Chapter 2

Forecast for Potential Solar PV Capacity in Brunei Darussalam

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1. Examples of Floating Solar PV Systems

The following are examples of existing floating solar PV (FSPV) systems:

- Yamakura Floating Solar Power Generation Station, Chiba Prefecture, Japan
- Singapore's floating solar farm on the Tengeh Reservoir
- Woodlands, Straits of Johor

(1) Yamakura Floating Solar Power Generation Station, Chiba Prefecture, Japan, 2018

- Polycrystal silicon panel : 305 watts (W)/panel x 44,898 = 13.7 megawatts electric (Mwe) (11.5 MWe transmitted)
- Annual output : 16,100,000 kilowatt-hours (kWh) (capacity factor 16 %)
- Surface area : 18 hectares (ha) (water surface area: 61 ha)

Figure 2.1. Yamakura Floating Solar Power Generation Station, Chiba Prefecture, Japan

Source: News release of Kyocera, 1 October 2021.

Kyocera's 13.7 MWe floating solar panels were damaged by 200 kilometres per hour (km/h) winds that Typhoon Faxai brought to the coastal city of Chiba in 2019. After around 2 years of

remedial work, the FSPV system restarted operations in 2021 with six separated solar panel islands as shown in Figure 2.1.

(2) Singapore's floating solar farm on the Tengeh Reservoir, 2021

- Made up of 122,000 solar panels spanning 45 ha
- Solar panels spread across 10 solar panel islands
- 60 megawatt (MW) peak solar PV ⇒ 60,000/122 = 490 W/panel

Figure 2.2. Tengeh Floating Solar Farm in Singapore

Source: Singapore International Water Week (n.d.) Sembcorp Tengeh Floating Solar Farm. https://www.siww.com.sg/spotlight-2023/programme/technical-site-visits/sembcorp-tengeh-floating-solar-farm

The solar farm was deployed as part of Singapore's goal to quadruple solar energy capabilities by 2025. The farm is designed, built, owned and operated by Sembcorp Floating Solar Singapore in partnership with the Public Utilities Board, which regulates and oversees the water supply system in Singapore.

(3) Woodlands, Straits of Johor, 2021

- Power generation : 5 MWe
- Configuration of farm : 13,312 panels, 40 inverters and >30,000 floats
- Annual output : 6,000 MWh (capacity factor 14 %)

The solar farm consists of electrical panels, a control system, 22-kilovolt (kV) transformers, and a landing point for the subsea cable transmitting generated power to the national grid. The floating PV system is designed with a robust constant tension mooring system.

Figure 2.3. Offshore Floating Solar Farm in Johor, Malaysia

Source: Hill, J. (2021), Sunseap Completes Offshore Floating Solar Farm in Straits of Johor. https://reneweconomy.com.au/sunseap-completes-offshore-floating-solar-farm-in-straits-of-johor/

2. Current State and Plans for Global FSPV Installation

Table 2.1 shows the current construction records and plans for FSPVs of 5 megawatt-peaks (MWp) or more. The largest of these is planned for Madhya Pradesh in India, which is expected to start generating 600 MWp in 2022–2023.

China accounts for the majority of FSPVs of 100 MWp or more, and these are characterised by the fact that FSPVs are installed in ponds made from abandoned mines.

As can be seen from Table 2.1, FSPVs are mainly installed in inland water bodies. This is because the environmental load given to the floating structure is much more severe in seas than in inland waters.

As for offshore FSPV, in addition to the 5 MWp installed in the Straits of Johor, a small offshore unit called SolarSea has been introduced in the Maldives. The unit is said to be able to withstand waves of up to 1.5 m high and winds of 10 km/h, as well as strong ultraviolet and humidity.

In Japan, there are no FSPVs installed on the sea yet, but a demonstration test of floating solar power generation is planned as the Tokyo Bay eSG project, with an implementation period from 2022 to 2024. The details of the implementation procedure are as follows.

- Design and installation of multiple floating systems
- Design and installation of floating structures and mooring systems for offshore use
- Verification of the effects of salt damage on electrical equipment
- Comparative verification of the power generation number of different types of floating systems, such as offshore and onshore

Table 2.1. Current State and Plans for Global FSPV Installation

Category	Size (kWp)	Water Body and Nearest City	Country	City/Province	Floating System Supplier(s) (and subcontractor, if possible)	Completion Year
L&D	600,000	Madhya Pradesh, reservoir formed by the Omkareshwar Dam	India	Khandwa District	-	2023
L&D	320,000	Dezhou Dingzhuang Floating Solar Farm reservoir in Shandong	China	Dezhou	Beijing Electric Company Huaneng Power International	2022
MS	150,000	Coal mining subsidence area, Huainan City (Fengtai Guqiao-Sungrow)	China	Anhui Province	Beijing NorttMan, Zhongya, Hefei Jintech New Energy Co. Ltd., Anhui ZNZC New Energy Co. Ltd., CJ Institute China	2018
MS	150,000	Coal mining subsidence area, Huainan City (Panji-China Three Gorges New Energy)	China	Anhui Province	Sungrow Floating (Anhui ZNZC New Energy Technology Co. Ltd.)	2018
MS	130,000	Yingshang coal mining subsidence area, (Liuzhuang mine-Trina Solar)	China	Anhui Province	Anhui ZNZC New Energy Technology Co. Ltd., Shanghai Qihua Wharf Engineering Co. Ltd., etc.	2018
MS	102,000	Coal mining subsidence area, Huainan City (Fengtai Xinji)	China	Anhui Province	Sungrow Floating (Anhui ZNZC New Energy Technology Co. Ltd)	2017
MS	100,000	Coal mining subsidence area, Jining City	China	Shandong Province	Sungrow Floating	2018
L&D	70,005	Mine Lake, near Huaibei (CECEP)	China	Anhui Province	Ciel & Terre International	2018
L&D	60,000	Tengeh Reservoir, Southwest, Singapore	Singapore	-	Sembcorp Industries	2021
MS	50,000	Coal mining subsidence area, Jining City (Shandon Weishan)	China	Shandong Province	Sungrow Floating	2017
L&D	45,000	Sirindhorn dam, Ubon Ratchathani	Thailand	-	-	2021
MS	40,000	Renlou coal mine in Haibei City (Trina Solar)	China	Anhui Province	Shanghai Qihua Wharf Engineering Co. Ltd., etc.	2017
MS	40,000	Coal mining subsidence area, Huainan City (20+20 Panji)	China	Anhui Province	Sungrow Floating	2017

Table 2.1. Current State and Plans for Global FSPV Installation (continued)

Category	Size (kWp)	Water body and nearest city	Country	City/Province	Floating system supplier(s) (and subcontractor, if possible)	Completion year
L&D	32,686	Mine Lake (Golden Concord Ltd (GCL)	China	Anhui Province	Ciel & Terre International	2018
MS	31,000	Coal mining subsidence area, Jining City (Shandong Weishan)	China	Shandong Province	Sungrow Floating	2017
MS	20,000	Coal mining subsidence area, Huainan City (Xinyil)	China	Anhui province	N/A	2016
L&D	18,700	Gunsan Retarding Basin	Korea, Rep of	North Jeolla	Scotra Co. Ltd.	2018
L&D	13,744	Yamakura Dam Reservoir	Japan	Chiba	Ciel & Terre International	Original 2018, modification 2021
-	10,982	Xuzhou Pei Country	China	Jiangsu Province	Ciel & Terre International	2017
L&D	9,087	Urayasu Ike	Japan	Chiba	Ciel & Terre International	2018
-	8,500	Wuhu, Sanshan	China	Anhui Province	N/A	2015
L&D	8,000	Lake in Xingtai, Linxi Country	China	Hebei	N/A	2015
L&D	7,550	Umenoki Irrigation Reservoir	Japan	Saitama	Ciel & Terre International	2015
L&D	6,800	Hiritani Ike	Japan	Hyogo	Takiron Engineering Co. Ltd.	2018
L&D	6,776	Amine Lake, Jining City	China	Shandong Province	Ciel & Terre International	2015
L&D	6,338	Queen Elizabeth II Drinking Water Reservoir	United Kingdom	London	Ciel & Terre International	2016
SEA	5,000	Straits of Johor	Singapore	-	Sunseap Group	2021

KWp = kilowatt peak, L&D: lake, dam, and water reservoir, MS = mining subsidence, SEA = sea area.
Source: World Bank Group, ESMAP, and SERIS (2019), *Floating Solar Market Report*; various websites.

3. Pros and Cons of FSPV

FSPV systems have different pros and cons from the points of view of design, installation, and operation. The pros and Cons of FSPV systems are listed below.

- Pros of FSPV:
  (1) Shortened construction period as no need for deforestation or ground preparation.
  (2) Maintaining forests and preserving limited land for other purposes, such as industrial needs.
  (3) The cooling effect of water leads to higher power generation efficiency compared to ground-mounted solar PV systems.
  (4) The shading effect of the panels helps to reduce evaporation and the presence of algae blooms in water.

- Cons of FSPV:
  (1) Onboard work and underwater work are necessary to install panels and structures.
  (2) The cost of building FSPVs is more expensive than ground-mounted solar PV, due to the need to build floating structures.
  (3) Shading effect of the panels leads to an increase in phytoplankton and, as a result, water degradation.
  (4) Necessity of FSPV system design that does not spoil the scenery.

4. Suitable Area for FSPV Installation

A suitable area for installing an FSPV system on the water surface has to fulfil the following conditions:

- High solar radiation: Brunei 4.00–4.99 kWh/m^2/day
- Environment
  (1) No shading effect on FSPV modules
  (2) Water depth: < 10 m
  (3) Stable water surface
  (4) Normal wind speed: < 34 m/s
  (5) Few water-level fluctuations
  (6) No severe weather conditions
- Grid connection
  (1) Connecting facility can be easily installed nearby
  (2) Underwater or floating cable connection to the facility

5. Candidate Sites for PV in Brunei

Table 2.2 and Figure 2.4 show the candidate sites for floating PV and ground-mounted PV.

Table 2.2. Candidate Sites for PV in Brunei Darussalam

Category	Site	Estimated Area (ha)	Estimated Capacity (MW)	Source
	Mengkubau Dam	197	125	(1)
	Benutan Dam	639	406	(1)
	Ulu Tutong Dam	517	329	(1)
	Kargu Dam	286	170	(2)
Brunei Bay	Serasa Bay	47	30	(3)
	Both sides of Temburong Bridge	1,000	640	(3)
	Muara Besar Island	47	30	(3)
Ground-mounted	Kg Belimbing	38	38	(1)
	Sungai Teraban	202	200	(1)
	Bukit Panggal	50	62	(2)
	Kg Tanjung Bungar	12	15	(2)
	Kg Seri Tanjung Belayang	50	62	(2)
	Kg Belingus	38.5	47	(2)

Ha = hectare, MW = megawatt.
Sources:
(1) 'Potential Sites for Solar Installation in Brunei Darussalam Nov 2022 Department of Energy', presented at 1st Working Meeting on the Green Hydrogen Production in Brunei Darussalam, 28 November 2022.
(2) Communications with the Department of Energy, Prime Minister's Office, Brunei Darussalam.
(3) 1st Working Meeting on the Green Hydrogen Production in Brunei Darussalam, 28 November 2022, and subsequent study.

Figure 2.4. Candidate Sites for PV in Brunei Darussalam

Source: Authors.

6. Capacity Factor in Brunei

6.1. Capacity Factor of FSPV

FSPV is said to have a 5%–10% increase in power generation efficiency compared to ground-mounted PV, as the panel temperature rise is suppressed by the cooling effect of the water. For this reason, when setting the capacity factor of FSPV to be installed in Brunei, we referred to Japan's Toyoake floating mega-solar power plant, for which the operating data have been published.

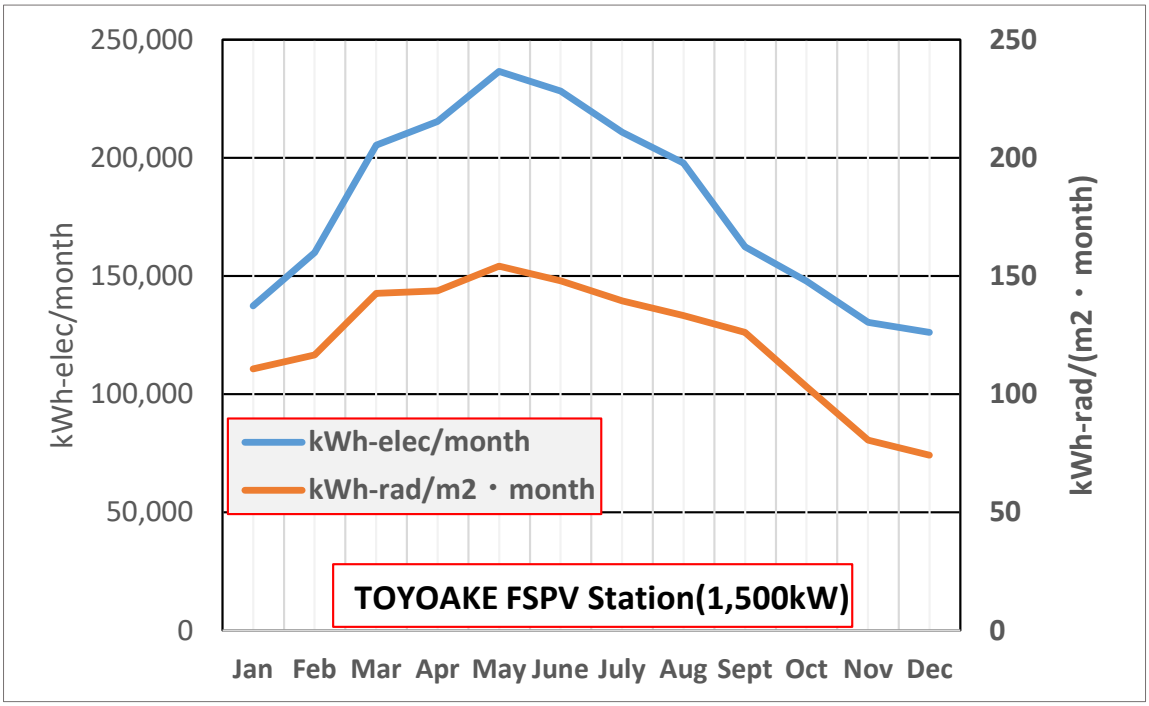
(1) Outline of Toyoake FSPV

- Location : Aichi Prefecture, Japan
- Installed Capacity : 1,500 kWp
- Area/panel : 1.9 ha/6,720 panels
- Operation : Since March 2017 (data for 2022 are shown in Figure 2.6)

Figure 2.5. Toyoake Floating Mega Solar Power Plant

Source: Toyoake City Office (n.d.). https://www.city.toyoake.lg.jp/4558.htm

Figure 2.6. Operational Data for Toyoake FSPV, 2022



Source: Authors.

(2) Comparison of climatic data on Brunei and Toyoake

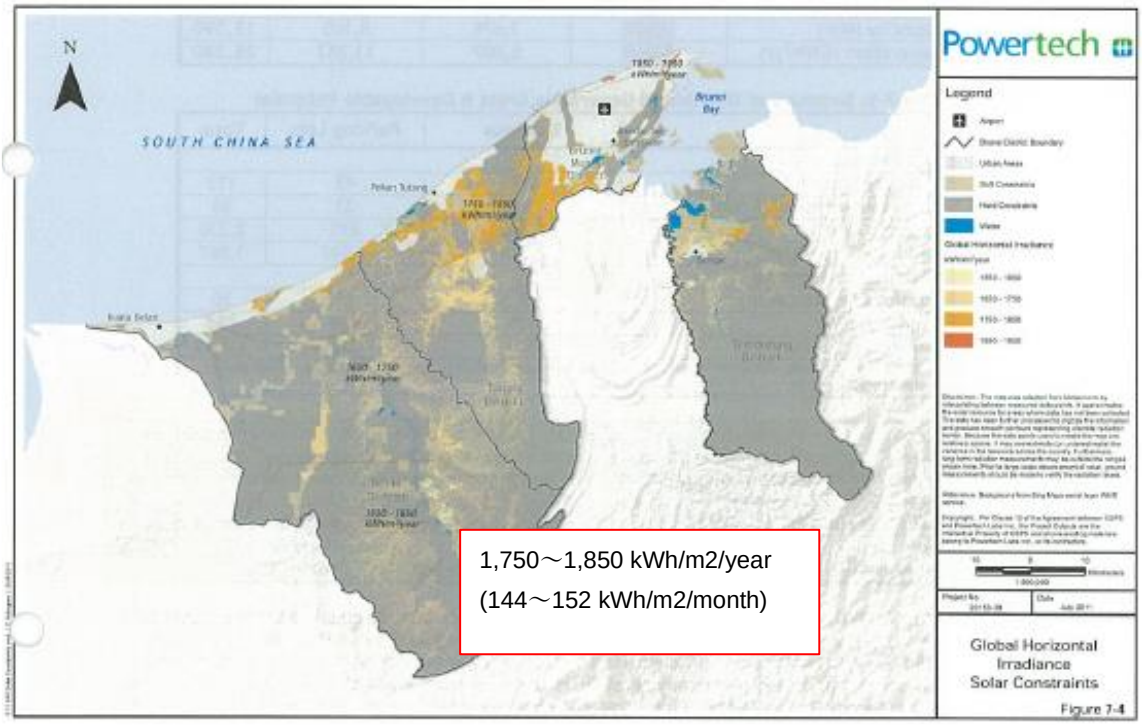
Table 2.3 shows data on temperature, humidity, precipitation, and solar irradiance for Brunei and Toyoake. The irradiance levels in Brunei are shown in Figure 2.4.

Table 2.3. Comparison of Climatic Data for Brunei Darussalam and Toyoake

	May	June	July	August	September
Temperature (°C)					
Brunei Darussalam	28.8	28.7	28.0	27.9	28.4
Toyoake	118.4	22.3	26.0	27.2	23.7
Humidity (%)					
Brunei Darussalam	78	77	79	78	76
Toyoake	72	78	81	77	77
Precipitation (mm)					
Brunei Darussalam	156.5	70.5	82.5	263.5	151.5
Toyoake	141	181	173	120	204
Solar Irradiance (kWh/m²/month)					
Brunei Darussalam	144–152 (annual average)				
Toyoake	154	148	139	133	126

Source: Brunei Darussalam: Communications with Department of Energy, Prime Minister's Office, Brunei Darussalam; Toyoake City (https://www.city.toyoake.lg.jp/).

Figure 2.7. Irradiance Levels in Brunei Darussalam



Source: *Feasibility Study for Alternative Energy Sources for Brunei Darussalam, A Report to the Centre for Strategic and Policy Studies*, submitted by Powertech, Canada, 2011.

(3) Estimation of capacity factor of FSPV in Brunei

As shown in Table 2.3, Toyoake's climate conditions from May to September are similar to those of Brunei, so the actual values of Toyoake's capacity factor (shown in Table 2.4) are taken for the estimation for Brunei.

Table 2.4. Capacity Factor at Toyoake

	May	June	July	August	September
Capacity Factor (%)	21	21	19	18	15

Source: Authors.

Based on the above, the capacity factor of FSPV in Brunei was set at 19% by adopting the average value from May to September at Toyoake.

6.2. Capacity Factor of Ground-mounted Solar

Mordor Intelligence[1] has reported that Brunei has a large solar potential due to its geographical location, with over 90% of the country having a solar potential of 1,400–1.600 kWh/kWp/year.

From the figure of 1,400–1.600 kWh/kWp/year, a capacity factor of 16%–18% was derived for ground-mounted solar, and a capacity factor of 17% was set for ground-mounted solar.

[1] https://www.mordorintelligence.com/industry-reports/brunei-power-market