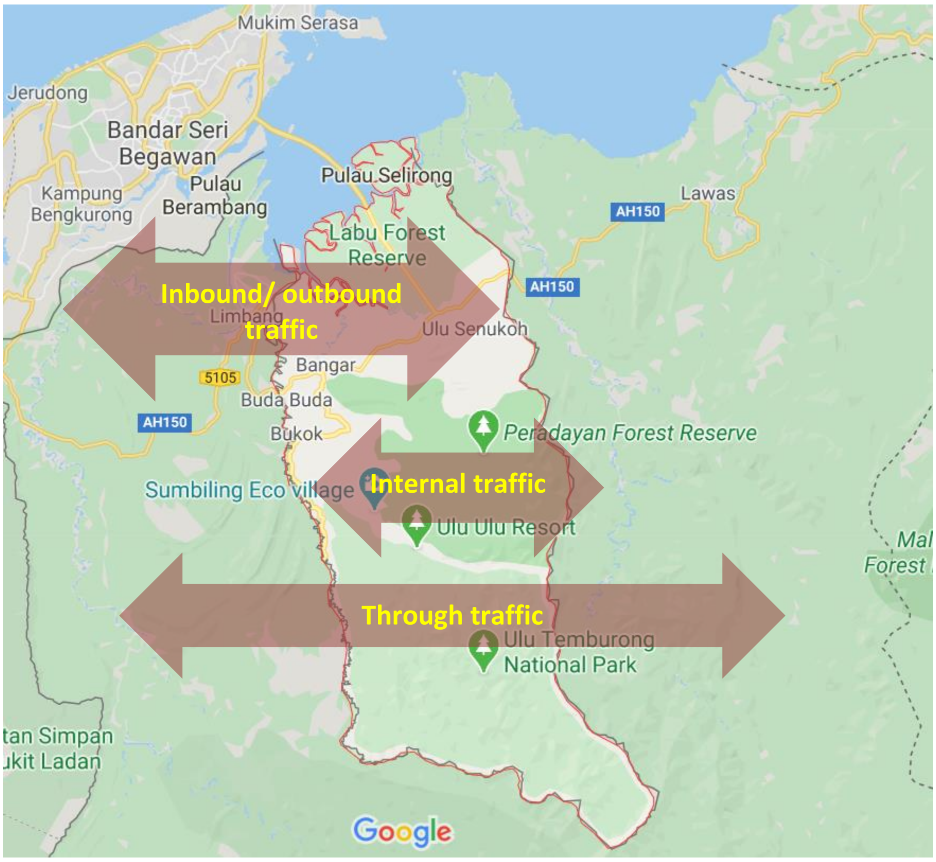
3. Low-Carbon Traffic System for Temburong District

3.1. Framework for analysis

Considering the growth of the district that includes economic and demographic aspects, activities, and land-use development up to 2030, the study proposed a mobility network for the district whose principles could be grouped into three trip categories:

- *Inbound/outbound traffic*: Tourists from BSB would visit Temburong via hydrogen-powered mass-transit bus through Temburong Bridge.
- *Internal traffic*: Tourists travel around Temburong district in non-carbon vehicles such as community buses, boats, and taxis.
- *Passing through traffic*: In the future, only non-carbon cars will be permitted to drive in Temburong district. This also aims to control the traffic volume (internal-combustion engine cars, buses, and trucks) between Sabah and Sarawak State in Malaysia, passing through Temburong. Brunei is located in the middle of the main road traffic corridor connecting the two Malaysian states.

Figure 3.24: Three Traffic Flow Categories



Source: Google Maps with Author's elaboration.

We included several events and proposals relating to the development of Temburong ecotown in this analysis framework. These will be discussed in detail in the following subsections:

- Land Transport Master Plan (LTMP) and Transport White Paper
- The opening of Temburong Bridge
- The development of Temburong district following the master plan proposed in ERIA and Nikken Sekkei Civil Engineering Ltd (2018)

3.3.1. LTMP and Transport White Paper

The Ministry of Communications Brunei Darussalam (2017) defined the high level of land-transport mission as achieving an integrated, efficient, safe, clean, and rapid land transport system that offers a choice for all and supports the sustainable economic development of Brunei Darussalam. The basic premise behind the mission is the need to support national economic, social, and cultural development in line with Wawasan 2035, but to achieve this across a range of transport modes and mitigate negative impacts on society and the natural and built environments.

Amongst the national and local programmes defined in the LTMP, we identified three interventions currently being prepared that should soon affect mobility and emission in Temburong district: green vehicle regulations and incentives; improvement to cross-border crossings and customs, immigration, quarantine, and security (CIQS) facilities; and Pan-Borneo highway and public transport enhancements (Table 3.6).

Table 3.6: National and Local Programmes in the Land Transport Master Plan that Might Affect the Mobility and Emissions in Temburong District

Intervention: National and Local Programmes	Preparation Period	Targeted Completion Year
Green vehicle regulations and incentives	2014–2025	2025
Improvements to cross-border crossings and customs, immigration, quarantine, and security (CIQS) Facilities	2016–2022	2022
Pan-Borneo highway enhancements	2018–2024	2024

Source: Extracted from Centre for Strategic and Policy Studies (2014).

Table 3.7: Green Vehicle and Border-Crossing Improvement Interventions

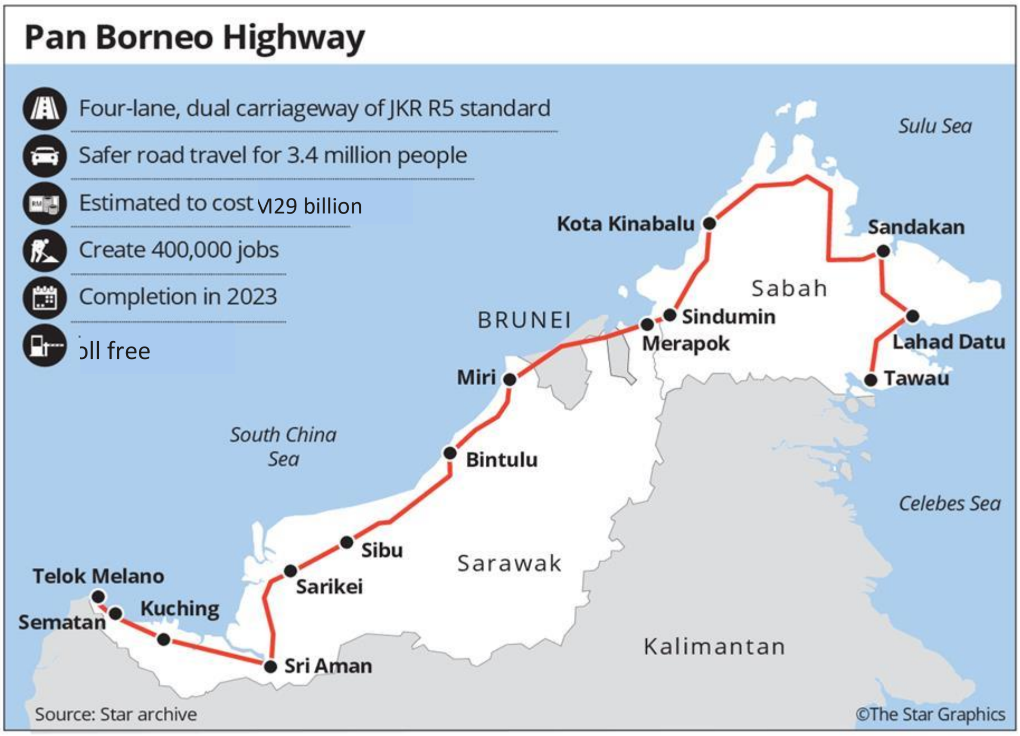
Intervention	Objective	Target Year		Key Actions and Milestones
		2025	2035	
Green vehicle regulations and incentives	Objective 2.2 – Promote energy efficiency and the progressive decarbonisation of the vehicle fleet and fuel cycle	48,000 kg of CO_2 for morning peak hours (down by 31% from reference case)	66,000 kg of CO_2 for morning peak hours (down by 40% from reference case)	• Strengthening of vehicle and fuel emission and consumption standards to Euro V and beyond (to 2025) • Working with industry on pilot and field trials of zero-emission vehicles, as well as charging infrastructure (to 2025) • Adoption and mainstreaming of decarbonised vehicle technology including full electric, fuel cells, and hydrogen (to 2035)
		>1% of vehicle fleet electric or hybrid	10% of vehicle fleet fully electric	
Improvements to border crossings and customs, immigration, quarantine and security (CIQS) facilities	Provide efficient access and operation for international gateways for passengers and freight, including ports, jetties, airports, and land border crossings	Journey time targets to airport, border crossings and Muara Port to be set	Journey time targets to airport, border crossings and Muara Port to be set	Linkage of Brunei Coastal Highway to wider improvements to Pan-Borneo Highway in Sarawak and streamlining of border crossing and CIQS procedures (to 2025)

Source: Extracted from Centre for Strategic and Policy Studies (2014).

The third intervention, i.e. Pan-Borneo highway and public transport enhancements, occupies theme no. 6 of the LTMP entitled 'Effective Regional and International Connections Lies in fact in the Framework of Brunei Darussalam, Indonesia, Malaysia, and the Philippines, East ASEAN Growth Area (BIMP-EAGA). This cooperative framework comprises sets of agreements between the four countries launched in 1994. This framework aimed at accelerating economic development in the four countries' focus areas that, although geographically distant from their national capitals, are strategically near each other in one of the world's most resource-rich regions.

Brunei Darussalam shares the Pan-Borneo highway[7] (Figure 3.25) connections and relations with Malaysia and Indonesia. Brunei also seeks regional economic, social, and environmental cooperation through BIMP-EAGA and the wider ASEAN community. Transport connections play an important role in supporting such cooperation and need to be made as efficient, attractive, and effective to reduce the economic and social costs of travel.

Figure 3.25: Pan-Borneo Highway



Source: *The Star* (2018).

Apart from the road network, shipping also plays a vital role in the BIMP-EAGA framework. In this aspect, it might be important to pay attention to the development of Muara Port.

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[7] The Pan-Borneo Highway is a road network on Borneo Island connecting two Malaysian states, Sabah and Sarawak, with Brunei and Kalimantan region in Indonesia. The highway is numbered AH150 in the Asian Highway Network and as Federal Route 1 in Sarawak. In Sabah, the route numbers are 1, 13, and 22. The length of the entire highway is expected to be about 2,083 kilometres (km) (1,294 mi) for the Malaysian section, 168 km (104 mi) for the Bruneian section, and 3,073 km (1,909 mi) for the Indonesian section. The Indonesian sections of the Pan-Borneo Highway is known as the Trans-Kalimantan Highway. The western route connects Pontianak city to Tebedu.

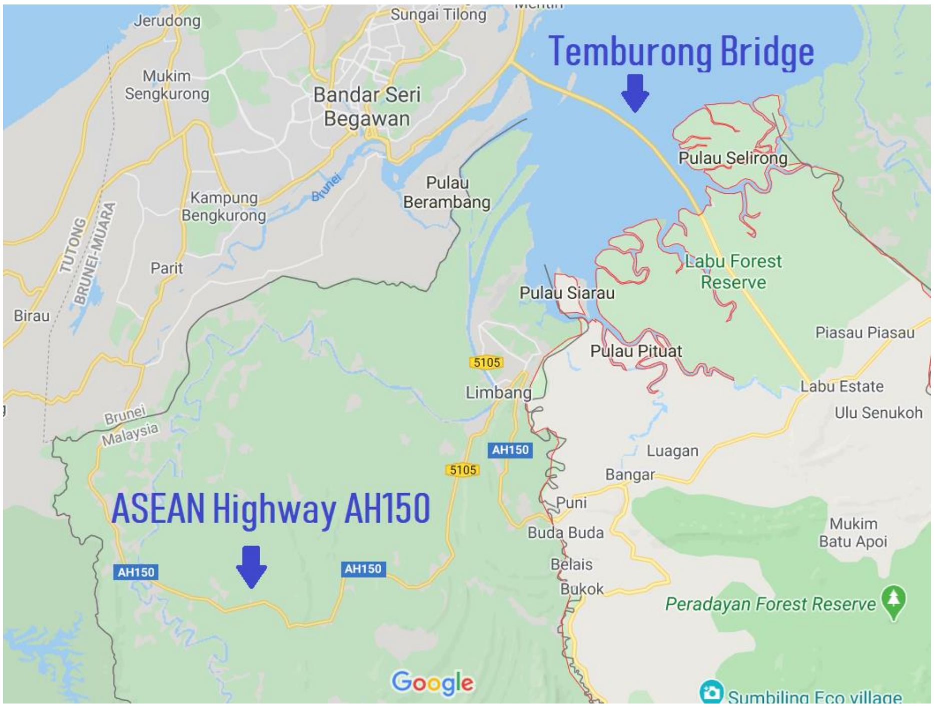
Rahman (2019) categorised Muara Port as a small-scale seaport but the Ministry of Foreign Affairs of the People's Republic of China (2020) considered it as a key focus in developing Brunei's role as a hub within the BIMP-EAGA subregion.

3.1.2. The Opening of Temburong Bridge

Temburong Bridge is a dual-carriageway bridge in Brunei and is the longest bridge in Southeast Asia. Spanning 30 kms, it connects Mengkubau and Sungai Besar in the Brunei–Muara district with the Labu Estate in Temburong district. According to Abu Bakar (2020), the bridge shall reduce travel time between the Brunei capital, Bandar Seri Begawan (BSB), and Temburong district from the current 2 hours of travelling via the Asian or ASEAN Highway 150 passing by the Malaysian Limbang district, or between 1 to 2 hours on a ferry between Brunei Muara and Temburong to less than 30 minutes using the new bridge.

Abu Bakar (2020) reported that Temburong Bridge was opened on 17 March 2020 for public use. The bridge is currently open daily from 6 a.m. to 10 p.m. with some access criteria for motorists using the bridge. Only Brunei-registered vehicles in classes I, III, IV, and VI can use the bridge. Brunei-registered commercial vehicles (class V) are required to apply for permission from the Bridge Maintenance Office. In the meantime, foreign-registered commercial vehicles are advised to continue using the designated ASEAN Highway 150 route, which requires crossing the Brunei Darussalam–Malaysia border twice, i.e. in Tedungan and in Puni, passing through Limbang in Sarawak Malaysia that separates Brunei Darussalam in two parts.

Figure 3.26: Current Main Road Access To and From Temburong District



Source: Google Maps (2020) with author's modification.

3.1.3. ERIA and Nikken Sekkei Civil Engineering Ltd (2018a) Temburong District Following the Master Plan (LTMP)

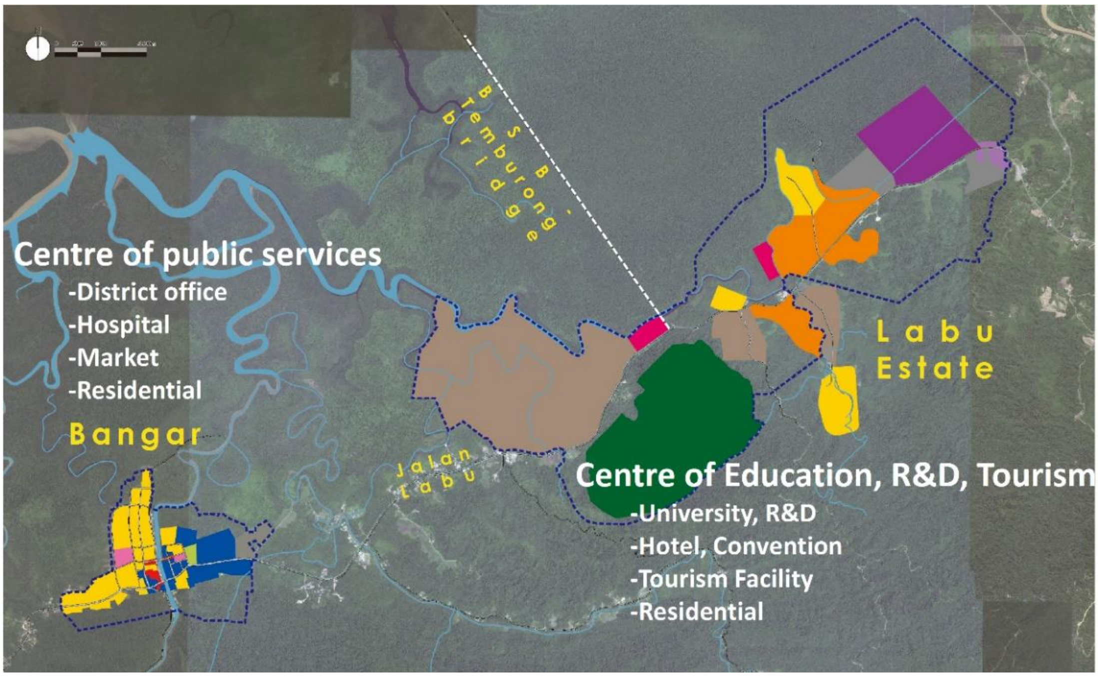
The Ministry of Primary Resources and Tourism (2017) projected that tourism visits to Brunei will increase from 281,213 visitors in 2015 to 451,000 visitors in 2020, a 15.63% annual increase. Temburong district was identified as one of the primary tourism products, together with BSB and Kampong Ayer. For Temburong district itself, the target was to increase the number of visitors from 10,646 in 2015 to 24,000 in 2020 through the development of the Batang Duri River Centre, River Resort; privatisation of the Temburong Rest House, Cultural, and Heritage Gallery; and the organisation of events such as the Temburong Marathon and the building of leisure and theme parks.

ERIA (2018a) proposed to develop Temburong district as a next-generation eco city, as part of the rich ecosystem of Borneo island aiming at zero–carbon emissions. The study proposed the following policies to balance the circulation of energy supply and demand: (i) renewable energy, (ii) a sustainable mobility system, (iii) sustainable architecture and agroforestry, and (iv) a small economy.

A sustainable mobility system is needed to minimise the energy consumption caused by movement. For example, hydrogen-powered buses (CO_2 zero) could bring tourists from BSB to Temburong district and tourists could travel around in Temburong in hydrogen-powered autonomous cars.

Proposing a master plan for the district until 2030 and considering the development plan of the sea bridge connecting BSB and Temburong, the study offered two development hubs in Temburong: Bangar and Labu Estate. As shown in Figure 3.27, Bangar will be the centre of public services and shall house the district office, hospital, market, and residential communities. Labu Estate, on the other hand, will be the centre of education, research and development (R&D), and tourism. It shall house a university, hotels, convention centres, and tourism facilities, including the Ulu Temburong National Park and Perdayan Forest Recreation Park.

Figure 3.27: Suitable Location for Development Hubs in Temburong

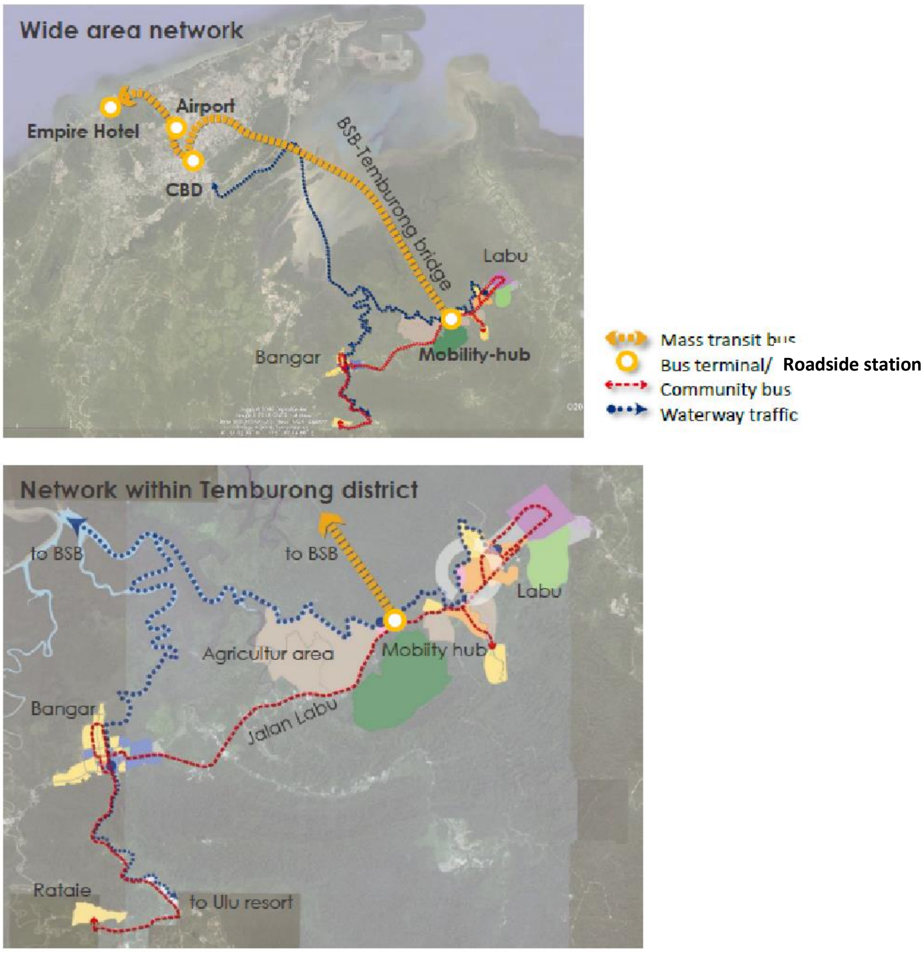


Source: ERIA (2018).

To develop sustainable mobility in Temburong, ERIA (2018) proposed the basic concept of a carbon-neutral society for eco-friendly Temburong district through the following:

- Suppression of traffic volume:
  - Control entry of vehicles from Temburong Bridge
  - Promote carpooling system
  - Introduce public transport
  - Encourage a new logistics system, such as drones, which does not depend on vehicles
- Prioritisation of transport devices with small environmental loads:
  - Develop traffic regulation that gives priority to EVs or FCVs
  - Introduce a transportation device that does not depend on automobiles, such as electric motorcycles
- Introduction of various transport devices to activate ecotourism:
  - Introduce various transportation devices such as autonomous vehicles, boats, buses, taxis, electric motorcycles, and bicycles.

Figure 3.28: Mobility Network of Temburong District

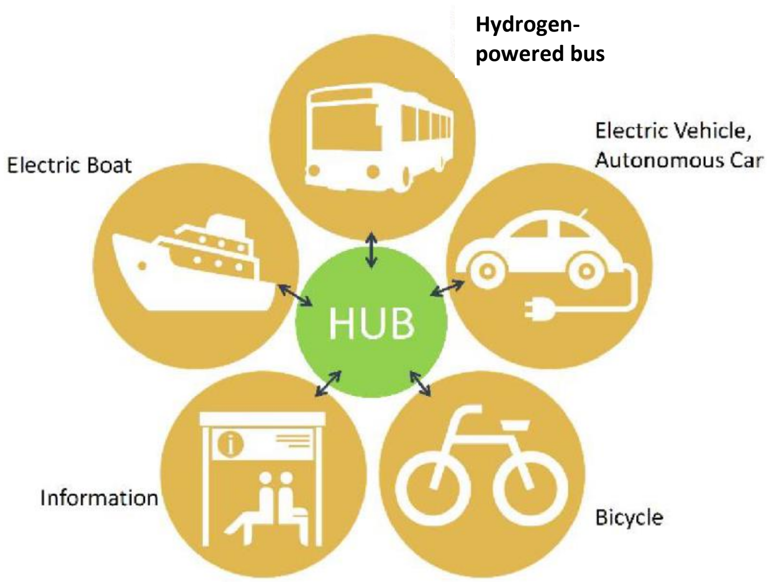


Source: ERIA (2018).

A mobility hub zone was proposed as a place where hydrogen-powered buses, electric cars, autonomous cars, electric boats, and bicycles are connected. Tourists arriving in Temburong from BSB via hydrogen-powered buses can transfer to other means of transport, such as electric cars, autonomous cars, electric boats, and bicycles, to go to other tourist spots.

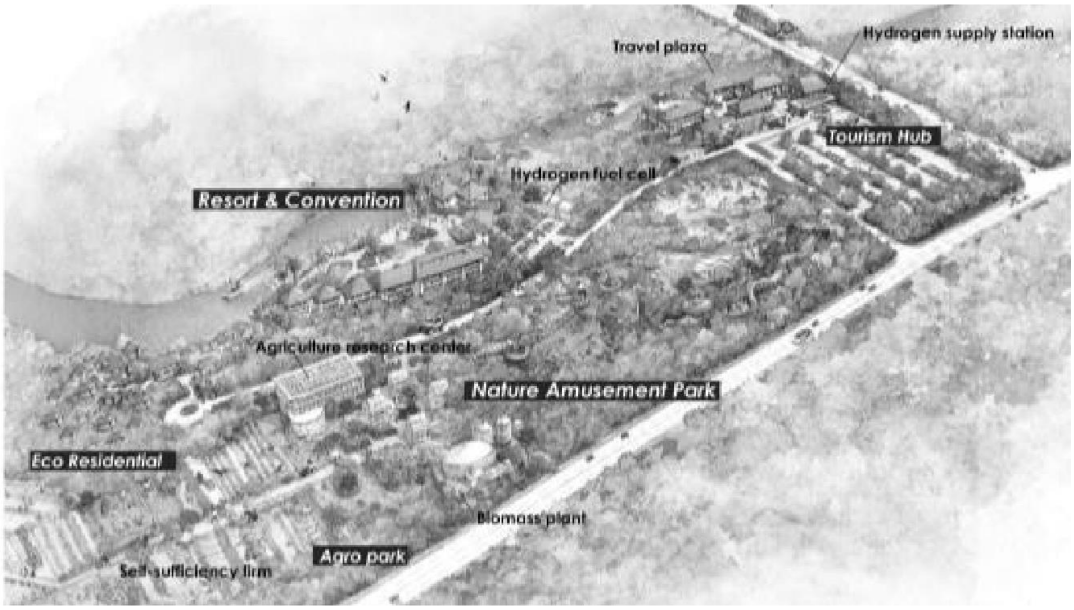
With the travel plaza here, tourists can enjoy many services such as accessing tourism information, booking tours and accommodation, and using the hydrogen supply station.

Figure 3.29: Mobility Hub Design



Source: ERIA (2018).

Figure 3.30: Mobility Hub Zone



Source: ERIA (2018).

3.2. Development of a low-carbon traffic system scenario

3.2.1. Methodology for Calculating Emissions from the Transport Sector

A basic methodology for calculating emissions from the transport sector is known as the ASIF methodology (Schipper et. al., 2000). The acronym ASIF stands for Activity-Structure-Intensity-Fuel data matrix.

Equation (3)…

$$G = \sum_{mode} \sum_{fuel} A_{mode,fuel} \cdot S_{mode,fuel}^{-1} \cdot I_{mode,fuel} \cdot F_{fuel}$$

where:

G = total emissions of GHGs in the regions, for example, given in tonnes of CO_2

A = transport activity in passenger- and/or tonne-kilometres

S = structure variable representing the load factors for the various modes and fuel types, i.e. occupancy of passenger vehicles such as passengers per vehicle, and an equivalent measure for freight, such as tonnes per vehicle.

I = measures of energy intensity in energy per vehicle kilometre for each mode and fuel type, which can be represented by vehicles' fuel economy given, for example, in litre/vehicle-kilometre.

F = simple carbon per energy constant for each fuel type.

3.2.2. Current Situation and the Potential Changes in the Traffic of Temburong District

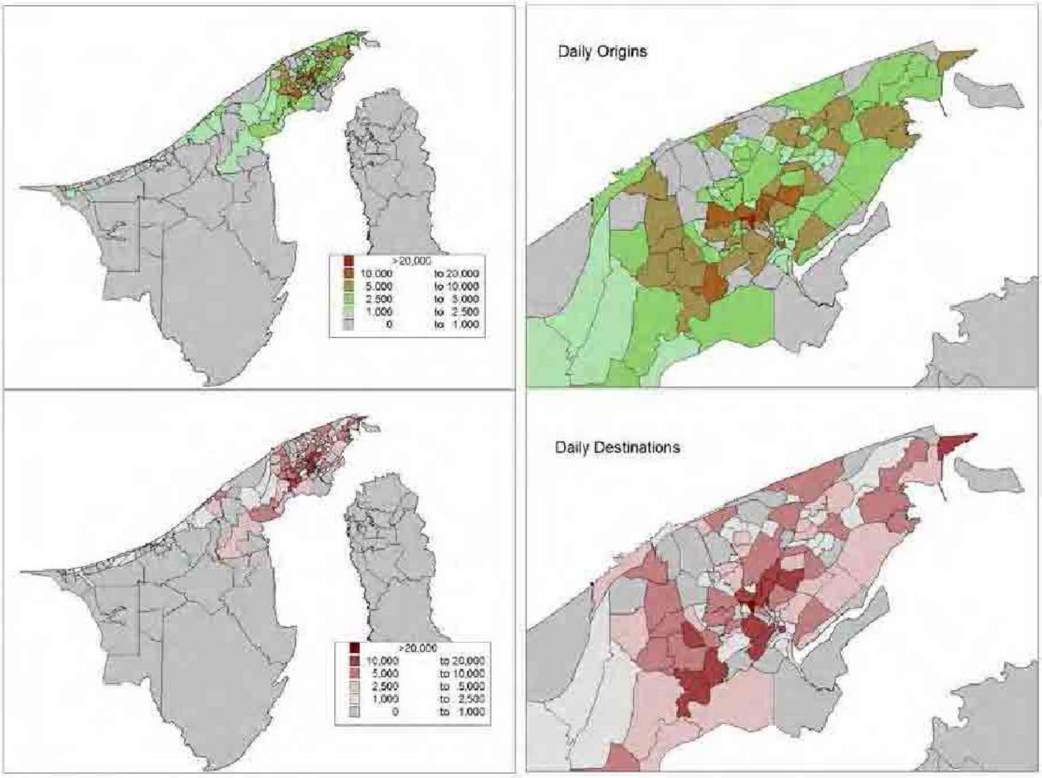
The Centre for Strategic and Policy Studies (2014) recorded that trip across Brunei is around 800,000 person-trips per day (from 7 a.m. to 7 p.m.), accounting for vehicle occupancy, the vast majority of which are by car. Over 300,000 vehicles were recorded in total at the Roadside Interviews (RSI) in 2014.

According to the survey conducted by the Centre, the daily total number of trips to and from Temburong district in 2012 was amongst the lowest in the whole Brunei Darussalam (Figure 3.31).

With the Temburong district as a primary tourist destination in Brunei and with the opening of the Temburong Bridge on 17 March 2020, the number of trips would increase significantly, not only those coming from or going to Temburong but also those passing through.

The two events will induce attraction to the district and, therefore, considerably increase the volume of inbound and outbound traffic, internal traffic, and passing-through traffic. Without any environmentally emphasised intervention and policy measures, the increasing traffic would be harmful to the district.

Figure 3.31: Daily Trip Origins and Destinations (All Modes – Persons) in 2012



Source: Centre for Strategic and Policy Studies (2014).

3.2.3. Proposed Framework for Developing a Low-Carbon Traffic System

Using the methodology to calculate GHG emissions as defined in Section 3.3.2.1, we estimated the contribution of the different interventions or policy measures (as described in Section 3.3.1).

Table 3.8 summarises the interventions or policy measures. We qualitatively estimated the effect of each intervention or measured implementation to each element (independent variable) of the GHG emission equation, i.e. activity, structure, energy intensity, and fuel carbon content. We then estimated the total impact of the measure on the total GHG emissions.

Table 3.8: Estimated Effect of Each Intervention to the Total Emissions of Greenhouse Gases in Temburong

Intervention	Activity (A)			Structure (S)		Energy Intensity (I)	Fuel Carbon Content (F)	Total Emissions of Greenhouse Gases (G)
	Inbound and outbound traffic	Internal traffic	Through traffic	Passenger occupancy rate	Freight load factor			
Brunei Darussalam Land Transport Master Plan								
Green vehicle regulation incentive	0	0	0	0	0	- -	- -	- -
Improvements to border crossings and CIQS facilities	+	+	+	0	0	0	0	+
Pan-Borneo Highway enhancements	+ +	+	+ +	0	0	0	0	+
Opening of Temburong Bridge	+ + +	+ + +	+ + +	0	0	0	0	+ + +
ERIA (2018) Master Plan for Temburong								
Control entry of vehicles from Temburong Bridge	- -	0	-	0	0	0	0	-
Promote carpooling system	-	-	0	+ +	0	0	0	- -
Introduce public transportation	-	+	0	+ +	0	0	0	- -
Encourage a new logistics system, such as drones, which does not depend on vehicles	0	-	0	0	0	0	0	-
Develop traffic regulations that prioritise electric	-	0	0	0	0	- -	- -	- -

vehicles or fuel cell vehicles								
Introduce transport devices that do not depend on automobiles, such as electric motorcycles	+	+	0	0	0	-	-	-
Introduce various transport devices such as autonomous vehicles, boats, buses, taxis, electric motorcycles, and bicycles.	+	+	0	+	0	-	-	-

Notes: 0 = neutral, -= slight reduction, - -= significant reduction, - - - = strong reduction, + = slight increase, + + = significant increase, + + + = strong increase.
CIQS = customs, immigration, quarantine, and security.
Source: Author’s elaboration.

4. Conclusions and Way Forward

Introducing low-carbon types of vehicle propulsion, namely, electric- and hydrogen-powered FC cars, would benefit Brunei in reducing total GHG emissions. However, the effects of BEV penetration on total emissions depend on the emission intensity of the power generation sector, whilst those of FC hydrogen vehicles rely on the emission intensity of hydrogen production.

Temburong district's designation as the main tourism destination in Brunei and the Temburong Bridge's opening will increase the district's attractiveness and increase traffic volume. These might also potentially increase total GHG emissions. The accompanying environment- and climate-related measures and interventions should realise the concept of ecotown, which should at least be carbon neutral.

The LTMP of Brunei and the ERIA master plan proposal for Temburong district provide some measures that should be implemented to ensure the realisation of the ecotown concept. Each measure or intervention contributes differently and in different intensities to the reduction of GHG emissions. This report quantitatively assessed these contributions.

Finally, the government might need to elaborate emission- and air pollution–capping policies for road vehicles using the Pan-Borneo Highway, especially in freight transport trips carried by commercial vehicles, such as heavy- and light-duty trucks and vans. The policies' primary objective is to decouple GHG emissions and air pollution growth from the freight movements along the Pan-Borneo Highway, especially those to and from Brunei and Temburong district and those just passing through. Herewith, the climate and environmental impacts of growth in trade in the concerned regions can be minimised.

As a continuation of this study, we recommended the following two steps to get more detailed impact assessment results of the different policy measure options for Temburong district's mobility.

First, develop a network-based traffic model for Temburong district that should serve as a tool to simulate the impacts of all transport-related policies in the framework of the district's development. The model should cover defined future period forecasted demand broken down into the different origins and destinations inside the district, between the different origins and destinations in the district, and the main external origins and destinations and the origins and destinations related to passing-through traffic. Herewith, the model should have a detailed representation of the Temburong road network's detailed disaggregation of origins and destinations outside the district, including origins and destinations in the relevant foreign countries. The demand should be detailed into the different vehicle types that should calculate energy use, air pollution and emissions, and assigned to the road network to enable micro-level analysis of traffic impacts, including congestion.

Second, use the above network-based traffic model as the primary tool to quantitatively assess the climate and environmental impacts of the different transport-related policy measures and interventions in Temburong district, Brunei Darussalam, or in a wider geographical scope, such as in the Pan-Borneo Highway or BIMP-EAGA framework.

Chapter 4

Road Map for the Implementation of the Master Plan of Temburong Ecotown

1. Introduction

ERIA has been studying the development of an ecotown in Temburong district per request from Brunei Darussalam.

Brunei Darussalam is expected to start developing the Temburong ecotown according to the 'Temburong Ecotown Master Plan in Brunei Darussalam', prepared by ERIA and Nikken Sekkei Civil Engineering Ltd in 2018.

In 2019, ERIA continued to support the Ministry of Energy, Manpower and Industry, with the Ministry of Development (MOD), in developing the Temburong ecotown through the study focusing on energy efficiency in the commercial sector and low carbon for the road transport and power generation sectors, as well as the preparation of the road map of the ecotown development.

The scope of the study for this report is the preparation of a road map of the Temburong Ecotown Development Master Plan with the following four separate terms through close communication with the Ministry of Energy, Manpower and Industry and MOD:

1. By 2021 (ASEAN Year of Brunei Darussalam)
2. By 2023 (APEC [Asia-Pacific Economic Cooperation] Year of Brunei Darussalam)
3. Middle term (by 2030)
4. Long term (by 2040)

This report is part of the output expected from the Study on Temburong Ecotown Development Phase 4.

2. Background of Temburong Ecotown Development

2.1. Brunei Vision 2035

Wawasan Brunei 2035 is the country's national vision towards 2035, as announced by the government in January 2008.

- It aims to develop Brunei into a nation widely recognised for its quality of life amongst the top 10 nations globally and its well-educated and highly skilled people.
- It aims to transform Brunei from an economy heavily dependent on oil and natural gas into a more economically diversified and dynamic nation.
- It aims to increase renewable energy use up to 10% of the national total energy consumption as conveyed in its Vision 2035.

In February 2017, the government announced the next phase of economic policies, reflecting progress towards Wawasan Brunei 2035. These policies will (i) stimulate other industries to overcome the dependence on oil and natural gas, (ii) implement measures to support domestic entrepreneurs, (iii) implement incentives for small and medium-sized enterprises, and (iv) make effective use of them when the ASEAN Economic Community is established.

2.2. Heart of Borneo Programme

In 2007, Indonesia, Malaysia, and Brunei announced the Heart of Borneo Programme, in which they promised to protect Borneo Island's central areas of forest covering about 220,000 square kilometres.

The objectives of the programme until 2020 are to (i) establish a protected area of 24 million hectares, (ii) prevent damage to all valuable forests, (iii) promote alternative sustainable long-term financial programmes that provide support for replacing deforestation activities to local people and governments, and (iv) strengthen the ecosystem's products and services.

The Heart of Borneo contains about 58% of Brunei's territory, including the mountainous region, which is the southern part of Temburong district. According to the programme, ecotourism promotion could leverage the protection of untouched forests in Temburong district. The national park in Temburong district covers 50,000 m^2, but tourists are allowed only in about 100 m^2 (tower canopy area and waterfalls area).

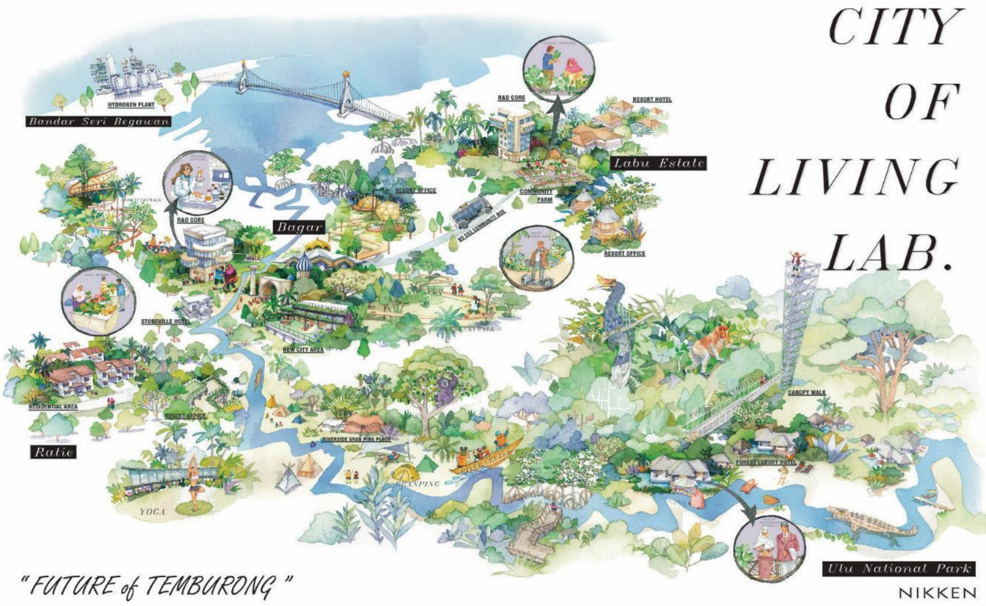
2.3. Temburong District Plan 2006–2025

In August 2010, the Town and Country Planning Department, OD established the Temburong District Plan 2006–2025 to guide and manage developments to meet key objectives of environmental management, social development, economic development, and rural and urban land use up to 2025. Sustaining the district's community development is one of the district plan's core strategies by providing adequate community facilities whilst preserving the richness of its forestry, biodiversity, and other natural resources.

2.4. Master Plan for Temburong Ecotown Development

ERIA and Nikken Sekkei Civil Engineering Ltd., combining the Temburong District Plan 2006–2025 and the idea of utilising hydrogen for fuel cell (FC) buses and other vehicles, formulated a master plan for the Temburong ecotown development. The master plan includes creating a 'Living Labo' related to the Heart of Borneo concept.

Figure 4.1: Future Image of City of Living Lab in Temburong Ecotown



Source: ERIA and Nikken Civil Engineering Ltd. (2018)..

2.5. Simulation study on energy mix for power generation in Temburong ecotown

Following the ecotown development plan for Temburong, a study was conducted in 2015–2016 to measure the impact of the application of energy efficiency technologies for buildings and installation of solar photovoltaic (PV) with electricity storage as power supply system based on the Temburong District Plan, 2006–2025. In the study, energy demand based on the buildings to be constructed in the ecotown was estimated in case the buildings were conventional buildings and were energy efficient. The electricity demand for the conventional and ecotown developments, including existing load, are estimated at 179 GWh and 146 GWh, respectively.

For the best mix of power generation, the following three scenarios were examined:

- Case 1: Diesel 12 MW with solar PV
- Case 2: Diesel 6 MW with solar PV
- Case 3: Only solar PV

The study recommended using diesel power initially and gradually shifting the power generation mix to greater solar PV use with a storage system. (Start with case 1 and shift to case 3.)

The simulation study also concluded that although all scenarios were feasible solutions, Brunei's solar radiation status can be weak during rainy and cloudy weather. In 2016, between March and May, the operation rate of solar PV was weak at 9%–13%.

To accomplish case 3, which is without diesel power generation, the available mix of solar PV in terms of the initial cost is for solar PV to have a capacity of 120 MW, even though this combination, levelized cost of electricity (LCOE) will be as high as US$40–50 cents. Then the combination of diesel power will be compromised at least in the initial stage, and more cost down of the solar PV system is expected.

3. Development Framework for Temburong Ecotown

3.1. Future vision and approaches for Temburong ecotown

For sustainable and balanced development with nature conservation, the Temburong ecotown sets the future vision of a carbon-neutral society to preserve wildlife in Borneo. It proposes strategic development through the following approaches or keywords:

- Living lab: diverse community, creative work and lifestyle
- Carbon-neutral: renewable energy, sustainable mobility system, sustainable architecture, agroforestry, and small economy
- Learning tourism: feature Temburong and Borneo, showcases of smart technology

The technological part of the ecotown concept is based on the following three principles:

1. Applying energy efficiency technologies to buildings to achieve lower energy demand;
2. Using renewable energy, such as solar PV; and
3. Utilising FC technology using hydrogen to operate buses and other motor vehicles

3.2. Socio-economic framework

3.2.1. Population Framework for Temburong District

The Temburong ecotown master plan estimated the future population of Temburong district, considering the new bridge connecting the capital city Bandar Seri Begawan (BSB) and Temburong. Table 4.1 shows the future population of 2030 and 2040.

Table 4.1: Population Framework of Temburong District

Year Area	2001 Census	2011 Census	2016 Census	2030 Projection	2040 Projection
Population of Temburong district	8,563	8,852	10,251	17,800	26,400
Annual growth rate of Temburong district	-	0.33%	2.98%	4.02%	4.02%
Population of Brunei Darussalam	332,844	393,372	417,256	471,000	488,800
Annual growth rate of Brunei Darussalam	-	1.68%	1.19%	0.87%	0.37%

Sources: 1. Data for 2011 and 2016: City Population HP.
2. Data of Temburong District for 2030: ERIA and Nikken Sekkei Civil Engineering Ltd (2018).
3. Data for Temburong District for 2040: Study Team analysis based on Temburong Ecotown Master Plan.
4. Data of Brunei Darussalam for 2030 and 2040: United Nations, Department of Economic and Social Affairs, Population Division (2019).

3.2.2. Demand for Electricity in Temburong District

Table 4.2 estimates electricity demand in Temburong district based on the future demand analysis of electricity conducted in the 'Simulation Study on Energy Mix for Power Generation in Temburong Ecotown' (Kimura, 2017), in consideration of various planned developments and the estimated future population in the Temburong Ecotown Master Plan.

In 2016, the actual electricity demand in Temburong district was 66 GWh, whilst the electricity demand in 2030 is based on the simulation study. The demand for 2023 and 2040 was estimated based on the electricity demand per person in 2030. The demand for 2040 was estimated considering the population increase and electricity demand in 2030 due to ecotown development in the simulation study.

Table 4.2: Demand for Electricity in Temburong District

Year	2016	2023	2030	2040
Demand	66 GWh	111 GWh	146 GWh	178 GWh

Source: Authors' analysis, based on Kimura (2017).

4. Scenario for Temburong Ecotown Development

Per the master plan for the Temburong ecotown development, a development scenario for Temburong ecotown was formulated by the following separate periods:

1. By 2021 (ASEAN Year of Brunei Darussalam)
2. By 2023 (APEC Year of Brunei Darussalam)
3. Middle term (by 2030)
4. Long term (by 2040)

Paying attention to (i) energy; (ii) tourism; (iii) university, research and development (R&D), and industry; and (iv) Bangar Urban Centre, the Study Team prepared the following scenarios:

1. By 2021 (ASEAN Year of Brunei Darussalam)

[Energy] To take advantage of the ongoing programme of creating an international supply chain of hydrogen, demonstrative operation of FC bus services will be started by using hydrogen produced of associated gas of oil extraction.

[Ecotourism] At the same time, in this phase, to take advantage of the completion of the BSB–Temburong Bridge, the development of tourist infrastructure and attractions supporting ecotourism in the Temburong district will be accelerated.

[University, R&D, and industry] In this phase, the construction of the new campus of University Islam Sultan Sharif Ali (UNISSA) will be started after the BSB–Temburong Bridge is open.

[Bangar Urban Centre] In this phase, the preparation of an implementation programme for improving the Bangar Urban Centre will be started, including improving inner roads and construction of the river port facility.

2. **By 2023 (APEC Year of Brunei Darussalam)**

[Energy] For increasing use of hydrogen produced from natural gas, the provision of basic infrastructure, such as hydrogen stations, will be expanded to increase the use of FC bus operation. For this purpose and for shifting to the increased dependency on renewable energy, a solar PV power generation plant will be constructed in Temburong district.

[Ecotourism] In this phase, more attractions for ecotourism will be developed to accommodate more ecotourists.

[University, R&D, and industry] The construction of the new campus of UNISSA will be continued. A new industrial park will be developed in Lab Estate to diversify economies in Temburong district.

[Bangar Urban Centre] The programme for improving Bangar Urban Centre will be continued by implementing the construction of the second bridge of Bangar and the preparation of Riverside Park.

3. **Middle term (by 2030)**

[Energy] The demonstrative use of hydrogen produced from natural gas will be expanded for FC bus operation. The excess hydrogen, after being used to operate FC buses, will be exported internationally.

[Ecotourism] In this phase, a hotel and convention complex will be developed to attract and accommodate high-end ecotourists.

[University, R&D, and industry] The construction of the new campus of a science and engineering university or science and engineering faculties of an existing university will be started. In collaboration with the new campus education and research function of the Science and Engineering Higher Education, an R&D Centre (R&D complex) will be developed in Lab Estate to diversify economies in Temburong district.

[Bangar Urban Centre] The Bangar Urban Centre Improvement Programme will be continued by constructing a new hospital or expanding its existing hospital and industrial estate.

4. **Long term (by 2040)**

[Energy] The commercial use of hydrogen produced from natural gas will be started to expand FC bus services in mainland Brunei and for FC passenger car operation.

[Ecotourism] In this phase, another hotel and convention complex will be further developed to upgrade the ecotourist destinations in Temburong district.

[University, R&D, and industry] In collaboration with the new campus education and research function of the science and engineering university or faculties, the R&D Centre (R&D complex) will be expanded in Lab Estate. This is to take advantage of the ongoing experimental operation of hydrogen production and FC vehicle systems, and ecotourism activities based on natural forest resources.

5. Road Map for Temburong Ecotown Development

5.1. Energy sector

5.1.1. Direction for the Development of the Energy Sector

a) Energy sources

Brunei's energy policy emphasises less dependency on oil and natural gas and towards the use of more renewable energy.

ERIA's Simulation Study on Energy Mix for Power Generation in Temburong Ecotown (Kimura, 2017) recommended the use of diesel power initially and the gradual shift in power generation mix to more use of solar PV as the costs of solar PV will decrease in the future. Therefore, it set an energy mix for power generation in Temburong district (Table 4.3).

Table 4.3: Energy Mix for Power Generation in Temburong District

Year	2016		2023		2030		2040	
Types	Electricity Generated, GWh	%	Electricity Generated, GWh	%	Electricity Generated, GWh	%	Electricity Generated, GWh	%
Diesel	105	100	53	45.1	0	0.0	0	0.0
Solar power plant	0	0	18	15.5	60	38.5	90	46.9
Biofuels from farmed goods and Forestry Industry	0	0	1	0.9	6	3.8	12	6.3
Transmission from Smart Grid	0	0	45	38.6	90	57.7	90	46.9
Total	105	100	117	100	156	100	192	100

Source: ERIA and Nikken Sekkei Civil Engineering Ltd (2018)..

The master plan study proposed to produce hydrogen using associated gas from gas fields, utilise hydrogen to operate FC buses and vehicles, and generate power from renewable energy sources, such as solar power. This operation of FC buses and vehicles is enabled by Brunei's strategy for hydrogen production and export, which will be experimented from 2020.

Due to the experimentation and the prospective full-scale strategy for hydrogen production and export, FC bus and vehicle operations would have a financial advantage over hydrogen production using solar PV electricity.

b) Efficient management of energy

Smart grids are a new way of distributing energy in which generation (from local energy sources and/or storage devices) is coordinated to supply electricity for satisfying local needs through an energy management system (EMS).

5.1.2. Projects for the Development of the Energy Sector

a) Priority projects of the energy sector

Table 4.4 lists the priority projects for the development of the energy sector in Temburong district. The priority projects with * are key projects to initiate and drive the energy sector's development towards a carbon-neutral society.

Table 4.4: Priority and Key Projects of the Energy Sector in Temburong Ecotown

Name of Project	Implementation Period
[EN-1] * Project of Construction of Hydrogen Production and Hydrogenation Plant in Brunei	2019
[EN-2] * Programme of Creation of International Supply Chain of Hydrogen (including Exportation of Hydrogen to Japan)	2020–2021
[EN-3] * Project of Construction of Solar Park (Photovoltaic Power Station) Phase 1	2022–2023
[EN-4] Project of Construction of Solar Park (Photovoltaic Power Station) Phase 2	2024–2030
[EN-5] Project of Construction of Solar Park (Photovoltaic Power Station) Phase 3	2031–2040

Source: Authors' formulation based on Temburong Ecotown Master Plan and Temburong District Plan 2006–2025.

b) Outlines of key projects of the energy sector

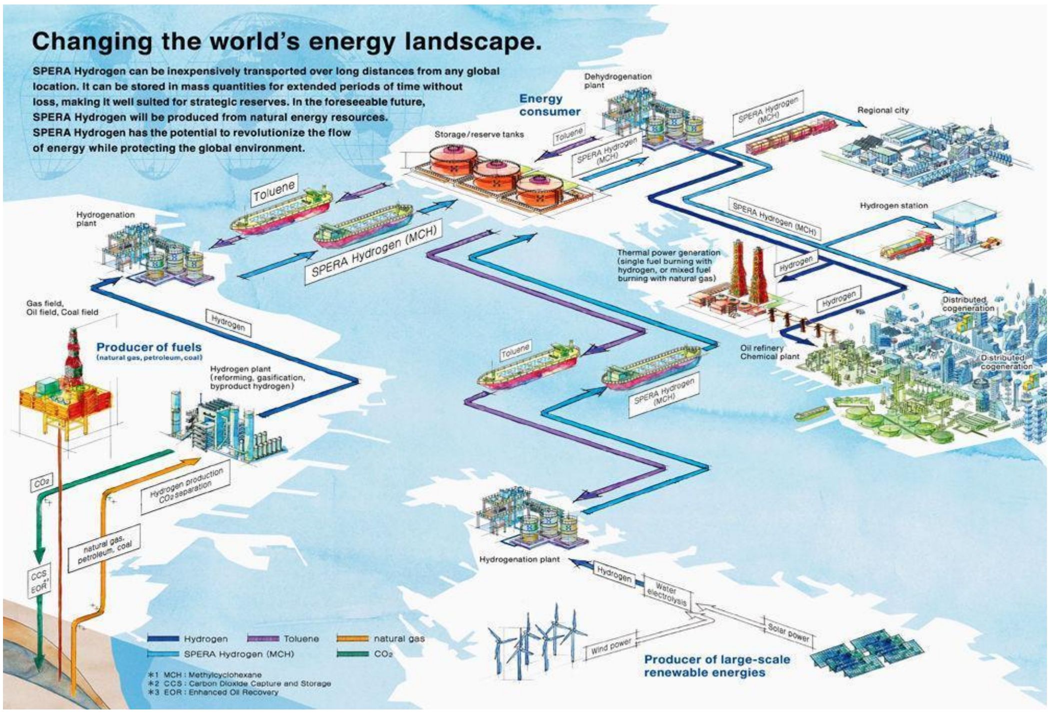
- **[EN-1] * Project of Construction of Hydrogen Production and Hydrogenation Plant in Brunei**
  In November 2019, a hydrogen production and hydrogenation plant was constructed in Brunei by the Advanced Hydrogen Energy Chain Association for Technology Development, which was jointly established by Chiyoda Corporation, Mitsubishi Corporation, Mitsui & Co. Ltd, and Nippon Yusen Kabushiki Kaisha. This plant was designed to produce hydrogen made of associated gas and to produce liquid hydrogen at normal temperature by utilising the Organic Chemical Hydride Method.

Figure 4.2: Hydrogenation Plant in Brunei

Source: Chiyoda Corporation (2017).

- **[EN-2] * Programme of Creation of International Supply Chain of Hydrogen (including Exportation of Hydrogen to Japan)**
  Liquid hydrogen at normal temperature to be produced by the hydrogenation plant of [EN-1] – The project can be easily transported to other countries by conventional chemical tankers, but not special tankers for low temperature liquid hydrogen or hydrogen gas. Therefore, now it is possible for Brunei to produce such liquid hydrogen at normal temperature (called SPERA hydrogen) for export. In an experimental programme, liquid hydrogen at normal temperature will be exported to Japan. When liquid hydrogen arrives in Japan, it will be transformed to hydrogen gas by a hydrogenation plant in Kawasaki City, Japan.

Figure 4.3: International Supply Chain of Hydrogen Using SPERA Hydrogen Technology

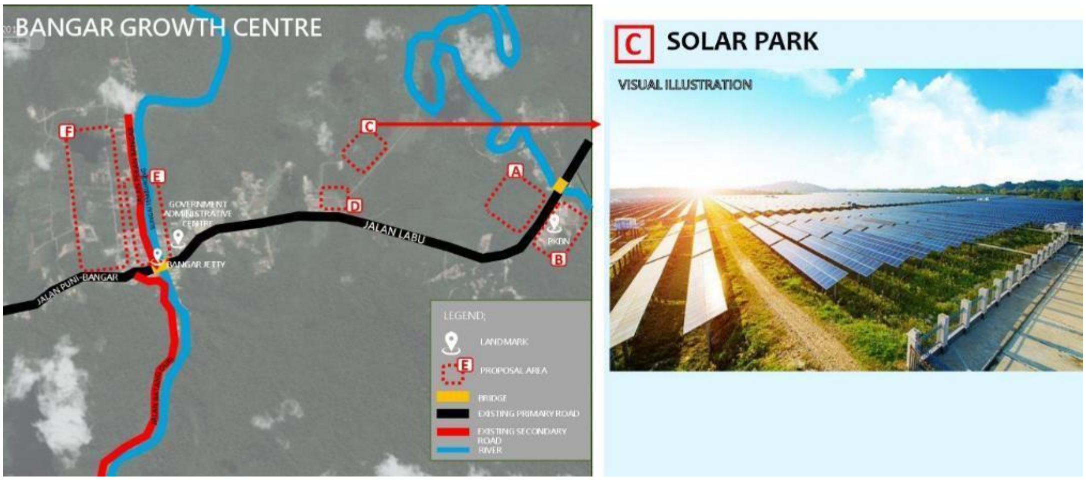


Source: Chiyoda Corporation (2017).

- **[E-3] * Study on Storage Battery to be Implemented in Temburong District**
  The storage battery is a fundamental facility for a successful ecotown with solar power as a primary power source. The field of storage batteries is constantly advancing, and the type of storage battery varies depending on the size, cost, life expectancy, etc. Therefore, it is necessary to determine which type of storage battery will be implemented in Temburong district.

- **[E-4] * Project of Construction of Solar Park (Photovoltaic Power Station) Phase 1 and [E-5] * Project of Construction of Water Electrolysis Plant for Hydrogen Production Phase 1**
  A land for establishing the Solar Park has been gazetted under the Ministry of Energy, Manpower and Industry at site C in Figure 4.4. Site C is around 12 ha. With solar PV panels installed in this area, the park can produce approximately 18 GWh, which is 16% of the district's energy demand in 2023.

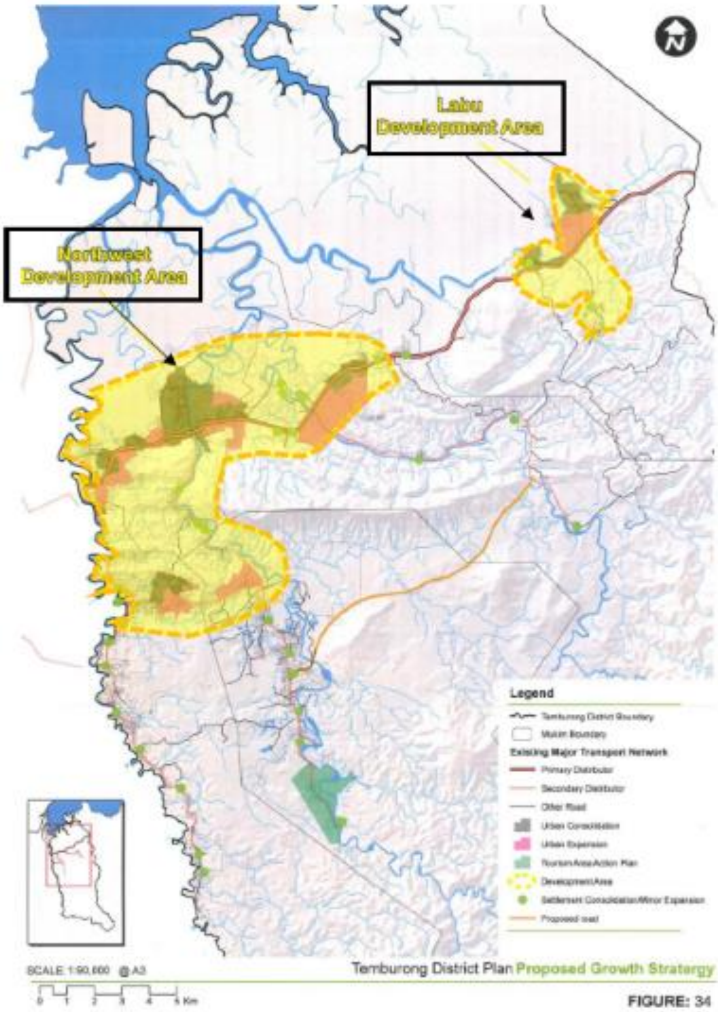
Figure 4.4: Location of Solar Park



Source: Town and Country Planning Department, Ministry of Development (2010).

However, this site is not large enough to accommodate a necessary solar PV power station and water electrolysis plant to support the whole district. Therefore, the Brunei government should identify such a large land for solar PV power stations and water electrolysis plants. It seems possible to identify and gazette such large sites within the developable areas, as shown in Figure 4.5. It is also necessary to identify 140 ha for Temburong district to become 100% sustainable with renewable energy, using solar power as its main power source.

Figure 4.5: Development Areas Proposed in Temburong District Plan, 2006–2025



Source: Town and Country Planning Department, Ministry of Development (2010).

- **[E-6] * Project for Establishment of Storage Battery Phase 1**
  Based on the study on storage battery, the type of storage battery should be selected along with the establishment of the Solar Park.

5.2. Transport sector

5.2.1. Direction for the Development of the Transport Sector

As a model of a carbon-neutral society, Temburong district aims to build an eco-friendly town as follows:

- *Suppression of traffic volume*
  - Control entry of vehicles from Temburong Bridge
  - Promote carpooling system
  - Introduce public transportation
  - Encourage a new logistics system, such as drones, which does not depend on vehicles

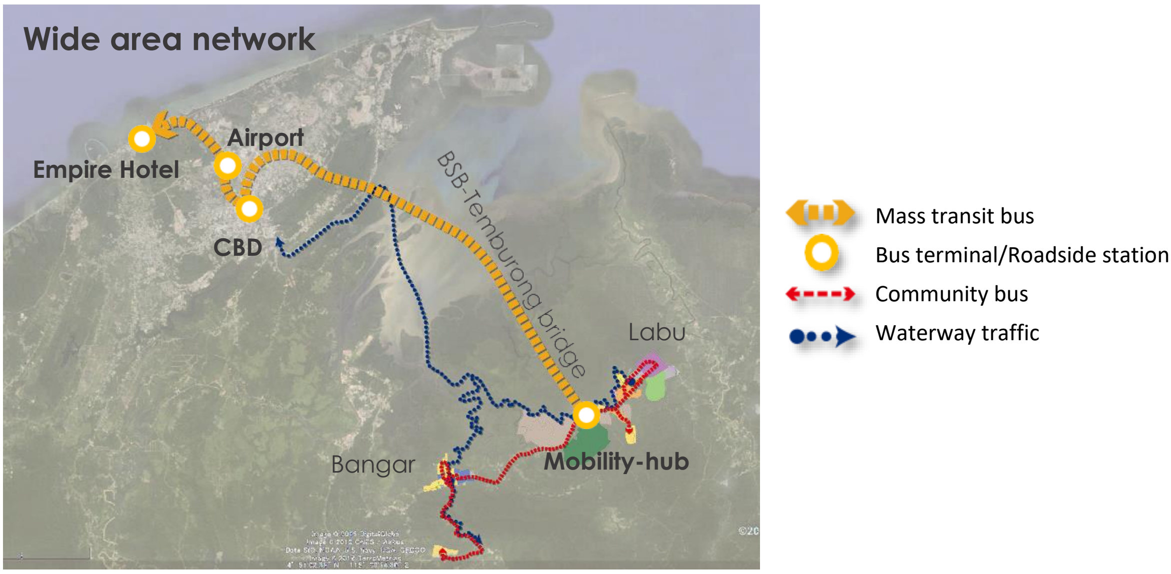
- *Prioritisation of transport devices with small environmental loads*
  - Develop traffic regulation that prioritises electric vehicles (EVs) or FC vehicles
  - Introduce transportation devices that do not depend on automobiles, such as electric motorcycles
- *Introduction of various transport devices to activate ecotourism*
  - Introduce various transportation devices such as autonomous vehicles, boats, buses, taxis, electric motorcycles, and bicycles.

However, to introduce FC vehicles in Temburong ecotown, it is necessary to consider using hydrogen from by-product gas of liquefied natural gas production since it will not be possible to produce hydrogen from renewable energy at the early stage. Chiyoda Corporation, exporting this type of hydrogen, plans to export a maximum of 210 tonnes of hydrogen in 2020 to Japan. For example, if the Brunei government could use 7% of this hydrogen, it is enough to have four FC buses to operate 365 days a year.

Through the construction of the BSB–Temburong Bridge and the introduction of FC vehicles, the following new mobility networks in Temburong district are expected:

- Tourists from BSB, such as the Empire Hotel, BSB airport, or the central business district, visit Temburong via hydrogen-powered mass-transit bus through Temburong Bridge.
- Tourists travel around Temburong district in non-carbon vehicles such as community buses, boats, and taxis.
- In the future, only non-carbon cars will be permitted to drive in Temburong district. This also aims to control the traffic volume (internal-combustion engine cars, buses, and trucks) passing through Temburong from Sabah to Sarawak State in Malaysia.

Figure 4.6: Mobility Network of Temburong and Connectivity with Bandar Seri Begawan



Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

5.2.2. Projects for the Development of the Transport Sector

a) Priority projects of the transport sector

Table 4.5 lists the priority projects for the development of the transport sector in Temburong district. The priority projects with * are key projects to initiate and drive the development of the transport sector towards a carbon-neutral society.

Table 4.5: Priority and Key Projects of the Transport Sector for Temburong Ecotown

Name of Projects	Implementation Period
[TR-1] * BSB–Temburong Bridge	2020
[TR-2] * Hydrogen Supply Stations for Fuel Cell Buses and Vehicles	2020–2021
[TR-3] * 'Mobility Hub' in the Gate Zone	2020–2021
[TR-4] * Mass Transit Bus Services by Fuel Cell Buses between Empire Hotel, Airport, and Temburong Mobility Hub	2022–2023
[TR-5] * Community Bus Services by Fuel Cell Buses within Temburong Ecotown	2022–2023
[TR-6] Expansion of Mass Transit Bus Services by Fuel Cell Buses between Empire Hotel, Airport, and Temburong Mobility Hub	2022–2023
[TR-7] Expansion of Community Bus Services by Fuel Cell Buses within Temburong Ecotown	2022–2023
[TR-8] Expansion of Fuel Cell Bus and Passenger Car Operation both in Temburong District and the Mainland	2024–2030

Source: Study Team.

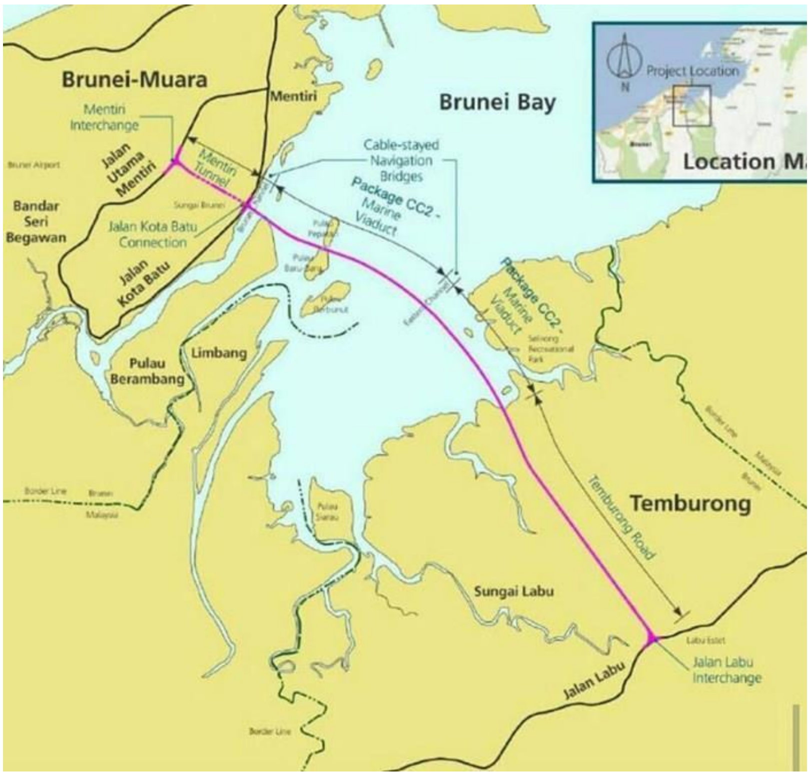
b) Outline of key projects of the transport sector

- **[TR-1] * BSB–Temburong Bridge**

  The Temburong Bridge Project is a 30-km dual two-lane bridge crossing Brunei Bay that connects Temburong district with Brunei's other three districts, including the international airport and port. Until this bridge was built, Temburong and the other three districts were connected via the river or by land through Limbang district of Sarawak, Malaysia.

  The construction of the bridge started in 2014 and was planned to be completed in 2019 but was completed in March 2020.

Figure 4.7: Route of Bandar Seri Begawan–Temburong Bridge



Source: ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

- **[TR-2] * Hydrogen Supply Stations for FC Buses and Vehicles**
  Hydrogen supply stations are necessary before FC buses and vehicles are introduced in Temburong. It is advised to use the hydrogen from by-product gas generated when gas is liquefied to promote FC vehicles from an early stage of ecotown development. In the future, when there is enough solar PV, hydrogen for FC vehicles can also be produced from 100% renewable energy.
  The first hydrogen supply station is planned to be established in the Gate Zone.

Figure 4.8: Image of Hydrogen Supply Station

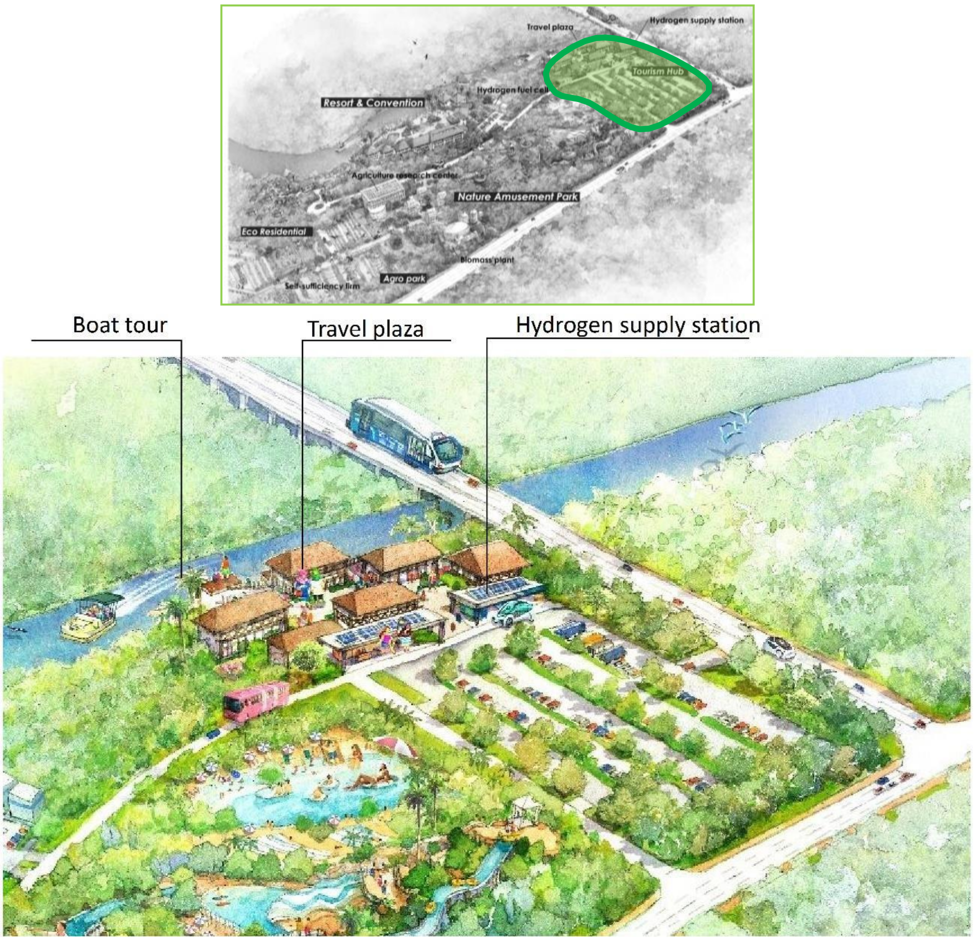
Source: Tokyo Gas (2020).

- **[TR-3] * Mobility Hub in the Gate Zone**

  A mobility hub is a place where hydrogen-powered buses, electric cars, autonomous cars, electric boats, and bicycles are connected. Tourists arriving in Temburong from BSB via hydrogen-powered buses can transfer to other means of transport such as EVs, autonomous cars, electric boats, and bicycles to go to different tourist spots.

  With the travel plaza here, tourists can enjoy many services such as accessing tourism information, booking tours and accommodations, and using the hydrogen supply station.

Figure 4.9: Image of Mobility Hub Zone



Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

- **[TR-4] * Mass Transit Bus Services by Fuel Cell Buses between Empire Hotel, Airport, and Temburong Mobility Hub**

  The energy supply system's medium-term target (by 2023) in the master plan considers the effective use of PV and pilot renewable energy–based hydrogen as existing technologies and use of EVs and FC vehicles. The Laluan Bas BSB–Bangar Route is proposed in the Temburong District Plan 2006–2025, which can be served by FC buses.

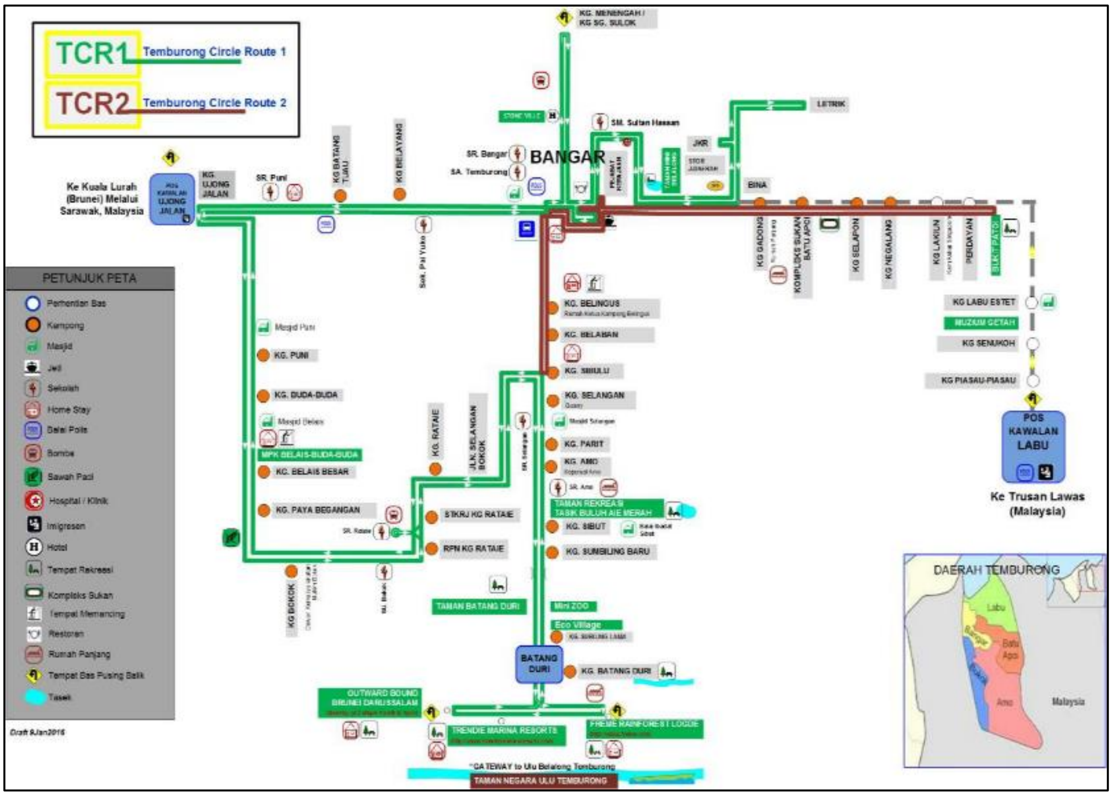
  Such FC bus needs approximately 3,850 kg of hydrogen per year if operating for 365 days.

Figure 4.10: Image of Fuel Cell Bus

Source: Toyota HP (2018).

- **[TR-5] * Community Bus Services by Fuel Cell Buses within Temburong Ecotown**
  The FC buses will provide community bus services in Temburong. The proposed bus network, including the two routes, is shown in Figure 4.11.

Figure 4.11: Proposed Bus Network in Temburong District



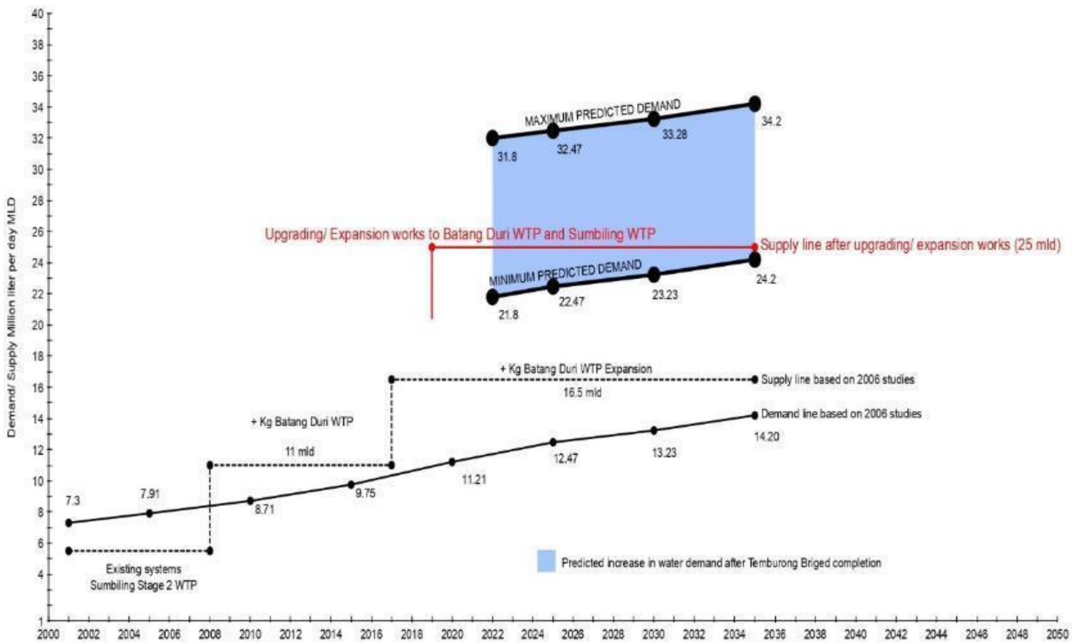
Source: Town and Country Planning Department, Ministry of Development (2010).

5.3. Water supply sector

5.3.1. Direction for the Development of the Water Supply Sector

Water resources must be developed to supply enough water to the increasing residential population and tourism infrastructures (hotels, resorts, and convention facilities), as well as university facilities and industries in Temburong ecotown. Since there are existing water resources and water treatment plants, the selected strategy for additional water supply in the short and medium terms is to upgrade the existing water intake facilities and water treatment plants. Then in the long term, by monitoring the increasing volume of water demand, it would become necessary to develop new water resources and new water treatment plants. See the analysis of potable water supply system and demand in Temburong district.

Figure 4.12: Potable Water Supply in Temburong District



Source: Town and Country Planning Department, Ministry of Development (2010).

5.3.2. Projects for the Development of the Water Supply Sector

a) Outline of key projects of the water supply sector

Table 4.6 lists the priority projects for the development of the water supply sector in Temburong district. The priority projects with * are key projects to initiate and drive the development of the water supply sector towards a carbon-neutral society.

Table 4.6: Priority and Key Projects of the Water Supply Sector for Temburong Ecotown

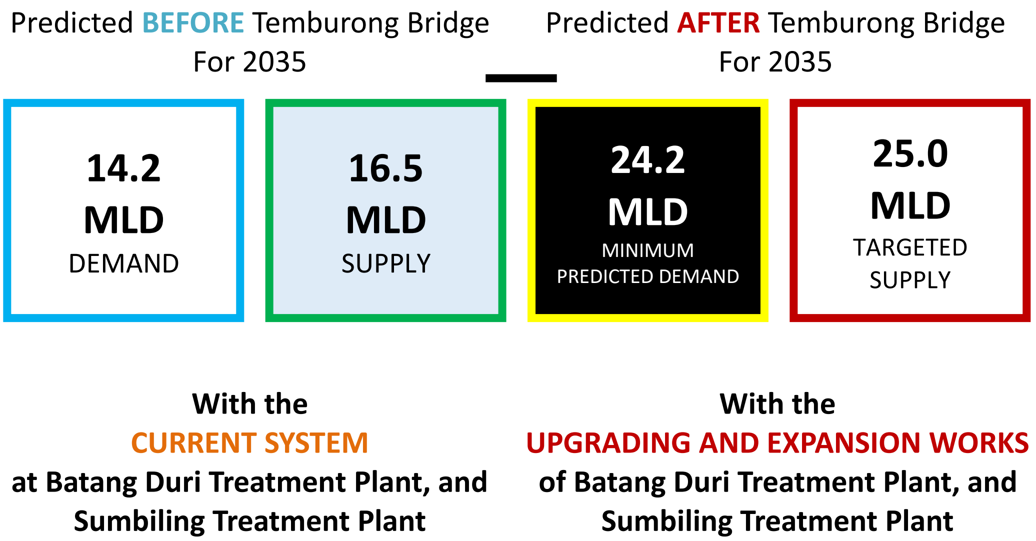
Name of Project	Implementation Period
[WA-1] * Upgrading of Existing Batang Duri Water Treatment Plant	2022–2023
[WA-2] Upgrading of Existing Sumbling Water Treatment Plant	2024–2030
[WA-3] New Water Treatment Plant at Batu Apoi of Capacity 30 mld	2031–2040

Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects of the water supply sector

- **[WA-1] * Upgrading of Existing Batang Duri Water Treatment Plant**
  The existing Batang Duri Water Treatment Plant, as well as necessary water intake facilities, will be upgraded and expanded to supply the increasing amount of potable water under the Temburong ecotown development. Moreover, water pipelines should be expanded to cover the Labu Estate.

Figure 4.13: Potable Water Supply for Temburong District



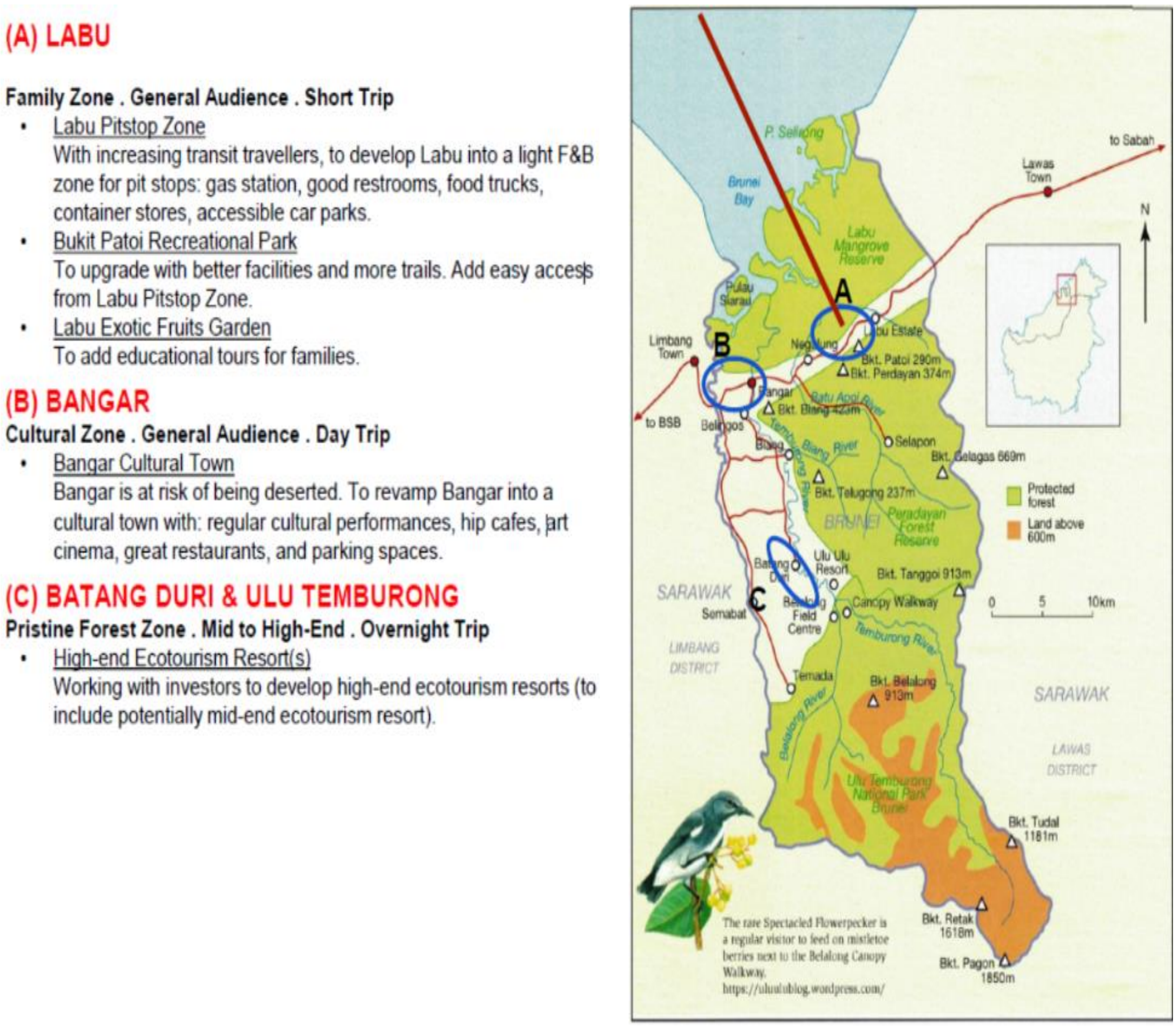
Source: Town and Country Planning Department, Ministry of Development (2010).

5.4. Tourism sector

5.4.1. Direction for the Development of the Tourism Sector

The Temburong District Plan 2006–2025 acknowledges ecotourism as an opportunity for the Temburong district. The district plan identifies three focus areas of ecotourism: (i) Labu, (ii) Bangar, and (iii) Batang Duri and Ulu Temburong (Figure 4.14). The district plan also projects the number of international tourists to arrive in Temburong in 2025 to be 478,000.

Figure 4.14: Location of Ecotourism Focus Areas in Temburong District



Source: Town and Country Planning Department, Ministry of Development (2010).

For Temburong district to develop its ecotourism potential, it is crucial to attract various types of visitors, including researchers and families, and provide sites for low-budget travellers to high-end travellers.

5.4.2. Projects for the Development of the Tourism Sector

a) Outline of key projects of the tourism sector

Table 4.7 lists the priority projects for the development of the tourism sector in Temburong district. The priority projects with * are key projects to initiate and drive the development of the tourism sector towards a carbon-neutral society.

Table 4.7: Priority and Key Projects of the Tourism Sector for Temburong Ecotown

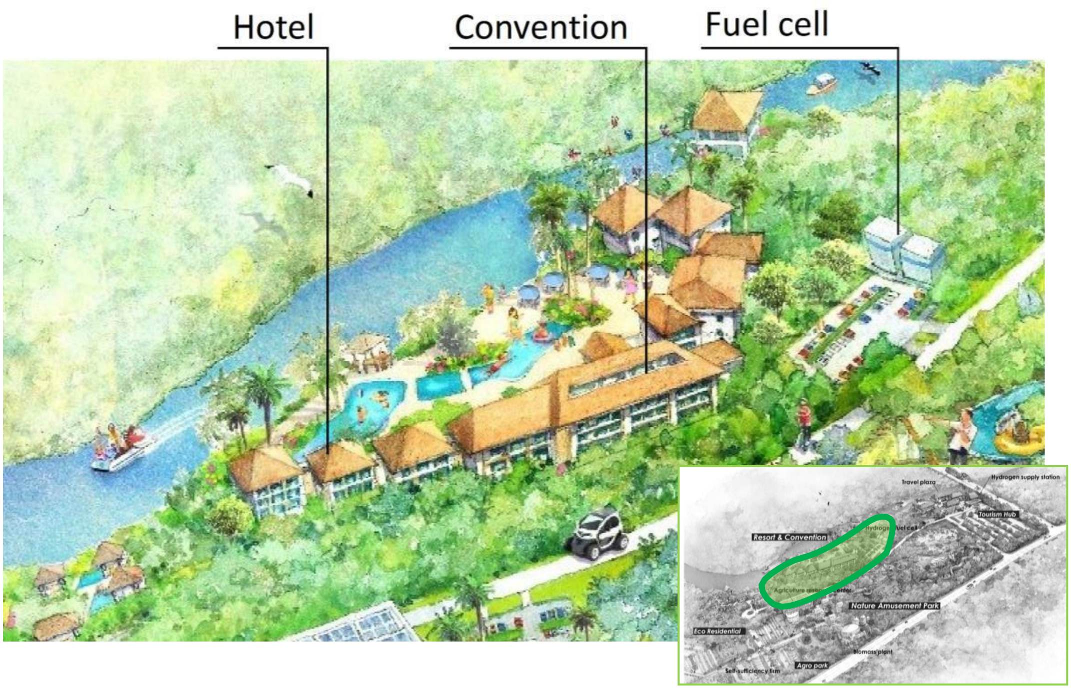
Name of Project	Implementation Period
[TO-1] * Resort & Convention in Gate Zone	2020–2021
[TO-2] * Tourism Hub (Information and Learning Centre for Ecotourism)	2020–2021
[TO-3] * Nature Amusement Park in Gate Zone	2022–2023
[TO-4] * Agro Park in Gate Zone	2022–2023
[TO-5] Hotel and Convention in Labu Estate Phase 1	2024–2030
[TO-6] Hotel and Convention in Labu Estate Phase 2	2031–2040

Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects of the tourism sector

- **[TO-1] * Resort and Convention in Gate Zone**
  The zone facing the river is the Resort and Convention Zone. This zone is expected to be a tourist hub between the Labu area's sightseeing and Perdayan Forest Recreation Park. This resort has hotel and convention facilities. The convention centre should be one of the venues of the APEC meeting to be held in Brunei in 2024. As the APEC venue, this hotel's power source will be hydrogen fuel cells to help promote the potential of hydrogen in each APEC country.

Figure 4.15: Image of Resort and Convention Zone in Gate Zone



Source: Nikken Sekkei Civil Engineering Ltd. (2018).

- **[TO-2] * Tourism Hub (Information and Learning Centre for Ecotourism)**
  The Tourism Hub will provide information and learning centre for ecotourism. It will be located in the Mobility Hub of Gate Zone, which is the gateway of Temburong district.

Figure 4.16: Location of Tourism Hub in Gate Zone

Source: ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

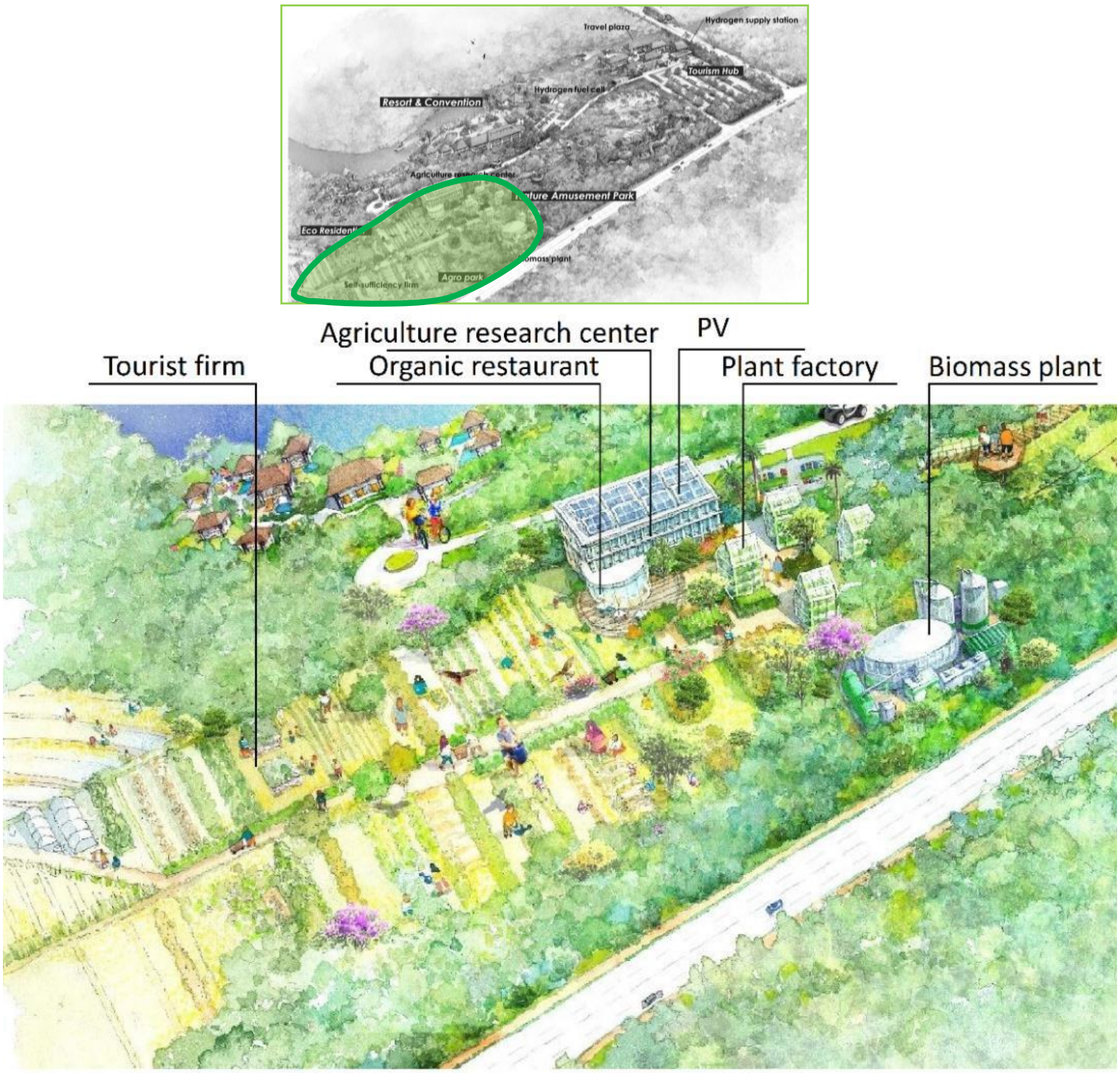
- **[TO-3] * Nature Amusement Park in Gate Zone**
  The restored forest will become the Nature Amusement Park. An adventure land and water park will be planned here. The construction of the Nature Amusement Park aims to create a new tourist destination in Temburong to encourage extended visits, such as staying more than two nights.

Figure 4.17: Image of Nature Amusement Park in Gate Zone

Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

- **[TO-4] * Agro Park in Gate Zone**
  Agro Park will be constructed to promote food self-sufficiency. This facility is planned to include an agricultural research institute, plant factory, and agricultural test site, and introduce PV and biomass plants as energy facilities. The park aims to improve agricultural productivity by linking surrounding agricultural lands like the existing one in the west. The park is also planned to attract tourists through a tourist farm and organic restaurant as part of the learning tourism ecosystem.

Figure 4.18: Image of Agro Park in Gate Zone



Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

5.5. Education sector

5.5.1. Direction for the Development of the Education Sector

With the improved accessibility to Temburong district and its prospective ecotown environment, the development of new university campuses is envisioned to be part of the Temburong Ecotown Master Plan. Currently, the development of a new campus for the Universiti Islam Sultan Sharif Ali (Islamic University) is planned.

Besides the new campus for the Islamic University, this road map study proposes to develop an additional new campus for a science and technology university or natural science and engineering faculties of the existing university in Labu Estate. Such a proposal aims to collaborate with experimental projects for renewable energy utilisation and ecotourism projects for learning forest ecology.

5.5.2. Projects for the Development of the Education Sector

a) Outline of key projects of the education sector

The priority projects for the development of the education sector in Temburong district are listed in Table 4.8. The priority projects with * are key projects to initiate and drive the development of the education sector towards a carbon-neutral society.

Table 4.8: Priority and Key Projects of the Education Sector for Temburong Ecotown

Name of Project	Implementation Period
[ED-1] * Construction of New Campus for Islamic University in Labu Estate	2020–2021
[ED-2] * Continuation of Construction of New Campus for Islamic University in Labu Estate	2021–2022
[ED-3] * Construction of New Campus for a University for Science and Engineering University or Science and Engineering Faculties in Labu Estate	2023–2030

Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects of the education sector

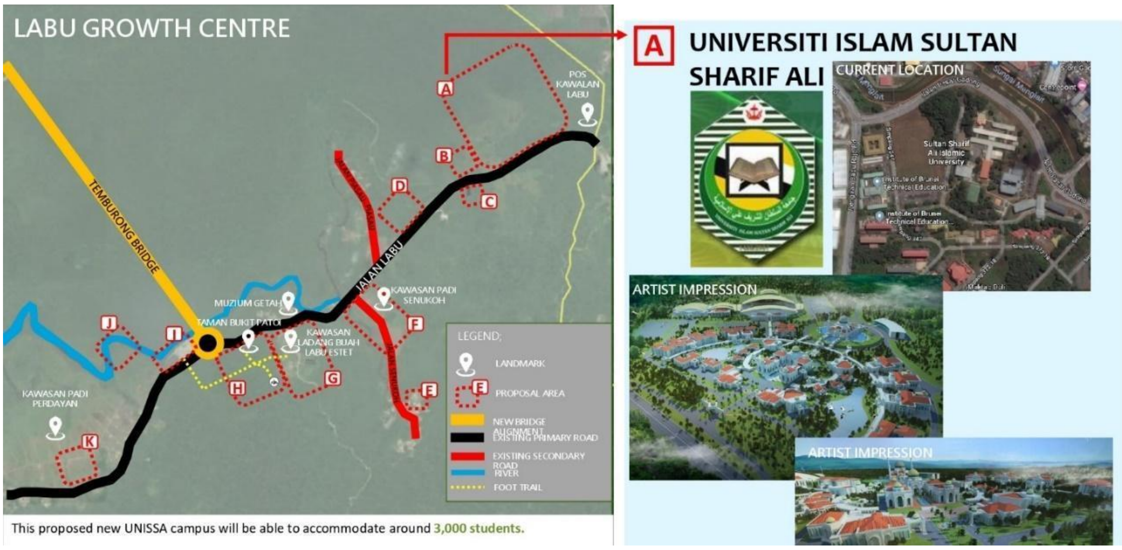
- **[ED-1] * Construction of New Campus for UNISSA Phase 1 in Labu Estate and [ED-2] * Continuation of Construction of New Campus for UNISSA Phase 1 in Labu Estate**
  The development of a new campus for UNISSA is an important part of Temburong ecotown development. A new campus for UNISSA is planned to be located in Labu Estate.

Table 4.9: Land Necessary for the New Campus of Universiti Islam Sultan Sharif Ali (2030)

Item	Amount
Area (ha)	310
Students (number of people)	3,000

Source: Town and Country Planning Department, Ministry of Development (2010).

Figure 4.19: Location of New Campus for Universiti Islam Sultan Sharif Ali



Source: Town and Country Planning Department, Ministry of Development (2010).

- **[ED-3] * Construction of New Campus for a University for Science and Engineering University or Science and Engineering Faculties in Labu Estate**
  To promote collaboration between experimental projects for the use of hydrogen and FC systems and science/engineering education/research, it is good to develop a new campus for a science and engineering university or science and engineering faculties of the existing university. Its location could be found in the Labu Estate adjacent to the R&D Centre.
  Another possible field for science for the new university campus is forest ecology, which could be the basis for ecotourism. The university or faculty located in Temburong district could provide advantageous education and research opportunities for forest ecology.

5.6. Industry sector

5.6.1. Direction for the Development of the Industry Sector

Diversification of economies and industries is one of the important directions for Brunei Vision 2035. Temburong district could provide a very ideal location for advanced technological industries. This is by utilising natural forest resources and hydrogen made from associated gas in the short to middle term and hydrogen made from solar power in the medium and long term. The BSB–Temburong Bridge is a real bridge to such a potential land of Temburong.

5.6.2. Projects for the Development of the Industry Sector

a) Outline of key projects of the industry sector

Table 4.10 lists the priority projects for developing the industry sector in Temburong district. The priority projects with * are key projects to initiate and drive the industry sector's development towards a carbon-neutral society.

Table 4.10: Priority and Key Projects of the Industry Sector in Temburong Ecotown

Name of Project	Implementation Period
[IN-1]* Development of Industrial Park in Labu Estate	2022–2023
[IN-2]* Establishment of R&D Centre Phase 1	2024–2030
[IN-3] Establishment of R&D Centre Phase 2	2031–2040

Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects of the industry sector

- **[IN-1] * Development of Industrial Park in Labu Estate**
  An industrial estate to accommodate non-polluting industries hopefully utilising existing forest resources will be developed in Labu Estate. The BSB–Temburong Bridge could greatly improve the connectivity between the International Airport and Labu Estate in Temburong district.

- **[IN-2] * Establishment of R&D Centre Phase 1**
  The location of Temburong district could provide two types of advantages: (i) closeness to natural forest resources in the Heart of Borneo, and (ii) closeness to experimental projects for hydrogen utilisation for FC systems for motor vehicles and buildings. These two different kinds of ecotechnologies would be the basis for an R&D centre in Temburong district.

5.7. Housing sector

5.7.1. Direction for the Development of the Housing Sector

Based on the population framework, housing demand is estimated to reach 1,715. Some of these houses will be constructed in eco-residential areas and new residential areas in Labu Estate.

5.7.2. Projects for the Development of the Housing Sector

a) Outline of key projects of the education sector

The priority projects for the development of the housing sector in Temburong district are listed in Table 4.11. Those with * are vital projects to initiate and drive the housing sector's development towards a carbon-neutral society.

Table 4.11: Priority and Key Projects of the Housing Sector in Temburong Eco Town

Name of Project	Implementation Period
[HO-1] * Eco Residential Area in Gate Zone	2020–2021
[HO-2] * Residential Areas Phase 1 in Labu Estate	2021–2022
[HO-3] Continuation of Residential Areas Phase 1 in Labu Estate	2023–2030
[HO-4] Residential Area Phase 2 in Labu Estate	2031–2040

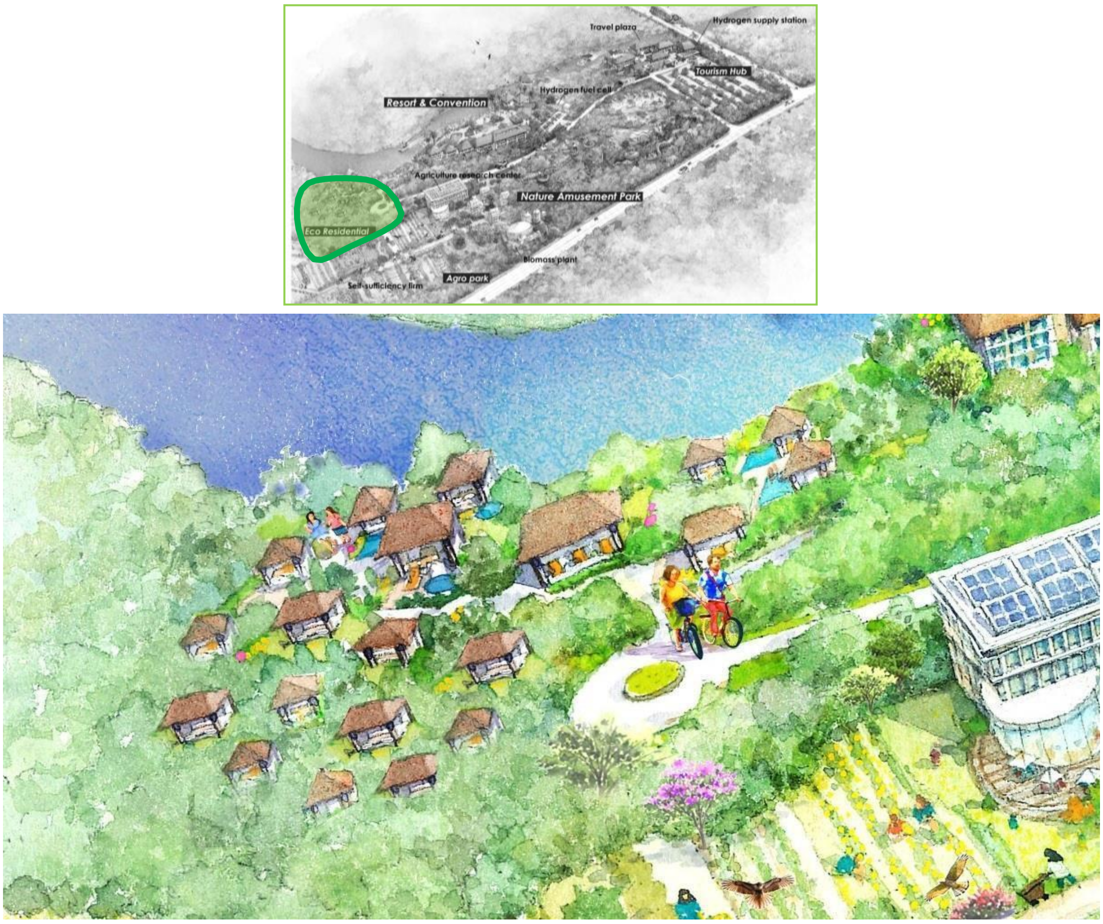
Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects of the housing sector

- **[HO-1] * Eco-residential Area in Gate Zone**

  The Eco-residential Area is planned next to the Resort and Convention Zone. Eco residential is a diverse community that is home to people working at the Gate Zone, such as energy and transportation workers, agricultural researchers, and employees in the service industry. With the introduction of smart technology, such as renewable energy and sustainable architecture, this area will become a living lab.

Figure 4.20: Image of Eco-residential Area in the Gate Zone

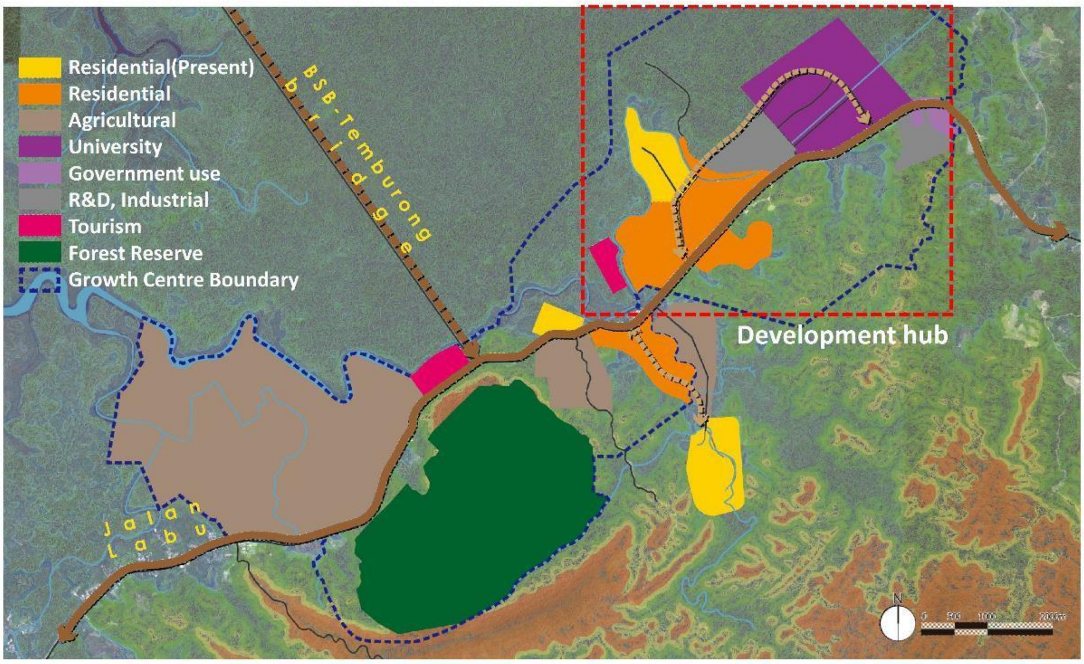


Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

- **[HO-2] * Residential Areas Phase 1 in Labu Estate**

  The existing residential areas divide the housing area into three villages. The master plan proposes housing development between the three villages to connect them, providing better service based on the optimisation of public services and the effect of scale.

Figure 4.21: Location of Residential Area in Labu Estate



Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

5.8. Development of Bangar Urban Centre

5.8.1. Direction for the Development of Bangar Urban Centre

Bangar, as the capital of Temburong district, will continue to be the essential growth centre for the district. As the centre of public services, Bangar will house the district office, hospital, market, and residential communities.

5.8.2. Projects for the Development of Bangar Urban Centre

a) Outline of key projects for the development of Bangar Urban Centre

Table 4.12 lists the priority projects for the development of Bangar Urban Centre are listed in Table 4.12. Those with * are key projects to initiate and drive the Bangar Urban Centre's development towards a carbon-neutral society.

Table 4.12: Priority and Key Projects of Development of Bangar Urban Centre

Name of Project	Implementation Period
[UC-1] * Improvement of Internal Road and Construction of Second Bridge of Bangar Phase 1	2020–2021
[UC-2] * Construction of Port Facility	2020–2021
[UC-3] * Improvement of Internal Road and Construction of Second Bridge of Bangar Phase 2	2022–2023
[UC-4] Riverside Park	2022–2023
[UC-5] New Hospital or Expansion of Hospital	2024–2030
[UC-6] Temburong Industrial Estate in Bangar	2024–2030

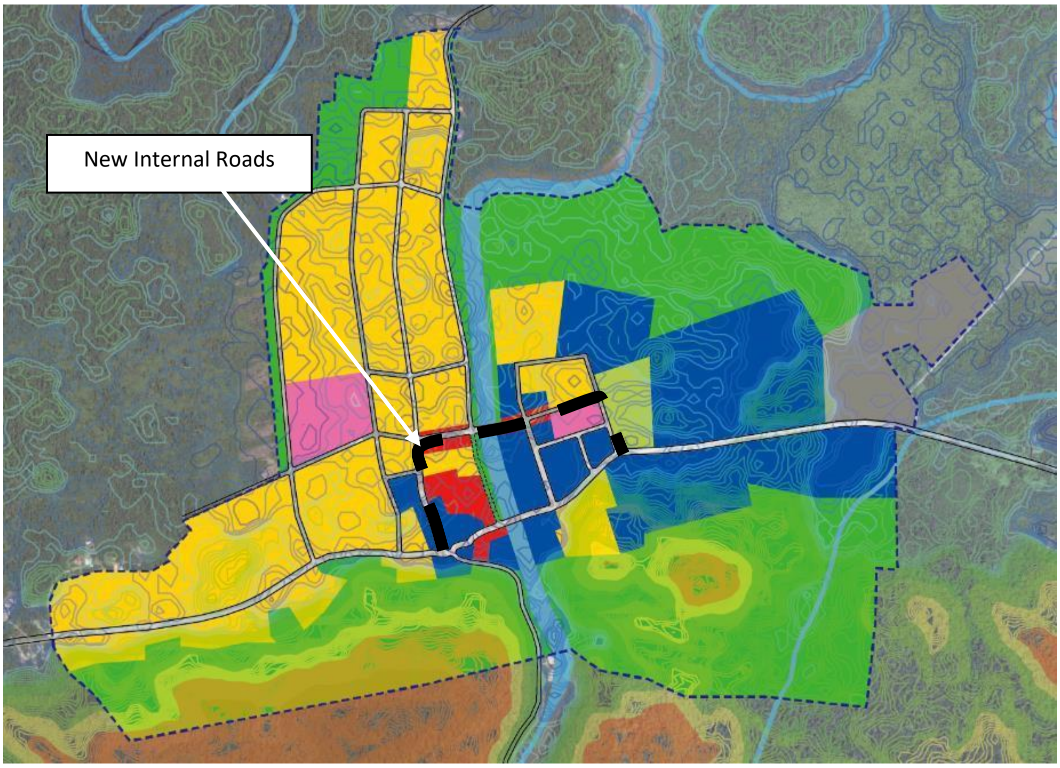
Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

b) Outline of key projects for the development of Bangar Urban Centre

- **[UC-1] * Improvement of Internal Road and Construction of Second Bridge of Bangar Phase 1 and [UC-3] * Improvement of Internal Road and Construction of 2nd Bridge of Bangar Phase 2**

  The Temburong River divides the Bangar area, and Jalan Labu is the only connection between the two areas. Considering the increase in population and expansion in the logistics sector, through-traffic should be separated from inner-city traffic through the construction of more inner roads and bridges. Figure 4.22 shows the new road and bridge for the inner-city traffic.

Figure 4.22: Location of New Internal Roads and Bridge in Bangar Urban Centre



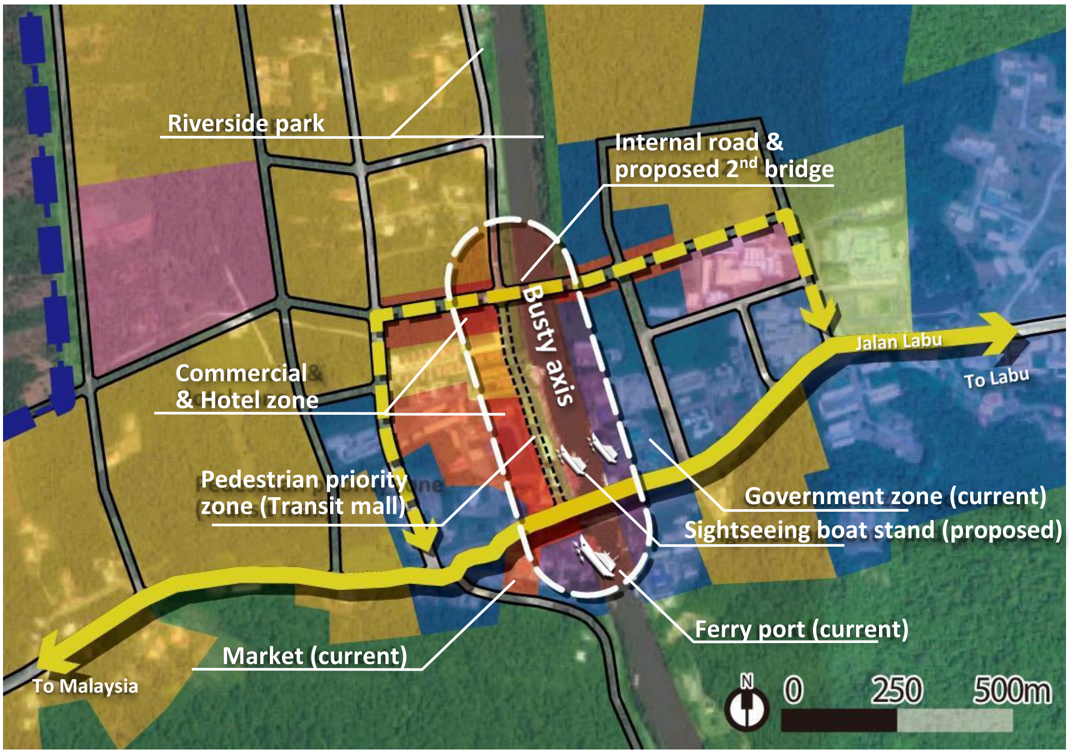
Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

- **[UC-2] * Construction of Port Facility**

  The main ferry port, downstream from Jalan Labu, is the terminal for high-speed, large vessels used to travel to the national capital and neighbouring countries. The study plans to introduce new river-related activities in Bangar and Labu, along with a sightseeing dock in the transit mall area in front of the commercial district on the left bank and the administrative area on the right bank. These new docks will avoid the complication of the high-speed, large vessel ferries and create a lively river space.

  The area around the new ferry port is also intended to be a bustling area with uninterrupted shopping space by pedestrianising part of the roads between the current commercial area and the Temburong River. This will create an urban space for the residents and tourists to enjoy.

Figure 4.23: Location of New Port and the Riverside Development Area in Bangar Urban Centre



Source: ERIA and Nikken Sekkei Civil Engineering Ltd. (2018).

5.9. Summary of road map for Temburong ecotown development

Table 4.13 summarises the priority projects of the road map for the Temburong Ecotown development.

Table 4.13: Summary of Priority and Key Projects in the Road Map for Temburong Ecotown Development

	Present	Present – 2021	2022–2023	2024–2030	2031–2040
Energy	[EN-1]*Hydrogenation Plant	[EN-2]*Exportation of SEPERA Hydrogen to Japan	[EN-3]*Photovoltaic Power Station Phase 1	[EN-4]*Photovoltaic Power Station Phase 2	[EN-5]*Photovoltaic Power Station Phase 3
Transportation	[TR-1]*BSB-Temburong Bridge	[TR-2]*Hydrogen Supply Stations for Fuel Cell (FC) Buses and Vehicles	[TR-4]*Mass Transit Bus Services by FC Buses between Empire Hotel Aiport, and Temburong Mobility Hub	[TR-6]*Expansion of Mass Transit Bus Services by FC Buses between Empire Hotel Airport and Temburong Mobility Hub	[TR-8]*Expnasion of Fuel Cell Bus and Passenger Car Operation both in Temburong District and Mainland
		[TR-3]*'Mobility Hub'in the Gate Zone	[TR-5]*Community Bus Services by FC Buses within Temburong Ecotown	[TR-7]*Expnasion of Community Bus Services by FCl Buses within Temburong Ecotown	
Water			[WA-1]*Upgrading of Existing Batang Duri Water Treatment Plant	[WA-2]*Upgrading of Existing Sumbing Water Treatment Plant	[WA-1]*New Water Treatment Plant at Batu Apoi of Capacity 20 Mld
Tourism		[TO-1]*Resort & Convention in Gate Zone	[TO-3]*Nature Amusement Park in Gate Zone	[TO-5]*Hotel and Convention in Labu Estate Phase 1	[TO-6]*Hotel and Convention in Labu Estate Phase 2
		[TO-2]*Tourism Hub (Information and Learning Centre for Ecotourims)	[TO-4]*Agro Park in Gate Zone		
Education		[ED-1]*New Campus of	[ED-2]*Continuation	[ED-3]*Construction	

		Islamic University in Labu Estate	of New Campus of Islamic University in Labu Estate	of New Campus of Science & Engineering Faculties in Labu Estate	
Industry			[IN-1]*Industrial Park in Labu Estate	[IN-2]*R&D Centre Phase 1	[IN-3]*R&D Centre Phase 2
Housing		[HO-1]*Eco Residential Area in Gate Zone	[HO-2]*Residential Areas Phase 1 in Labu Estate	[HO-3]*Continuation of Residential Areas Phase 1 in Labu Estate	[HO-3]*Residential Areas Phase 2 in Labu Estate
Urban Centre Bangar		[UC-1]*Internal Road	[UC-3]*2nd Bridge of Bangar	[UC-5]*New Hospital or Expansion of Hospital	
		[UC-2]*Port Facility	[UC-4]*Riverside Park	[UC-6]*Temburong Industrial Estate in Bangar	

Source: Authors' analysis based on ERIA and Nikken Sekkei Civil Engineering Ltd (2018).

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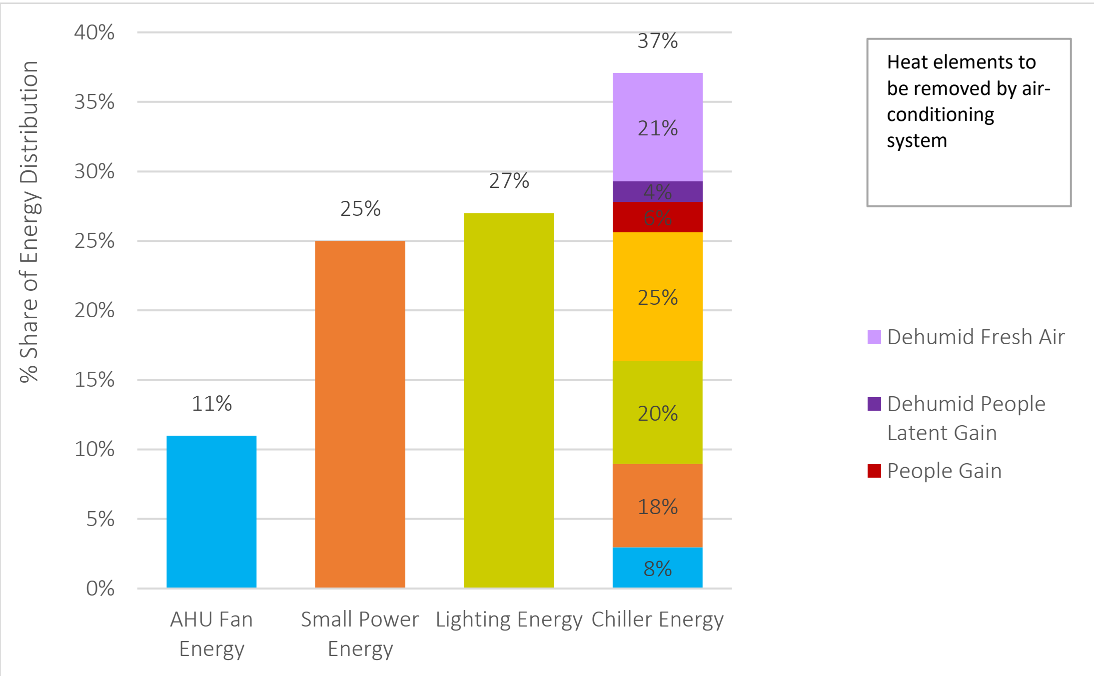
Appendix 1: Fundamentals of Energy Efficiency in Buildings

As illustrated in Figure A1, the energy use for air-conditioning and mechanical ventilation (ACMV) systems is expected to be a significant energy user in Temburong developments. Based on the study conducted by the Public Works Department Malaysia 2017 (Building Sector Energy Efficiency Project (BSEEP), the percentage share of energy use by the ACMV in Malaysian office buildings is about 50% of the total energy consumption in buildings. Energy consumption from air-conditioning is mainly required to remove heat from solar heat gain in a building. It is also needed to remove heat from electrical lighting, electrical equipment, and human occupancy and provide fresh air in the building. The fundamentals of energy efficiency in buildings will hopefully offer basic information to understand better building energy use and fundamental steps to achieve energy efficiency in buildings, ranging from no- or low-cost to medium- and high-cost measures.

Figure A1: Typical Energy Breakdown in an Office Building in Malaysia



Source: Public Works Department Malaysia (2017).~~3~~

Sections 1.1.1-C and 1.2.1-A explain why passive design measures should be considered first to control solar radiation and conduction heat gains into buildings. Therefore, energy efficiency in buildings should be prioritised according to the following eight fundamental steps[8]:

[8] Adapted from BSEEP, Building Energy Efficiency Technical Guideline for Active Design, Building Sector Energy Efficiency Project (BSEEP), Public Works Department Malaysia (2017).

1) Control of solar heat gain

The control of solar heat gain is a combination of building orientation, building envelope design approach in the design of façades, and selection of suitable glazing and building materials (refer to PBD12 EEC:2015 or MS1525:2019) to meet the minimum energy efficiency performance as explained in Sections 1.1.3.1 and 1.4.1.

2) Conduction heat gain due to building fabric

The difference in temperature between outdoor space and indoor space will cause conduction heat gain through building walls/ or fabric. The selection of suitable building materials with low thermal transmittance or U-values and the use of roof and wall insulation will reduce this heat gain (refer to PBD12 EEC:2015 or MS1525:2019).

3) Minimise heat island effect[9]

The intent is to reduce the heat island effect or thermal gradient difference between building development and immediate surroundings to improve the microclimate surrounding the building. This can be achieved through green landscaping; use of paving materials with a solar reflectance index of at least 29; provision of shade over 50% of the site's hardscape (including sidewalks, courtyards, plazas, and open-air parking lots); and open-grid pavement system.

4) Chiller system efficiency

With minimised solar radiation and conduction heat gains, the next major building system that consumes significant energy is ACMV. A significant energy-consuming component of the ACMV system is the chiller system. A high-efficiency chiller system can significantly reduce the total energy use. A typical chiller system consists of chillers, chilled water, and condenser water pumps and cooling towers. The selection and design configuration of chillers are important. However, the O&M of chiller systems is also essential because most chillers are not efficient when operated at part loads. Poor maintenance can also cause a drop in chiller operational efficiency. Temperature setting at a room temperature of 24^0C can save electricity in the operation of the air-conditioning system. Air flushing in buildings with early morning cool air can also save electricity by delaying the start of the air-conditioning system in the mornings.

5) Lighting efficiency

Natural daylight harvesting, which is the most efficient method because it provides light without operating cost and the least amount of heat emission to building spaces, should be prioritised. If it is necessary to have electric lighting, use PBD12 EEC:2015 or MS1525:2019 (for updated information) to design the lighting requirements, using energy-efficient lighting with high lighting efficacy, proper zoning of lighting circuits, etc.

[9] Green Building Index Malaysia, www.greenbuildingindex.org

6) Reduce plug loads

Reducing plug loads in buildings can be achieved by selecting energy-efficient appliances and equipment according to MEPS, where applicable. The benefits of choosing energy-efficient appliances and equipment are savings in electricity use and reduction in heat emissions. Hence, these result in reduced cooling load requirements, which means that air-conditioning system capacity can be downsized. Further reduction of energy use can be achieved if the standby power of electrical appliances and equipment is switched off overnight or not in use for an extended period because standby power consumes electricity.

7) Fan efficiency

Air-conditioning systems require fans such as air-handling and fan coil units to deliver cool air to building spaces. Fan efficiency is attributed to selection of fans, high efficiency or conventional motors, ducting design and losses, air filtration system pressure losses (due to dirty and clogged filters), and choice of fan speeds (higher speeds consume more electricity).

8) Control of outdoor air intake and infiltration

Fresh air should be provided in buildings. However, prolonged and excessive outdoor air intake will cause a high latent (moisture) load, which will increase electricity consumption by the air-conditioning system. This excessive load can be overcome by using a CO_2 sensor to control the mechanical outdoor air intake system in accordance with the pre-set level in the sensor.

The above discussion shows that it is possible to achieve energy efficiency in buildings through passive and active energy efficiency measures. Fundamental steps 1, 2, and 3 on control of solar heat gain, conduction heat gain, and minimising heat island effect are passive energy efficiency measures. Other fundamental steps are active energy efficiency measures. Some of these fundamental steps require no or low costs. Examples of these measures are building orientation through project planning, natural daylight harvesting, and selection of energy-efficient appliances and equipment through design, choice of fan speed, room air temperature setting at 24°C, air flushing with early morning cool air, selection of low-fan speeds, switching off electric appliances and equipment when not in use for a long time, etc.

These eight fundamental steps summarise various options available – ranging from the project planning stage to the building design stage and operational stage – to achieve energy efficiency in buildings. The options are almost limitless and are really up to the designers' creativity to address each fundamental step to suit owners' and developers' project requirements and budgets. The results for implementing these fundamental steps in building development will be rewarding in terms of the following:

a) Reduce solar heat gains.
b) Improve the microclimate in the building surrounding to cool the local ambience. Hence, natural ventilation in some areas of a building may be possible, without air-conditioning certain building spaces.
c) Reduce heat emissions from lighting, appliances, and equipment.

d) Reduce cooling load for air-conditioning system.
e) Air-conditioning equipment andsystem can be downsized, hence, saving capital costs.
f) Reduce energy consumption, hence, save energy.
g) Improve thermal comfort.
h) Provide a healthy indoor environment with adequate fresh air supply and cleaner air through regular maintenance requirements to clean air-handling unit filters.
i) Energy-efficient buildings contribute towards the mitigation of GHG emissions.

Appendix 2
Building Energy Management System

Appendix 1 distinctively describes the fundamentals of energy efficiency measures. Aside from these measures, it is also essential to adopt a system to obtain, monitor, and evaluate such measures. Hence, a building energy management system (BEMS) could perform the above. BEMS is a computer-based automated system that monitors and controls all energy-related systems from the mechanical and electrical equipment in a building. A BEMS is otherwise also known as building automation or integrated building control system. A comprehensive BEMS should provide the following:

a) The ability to gather data from every available energy source, whether it is old, new, integrated, or stand-alone
b) The ability to identify problems and trends by analysing both single- and multi-variable data
c) The ability to provide alerts if the building's energy consumption exceeds the preset parameters
d) The ability to integrate with control systems to automate responses and input data
e) The ability to provide early warnings for any mechanical or electrical failures
f) The ability to identify energy waste and to recommend fixes, allowing for easier payback
g) The ability to benchmark the building's energy use against other buildings in similar climates

BEMS implementation is already starting to be a standard system in new buildings because of its benefits, as follows:

a) Provides real-time remote monitoring and integrated control of a wide range of connected systems, allowing modes of operation, energy use, environmental conditions, and so on to be monitored and allowing hours of operation, set points, etc. to be adjusted to optimise performance and comfort
b) Can predict problems and informs and provides a schedule for a maintenance programme
c) Allows facilities to power equipment only when needed. For many facilities, this eliminates the waste of lighting, heating, and cooling portions of the building that are not used around-the-clock. BEMS can allow savings of 10%–15%, according to a claim in the US Green Building Council. If BEMS is operated properly, it should allow energy use to be optimised without compromising comfort or performance.
d) BEMS allows records of historical performance to be kept, enables benchmarking of performance against other buildings or sites, and may help automate report writing.
e) BEMS can perform its functions entirely automatically, day in, day out, year after year without the need for much interaction. For many users or owners, such as data centres

or healthcare installations, ‘system downtime’ is not acceptable. Therefore, the system needs to be robust, reliable, and adapt or expand with the customer’s needs.

f) BEMS will report and demonstrate visually how energy use and carbon emissions are being reduced, helping to meet legislative and corporate social responsibility demands.

A typical BEMS comprises the following components:

a) Central equipment (processing equipment)
b) Human Man Interface software
c) Network backbone
d) Tier 1 hardware (building controller, advanced application controller) – general
e) Tier 2 hardware (application-specific controller, smart actuator) – specific
f) Sensors, transmitters, transducers
g) Smart touchscreen

Some key features and areas that BEMS is deployed are for an integrated township. BEMS could be integrated within the township and buildings to form a huge BEMS for the township itself and a centralised management control building and monitoring centre. The township module could also include the power supply smart grid system to control the electricity network’s supplies from the utility or internal self-generation, smart transportation network, and township asset management. BEMS is also deployed for both commercial and residential developments. BEMS is used for commercial development to control the mechanical and electrical systems such as the air-conditioning systems, lightings, fire detection and alarm, indoor air quality, security systems, and energy supply and load management. For residential development, BEMS will be providing comfort and flexibility to end users and often commonly termed as Smart Home System, which includes motion detectors; window, door, lighting controls and environmental monitoring; and other automation control of house appliances.

To utilise BEMS well, the International Electrotechnical Commission (IEC) has derived a new standard under IEC 60364:8-1 Standards on Low-Voltage Electrical Installations - Part 8-1: Energy Efficiency. The standard provides a guide to the possible implementation of the EMS of BEMS as per Figure A2.

The standard specifies that for the EMS to function, the system shall obtain requirements from the following:

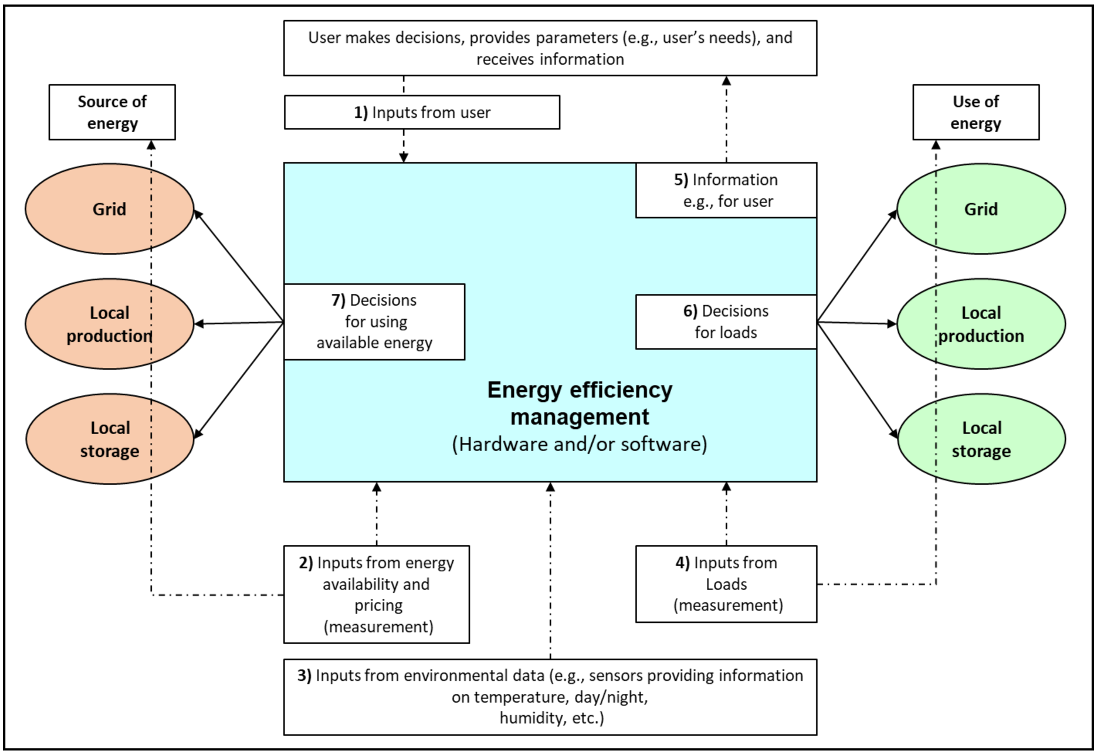
a) User

Requirements from the user are the first input to consider. These requirements will be the key input to design the energy efficiency management system. The designer or user shall at least consider the following:

- selection of energy-efficient appliances,
- assignment of load priority for use as an input of the load optimisation process,
- the intended use of the installation in providing an energy-efficient design, and

- provision of a manual override facility, which enables the user to control automated functions.

Figure A2: Energy Efficiency and Load Management System Diagram



Source: International Electrotechnical Commission (IEC), 2019.

b) Inputs from loads, sensors and forecast, inputs from energy suppliers

Electrical parameters are measured to determine the electrical consumption. The measurement needs to be substantiated by the size of driving parameters such as people's presence, temperature, air quality, etc. Energy measurement provides the subscriber with an awareness of his energy consumption. Consequently, device accuracy and measuring range shall be adapted to the intended use. From a general point of view, the highest metering accuracy is important at the installation's origin. It is used for invoicing or similar purposes and for measuring and assessing the whole installation's efficiency. It also enables assessment of the entire installation efficiency by summation of the parts. A lower level of accuracy is generally sufficient downstream. Measurement equipment shall be installed according to the application and to its location within the installation. IEC 61557-12 defines power metering and monitoring device classification with minimal required functions according to its application. The EMS for energy efficiency shall not impair communication for other purposes such as safety, control, or the operation of devices or equipment. Examination of historical data is an input for estimating energy demand. Regarding the quality and effectiveness of obtaining a high level of energy efficiency, a communication system of all required and foreseen data should be provided.

c) Loads

The association of measuring devices with external current or voltage sensors builds a complete system required to measure the active energy, which is the primary energy efficiency parameter. The load shedding capability of BEMS shall be based on the suitability of the load for power interruption and user acceptance of power interruption to that load. Some current-using equipment, such as information and communications technology equipment systems, desktop computers, and TV sets, are not suitable for load shedding. Others like heaters and fridges can accept a shedding up to a certain period without impacting on their service. The maximum time of shedding for each mesh is determined by the individual current using the information on loads' ability to accept a shedding, and the corresponding duration is useful. Occupancy or regulation must be considered when to accept load shedding. The decision to switch off or switch on specific current-using equipment is related to the energy forecast, the power demand to be expected, and the electrical energy available. There are relationships between potential improvements in energy efficiency, lifetime, and the maintenance of devices, systems, and installation.

Some measures taken to improve the system's energy efficiency (in terms of energy management) may have some drawbacks if the device choice is not appropriate. Consideration should be given to how the implementation of energy efficiency measures, active or passive, can impact the equipment's lifetime. Equipment should be selected to be suitable for this energy management.

Additional forecast inputs are also to be used for the energy efficiency management system, such as:

- weather forecasts to efficiently manage current-using equipment with thermal inertia,
- occupancy forecasts to prevent unnecessary use of current-using equipment,
- production forecasts for renewable energy, and
- manufacturing forecasts for adaptation of the production.

d) Inputs from the supplies: energy availability and price

Information concerning energy availability and pricing, which may vary with time, shall be considered in BEMS. The relative price and availability of energy from the locally generated versus utility-supplied sources impact the decision on which source to use and/or the charge or discharge of the electrical storage, if any.

e) Monitoring the performance of the electrical installation

The installation should be designed at least with a user interface to measure its total electrical energy consumption for a certain period at a minimum every hour. This data and the related cost of energy information should be logged and stored for some time.

f) Management of loads through the meshes

The overall power demand should be optimised as far as possible to aid the overall energy reduction of the installation. The design of the management system depends on the availability of each source. The needed continuity of supply and the demand response requirements are essential for the installation's overall energy efficiency. These aspects shall lead to an appropriate selection of source switching equipment.

Besides the EMS explained above, most BEMSs also provide some key features, which are summarised below:

Real-time monitoring

Unlike interval data, real-time energy monitoring provides the user with key energy data *in the moment* – not on a 24-hour time delay. This makes it easier to pinpoint weaknesses and areas for improvement.

Historical data

Historical data also plays a vital role in EMSs. It compares current energy consumption to previous years, visualises energy trends, and diagnoses past problems.

Power quality analysis

Power outages cost companies billions of dollars every year in lost revenue, damaged equipment, and idle employees. A BEMS, which integrates power quality analysis, can sniff out these power disruptions before they occur.

Customised reporting

There is no 'one size fits all' in energy reporting. Individual pieces of information may be valuable to one employee but useless to another. Customised reporting will allow quick essential information in the hands of those who need it.

Automated billing

For utility suppliers, billing can be a troublesome task. Many companies outsource their billing operations, a move that can cost tens of thousands of dollars per year. Some energy management software comes fully equipped with automated billing capabilities to make it easier for the billing system.

Energy consumption benchmarking

BEMS could provide features comparing the user building's historical energy consumption with the benchmark's current energy consumption. This could assist the user in understanding and comparing the building's ongoing performance.

Building optimisation

This functionality allows the EMS to interact with the building's systems to optimise their performance on a real-time basis.

Ongoing performance analysis – ensures that the system is working optimally.

Demand response – allows the system to respond to changing factors, such as high energy costs or system resource capacity needs.

Energy dashboard

A display that allows users to access and understand energy consumption data

Measurement and verification – ensure that energy efficiency measures or system improvements are producing the expected results. It is essential for identifying the system's return on investment.

Notifications and alerts

A feature that notifies the user of any issues – from maintenance needs to problematic equipment.

BEMS in recent years evolved and incorporated the advancement of digitalisation, automation, and industrialisation. The following are some additional advanced features:

Automated building control – allows the EMS to interact with the building's devices and systems actively.

Advanced metering infrastructure (AMI) analysis **-** allows AMI data to be collected from a utility at specific time intervals. This provides a more accurate understanding of a building's energy consumption.

Automated demand response – helps reduce energy use during peak load events by automating the control of a building's components or systems

Whilst the BEMS have features that are beneficial to the energy efficiency efforts, there are still concerns and issues on BEMS that hinder the effective use of the system, such as:

- Lack of qualified maintenance team to handle the BEMS;
- Lack of support from management to implement the BEMS;
- Obsolete software used after a period the BEMS is implemented;
- Interfacing issues with third-party controller;
- Lightning surge damages the electronic equipment in the BEMS, thus, not giving a reliable manner for control and monitoring; and
- Inaccuracy in measurement tools and parameters.

Appendix 3
Building Energy Simulation

Building envelope design would require calculations such as overall thermal transfer value (OTTV) and roof thermal transfer value (RTTV) as described in Section 1.3.1. Designers are also mandated to produce other required energy calculations for quantification and optimisation purposes. Building energy simulation (BES) replicates building energy performance aspects using a computer-based mathematical model based on fundamental physical principles and sound engineering practices. BES is a useful design tool to quantify and optimise building energy performance. Other terms used to describe the same topic are:

- Building performance simulation
- Building performance modelling
- Building energy modelling

Developing BES will provide much greater benefits than manual calculations because optimisation can be done easily by changing some parameters, such as selecting building materials, building orientation, façade design, etc. BES benefits could be summarised as follows:

a) Understand the total cost of ownership

BES models can reveal the true cost of ownership and the impacts beyond the basics, such as factoring in depreciation rates and annual maintenance costs. BES could calculate 'simple payback' or break-even on the efficiency, given the equipment cost.

b) Achieve 'green building' standards

The Leadership in Energy and Environmental Design (LEED) and other green building certifications have set energy modelling requirements for achieving certain benchmarks of its standards. These certifications have a strict set of guidelines to achieve varying levels of LEEDS ratings. Energy modelling is one way to determine the required level.

c) Comply with utility and municipality rebate programme

Local governments and utility companies understand the cascading benefits of getting building owners on board with lower energy use. Hence, in some countries, BES is a requirement to comply with in utility and municipality rebate programmes.

The BES software is readily available in the market, and most of the software are similar in purpose and functions, i.e. they simulate energy consumption patterns in a building. For BES to generate a good report, it is critical to ensure that inputs to simulations are provided as accurately as possible per site installations and conditions. Some inputs required for BES are as follows:

- Climate – ambient air temperature, relative humidity, direct and diffuse solar radiation, wind speed and direction;
- Site – location and orientation of the building, shading by topography and surrounding buildings, ground properties;
- Geometry – building shape and zone geometry;
- Building envelope – materials and constructions, windows and shading, thermal bridges, infiltration and openings;
- Internal heat gains – lights, equipment, and occupants including schedules for operation and occupancy;
- Ventilation system – transport and conditioning (heating, cooling, humidification) of air;
- Room units – local units for heating, cooling, and ventilation;
- Plant – central units for transformation, storage, and delivery of energy to the building;
- Controls – for window openings, shading devices, ventilation systems, room units, plant components.

Numerous BES standards are available. In Malaysia, BES requirements are mentioned in the Malaysian Standard, MS1525:2019 Energy Efficiency and Use of Renewable Energy for Non-residential Buildings – Code of Practice (Third Revision), under Clause 10: Building Energy Performance. The BES method is defined as a performance-based approach computing the predicted energy use of buildings. MS1525 sets a criterion that the BES should be performed twice during the design of the building. The first simulation should be for the building as designed according to architectural design drawings, referred to as the building design. The second simulation is for a reference building referred to as the base building. The base building shall meet the relevant minimum requirements as specified in this standard. Compliance with the standards will be established if the building design's annual energy use does not exceed that of the base building as calculated by the same simulation programmes. The energy performance rating for equipment or components specified in the design building is not less than the rating used to calculate the base building energy consumption. The standard also specifies the minimum simulation requirements for the simulation programme used. The simulation programme should be computer based to analyse energy consumption in buildings. The simulation programme should include calculation methodologies for the building components being modelled and incorporate the following:

a) A minimum of hourly variation in occupancy, lighting power, miscellaneous equipment power, thermostat set-point, and ACMV system operation, defined separately for each day of the week and holidays;
b) Thermal mass effect; and
c) Sufficient thermal zone to model the design building.

Commercially available software for simulation programmes such as, but not limited to, Energy Plus, ESP-r (Energy Simulation Software tool), eQuest, TRNSYS, DOE-2, IES, and Open Studio.

The basic steps in energy simulation can be summarised as follows:

a) First step – creation of a building

The creation of the building is the earlier stage of an energy simulation. This process can be done, for example, by inserting the coordinates in the software tool such as in the simulation programme or by uploading files from other software, such as AutoCAD or Google Sketch Up. After that, it is possible to see the figure introduced in the programme tool through the specific file format that connects to AutoCAD and view it in this format. Once the formatting is determined, the dimensions of the organisational structure, geometry, and materials used in the components of the building architecture will be specified.

b) Second step – step – simulation of the building

In this step, variables to be considered are established in the building simulation, and the programme is run. The thermal performance of the building can be varied according to its use. Therefore, it is important to specify the type of building (office, hotel, etc.), the human activities carried out, the existing equipment (lighting, refrigeration, air-conditioning systems, water heaters, and boilers, etc.), and their daily schedules. The description of these parameters allows establishing the internal heat load and ventilation.

c) Third step – analysis of results

After running the programme tool, it should be checked for any error or severe mismatch introduced in the set of variables. In some cases, the simulation software tool issues its own warnings in a final report containing the results from which should be retained all the relevant conclusions. Energy analysis or energy modelling is used to

- compute for the BEI,
- predict the monthly energy consumption and bills,
- predict the annual energy cost,
- identify annual CO_2 emissions,
- compare and analyse different efficiency options, and
- determine life cycle payback on various options.

Whilst BES features benefit the energy efficiency efforts, there are still concerns and issues on BES that may hinder the effective use of the simulation programme, such as the following:

a) There is a lack of qualified professionals in this region to carry out and be familiar with the simulation.
b) Simulation is not a mandatory requirement in energy efficiency efforts. Most of the time, manual calculation is preferred and is sufficient.
c) It is costly for companies to be spending labour and software costs.

d) Input data from manufacturers are inaccurate.

e) Awareness of BES benefits is low.

Moving forward with BES, the industry needs to set criteria or requirements for energy simulation for a higher category of building ratings to achieve the energy efficiency requirement and ratings. This would encourage more use of BES. More awareness of BES should be made via training and workshops to encourage more BES users and practitioners, especially professionals like architects and engineers. Potential collaboration with universities should also be established to develop the basic requirements of energy simulation for buildings in the country.

Appendix 4
EEC Building Design Submission Format

Table A4.1: General Project Information

EEC BUILDING DESIGN SUBMISSION FOR DESIGNATED BUILDING PROJECT INFORMATION	
PROJECT NAME	
PROJECT OWNER/DEVELOPER	
PROJECT ADDRESS	
CONTACT PERSON	
CONTACT TEL & EMAIL ADDRESS	
ARCHITECT	
MECHANICAL ENGINEER	
ELECTRICAL ENGINEER	
CIVEL & STRUCTURAL ENGINEER	
LANDSCAPE CONSULTANT	
OTHER SPECIALIST CONSULTANT(S)	
TOTAL GROSS FLOOR AREA (less carpark area within building)	
BUILDING DESCRIPTION	

Table A4.2: Design Information for Step 1 Assessment: Prerequisite Requirements

	Confirmation of Prerequisite Requirements by Principal Submitting Person	Assessment Officer's Review Comments
Overall Thermal Transfer Value	OTTV =	
Roof Thermal Transfer Value	RTTV = (Applicable if building roof is provided with skylight and the entire enclosure below is fully air-conditioned, e.g. atrium.)	
U-value for roof	To state type of roof construction: U-value =	

Table A4.3: Design Information for Step 2 Assessment: Basis of Design

	Information	Assessment Officer's Review Comments
Basis of design: Major equipment selection (MEPS ratings/equipment EEI ratings)		
Basis of design: Design value of system intensity and other relevant energy efficiency design parameters		

Table A4.4: Information for Step 3 Assessment

	Information	Assessment Officer's Review Comments
Sub-metering for major load centres	Electrical sub-metering for load centres	
BEMS a. Compliance with PBD12 EEC:2015, Brunei b. Other functions: Computation and monitoring of BEI with tracking and reporting capability for analysis and energy audit purposes.	Provision of BEMS functions	
BEI labelling	To declare computed BEI value	