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Volts from the Blue—Is Combined Floating Solar and Hydro the Energy Solution for ASEAN?

Land-Scarce ASEAN Countries Are Perfectly Positioned to Benefit From Cost-Competitive Waterborne Solar Power Generation

Executive Summary

The COVID-19 outbreak has put significant pressure on utility companies around the world, often exposing operational weaknesses. The International Energy Agency (IEA) has found that lockdowns have driven down global power demand by 20.0%, with a similarly destabilizing effect seen in ASEAN countries. Countries such as the Philippines and Malaysia, which implemented strict quarantine and rigorous movement control, saw falls in power demand of up to 16.0%. Vietnam and Singapore, which took a softer approach, saw smaller falls. Indonesia's PLN power utility saw a 9.6% reduction in demand in its biggest Java-Bali grid.

Such large falls in power demand present balancing challenges to electricity grids and increase the overall cost of power for utilities that are burdened by baseload power and capacity payment contracts. In competitive markets, a reduction in overall demand would influence the dispatch of resources and the generation mix and could drive out obsolete generators.

Large falls in power demand present balancing challenges to electricity grids and increase the overall cost of power for utilities.

If the COVID-19 pandemic outbreak is to teach one lesson, it would be that utility companies need agile operating systems. Finding a good balance between supply and demand could not be more important than during a time of crisis, on top of finding the lowest cost of supply. Good system-level planning, based on well-understood system needs, is crucial for grid stability, reliability, and most important, resilience.

The ASEAN 10-member regional bloc—Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, Cambodia, Lao PDR, Myanmar, and Vietnam—will have power demand growing at among the world's fastest rates

over the next decade. Southeast Asia's energy requirements have grown by 60.0% over the last 15 years and are forecast to grow another two-thirds by 2040.[1]

The ASEAN countries are home to more than 8.0% of the world's population and produces over 6.0% of global GDP, but host less than 3.0% of global renewable energy installations.[2] Consequently high dependence on coal locks in obsolete technology, ensuring that pollution will remain an ongoing source of political tension, not to mention exacerbating climate change.

The ASEAN market potential of FPV is at least 24GW.[3] Most ASEAN countries are net importers of fossil fuels, exposing them to severe and escalating energy security risks with resulting economic consequences such as negative trade balances and supply risks. But ASEAN's energy outlook could be significantly improved by investing in renewables, specifically grid-level solutions such as hybridizing floating solar photovoltaics (FPVs) with existing hydro plants. Much of the cost advantage of hybridizing FPV with hydro comes from having minimal site costs and the opportunity to connect to existing grid, substation, and transmission infrastructure rather than starting from scratch.

IEEFA Philippines finds that the combination of FPV and hydro on existing dams is a cost-competitive way to meet incremental demand. FPV is cheaper than power plants fueled by imported coal, which is priced at USD 0.08 to USD 0.14 per kWh. In the absence of land acquisition costs, floating solar PV electricity can cost USD 0.04 per kWh and can be blended with an existing hydro plant or an energy storage unit.

Hybridizing FPV with hydro has minimal site costs and comes with a connection to existing grid infrastructure.

In the Philippines, FPV's market potential is 11GW from 5.0% of its water surface, which could power up to 7.2 million households.[4] Moreover, recently proven co-benefits of FPV include the ability to withstand powerful waves and gusty winds of up to 170 kilometres per hour**.** Despite FPV facing incremental insurance costs, its proven durability against typhoons makes FPV both a cost-competitive and resilience option for countries like the Philippines which sit on a typhoon belt with an average of 20 typhoons per year. [5]

IEEFA Indonesia finds that the combination of FPV and hydro on existing dams in Indonesia trumps the economics of adding new baseload coal-fired power plants on

[1] The ASEAN Post, ASEAN'S insatiable demand for energy. March 11, 2019.
[2] IEA: Southeast Asia Energy Outlook 2019.
[3] Estimate is based on per country estimates: Philippines (11GW), Indonesia (3.9GW), Thailand (8.5GW), Lao PDF (1GW). Malaysia, Singapore, Cambodia, and Vietnam do not have published market size data on FPV.
[4] Eco-business.com How the Philippines can lead in floating solar technology
[5] Reliefweb.int: First typhoon 2020 hits the Central Philippines.

grid systems such as the Java-Bali network that already have generation overcapacity.

The market potential of FPVs on existing dams and reservoirs in Indonesia reaches at least 3.9GW. Some of these bodies of water already have installed hydro capacity of 3.3GW. IEEFA calculates that in Java alone, there is a potential for 1.9GW of FPV alongside the existing 2.5GW of hydro capacity. When combined, the cost of power from these two methods of generation is USD 0.05/kWh compared to the USD 0.06/kWh for new coal fired power plants.

Co-locating FPVs with existing hydropower plants enables faster addition of generation capacity, potentially at a lower cost than coal-fired plants in some regions. The claim that coal-fired power is cheaper than renewables is now more questionable than ever in some ASEAN markets.

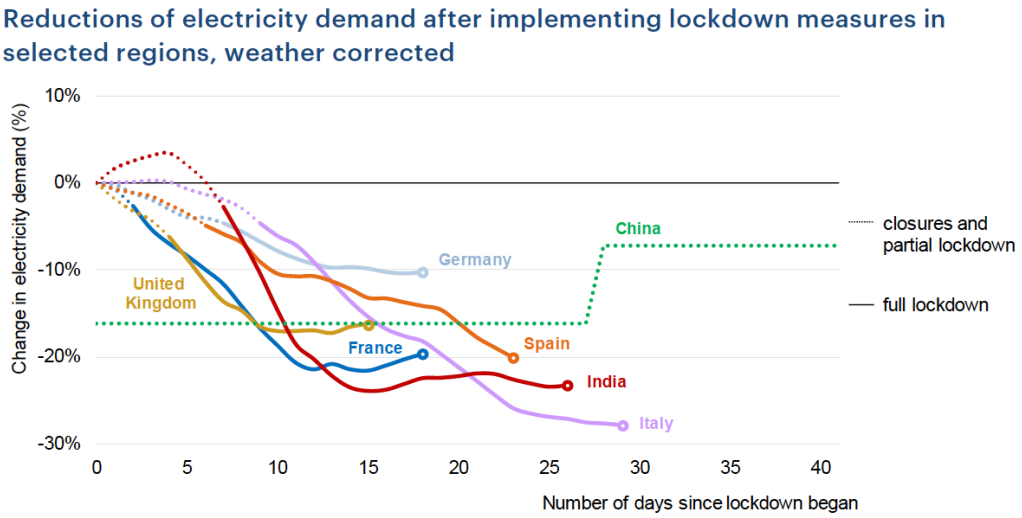
Introduction

In 2019, the International Energy Agency (IEA) estimated Southeast Asia's power demand would double to more than 2,000 terawatt-hours over the next 20 years.[6] This pace of growth is double that of other regions. However, lockdowns to prevent the spread of COVID-19 have driven down global power demand by 20.0% or more and have similarly affected Southeast Asia power demand.[7] Reduced commercial and industrial electricity demand far outweighed increases in residential consumption, especially in countries that implemented full lockdowns.

The ASEAN regional bloc—Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, Cambodia, Lao PDR, Myanmar, and Vietnam—was no exception to this global trend. Power consumption declined far faster in the Philippines and Malaysia, which quickly implemented strict lockdowns, than it did in countries with a more gradual approach such as Vietnam and Singapore.

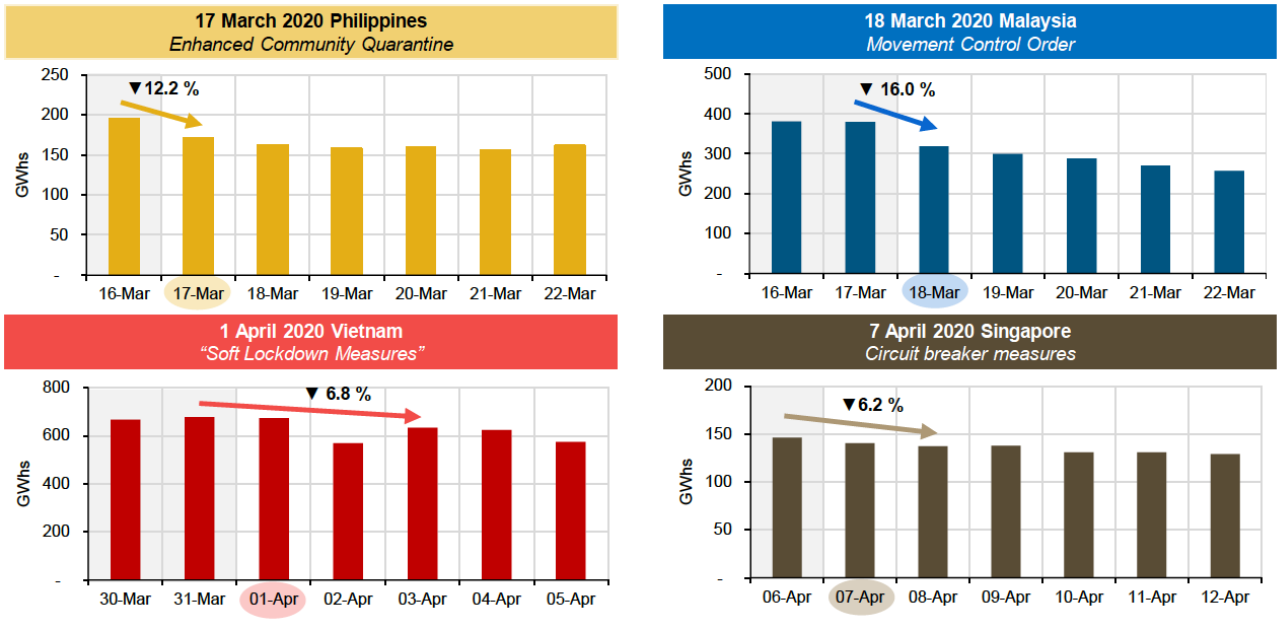
[6] IEA Southeast Asia energy outlook 2019. October 2019.
[7] IEA Global Energy Review 2020. April 2020.

Figure 1: Impact of Lockdown Measures on Electricity Demand



Source: IEA. Global Energy Review 2020. April 2020.

Figure 2: Impact of Movement Restrictions on Power Demand in Some Asian Markets



Source: COVID-19 Lockdowns and Power Demand. The Lantau Group. May 2020.

For the vertically integrated electricity sectors in countries such as Indonesia, Thailand and Vietnam, dramatic falls in demand create complex challenges. These range from finding the right power balance to managing an increase in the overall per unit cost of power. Because many utilities have capacity payments in their power purchase agreements (PPAs) with private generators, state operators have

no choice but to shut down their own older and less-efficient power plants. In Indonesia, these are mostly coal-fired power plants owned by PLN, the state electricity company.

In competitive power markets, such as the Philippines and Singapore, a reduction in overall demand would have an impact on the dispatch of resources and the generation mix, which could also sideline inefficient older generation plants. However, in the Philippines, end-users end up paying for such inflexibility. This is a good time for ASEAN countries to consider modular domestic renewable energy to meet incremental demand at the lowest price.

Floating solar photovoltaic (FPV) installations are an untapped opportunity for countries with large populations and competing land-use such as urbanization, energy production, and growing food. Unlike the harsh and often underpopulated plains of China and India, ASEAN countries typically have high population density and the geography of island archipelagos with little flat land.

The combined GDP of ASEAN members is USD 2.8 trillion, equivalent to United Kingdom. The combined population is 650 million, accounting for approximately 8.5% of the global population while occupying a land mass of around 2.74 million square kilometres (smaller than the land area of India).[8] ASEAN's average population density was 143 people per square kilometre in 2017 with steady growth. Refer to Table 1 and Table 2.

Table 1: Socio-Economic and Geographic Data of ASEAN Members

Country	GDP (2018) in US Millions	GDP Growth Rate (2020 Forecast)	Population (2018)	Population Density – Number of People per sq. km (2018)	Land Mass (2018) in sq. km	Inland Water (Major Rivers, Lakes and Reservoirs) Area in sq. km
Indonesia	1,042,173.30	5.2%	267,663,435	148	1,811,570	102,010
Malaysia	358,581.94	4.7%	31,528,585	96	328,550	2,250
The Philippines	330,910.34	6.2%	106,651,922	358	298,170	1,830
Singapore	364,156.66	1.4%	5,638,676	7,953	709	10
Thailand	504,992.76	3.2%	69,428,524	136	510,890	2,230
Brunei Darussalam	13,567.35	1.5%	428,962	81	5,270	500
Cambodia	24,542.47	6.8%	16,249,798	92	176,520	4,520
Lao PDR	17,953.79		7,061,507	31		6,000
Myanmar	71,214.80	6.8%	53,708,395	82	653,080	23,840
Vietnam	245,213.69	6.7%	95,540,395	308	310,070	21,160
Total	2,973,307.10	-	653,900,199	-	4,094,829	164,350

Source: GDP Data, Population Data, Land Mass Data: World Bank national accounts data, and OECD National Accounts data files; GDP Growth Data: Asian Development Bank. Asian Development Outlook 2019 Update.; Inland Water Data: World Atlas. 2017.; Population Density: World Bank Data.

[8] US-ASEAN Business Council: What is ASEAN?

Table 2: ASEAN Population Density, 2008–17

Rank	Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Singapore	6,846	7,025	7,146	7,273	7,379	7,500	7,598	7,689	7,789	7,796
2	Philippines	302	307	310	316	322	327	333	339	344	350
3	Vietnam	257	260	262	265	268	271	274	277	280	283
4	Indonesia	119	121	122	126	128	130	132	133	135	137
5	Thailand	130	130	128	129	130	130	131	131	131	132
6	Malaysia	83	85	86	88	89	91	93	94	95	97
7	Cambodia	76	78	79	80	81	81	82	84	85	87
8	Myanmar	86	87	88	89	89	76	77	78	78	79
9	Brunei Darussalam	65	70	67	68	69	70	71	72	72	73
10	Lao PDR	25	26	26	27	28	28	29	27	28	29
	ASEAN	127	129	130	133	135	136	138	140	141	143

Source: ASEAN Secretariat 2018.

The geography and demographics of ASEAN present a distinctive opportunity for FPV. As is often the case in the energy sector, resource availability and constraints pave the way for planning resource-efficient outcomes. ASEAN's land scarcity, and the lack of primary energy resources and associated infrastructure, have created a high barrier for some land-intensive renewable energy options while the alternative of imported fossil energy is expensive. As a result, FPVs are an opportunity for ASEAN countries to build additional power capacity. The bloc's market potential could reach up to 24GW of FPV.[9]

Some of the region's more mature companies have recognized this opportunity. Examples include:

- **Thailand** – The state-owned Electricity Generating Authority of Thailand (EGAT) has plans to install 2.7GW of FPV capacity via 16 solar farms on existing hydroelectric dams by 2037.[10] If all these projects materialize, FPV would account for 10.0% of the country's clean energy.[11]

- **Vietnam** – Last year, Vietnam commissioned its first FPV, the 47.5MW De Mi Project in south-central Vietnam.[12] Vietnam plans to hold tenders of up to 400MW of FPV[13] this year.

- **Indonesia** – PLN, Indonesia's state-owned utility company, signed a first-of-its-kind FPV deal with UAE's Masdar for a targeted 145MW at USD 0.058 per

[9] Estimate is based on per country estimates: Philippines (11GW), Indonesia (3.5GW), Thailand (8.5GW), Lao PDF (1GW). Malaysia, Singapore, Cambodia, and Vietnam do not have published market size data on FPV.
[10] IEEFA: Thailand plans 2.7GW of floating solar capacity.
[11] Renewable Energy World: Thailand Planning Massive Floating Solar Power Plants.
[12] Mongabay: Floating solar power along the dammed-up Mekong River.
[13] pv-tech: Vietnam targets floating solar projects with pilot renewable tender.

kWh,[14] the cheapest solar energy supplied in Indonesia to date.

- **Singapore** – Sembcorp signed a 25-year PPA for 60MW floating in May. The generated power will be used to meet the energy needs of Singapore's National Water Agency's five local waterworks, including Marina Barrage.[15]
- **Malaysia** – Chinese solar maker Risen Energy Co Ltd won a bid for Malaysia's 150MW floating PV park.[16]

Experience from the Philippines, which is frequently battered by typhoons, shows that FPV can withstand big waves and gusty winds. A system there survived more than 10 typhoons including Typhoon Mitag, the most powerful typhoon of 2019 with wind speeds reaching up to 170 kilometres per hour. The Philippines, conservatively, could operate 11GW of floating solar, assuming 5.0% coverage of water surfaces (lakes and reservoirs), and could power up to 7.2 million households,[17] more than 30 percent of total households.

As is often the case in the energy sector, resource availability and constraints pave the way for planning resource-efficient outcomes.

Installation options can vary depending on modular technologies, allowing for different configurations and layouts. For example, French developer Ciel & Terre International (C&T) has deployed FPV systems on irrigation ponds, mine lakes, water retention ponds, wastewater treatment ponds, industrial reservoirs, and hydroelectric dams.

Sumitomo Mitsui Construction Co., Ltd. (SMCC), a large Japanese general construction company, has deployed FPV systems on lakes, reservoirs, industrial retaining ponds and flood control reservoirs. Huainan Sungrow Floating Module Scientific and Technical Co., Ltd (Sungrow Floating), has deployed FPV systems in lakes, agricultural ponds, and water-treatment reservoirs.

While floating solar systems are more expensive to install, the greater efficiency might offset the higher cost. The World Bank notes FPV systems are 18.0% more expensive than land-based PV because they need floats, moorings, and more resilient electrical components, although FPV insurance costs just 0.1 percent more than land-based PV. However, FPV systems are expected to improve the performance ratio by 5.0% compared to land-based systems.[18] By placing solar

[14] Jakarta Post: UAE's Masdar to support development of Indonesia's largest solar power plant.
[15] Renew Economy: Massive 60MW floating solar plant secures 25-year PPA in Singapore.
[16] Renewables Now: Risen Energy to equip 150-MW Malaysian floating PV park.
[17] Eco-business.com: How the Philippines can lead in floating solar technology in Asia.
[18] World Bank Group, ESMAP and SERIES, 2019: Where Sun Meets Water: Floating Solar Market Report. Washington, DC: World Bank.

panels on water, the cooling effect helps to reduce thermal losses—potentially increasing the efficiency of the panels by an estimated 10.0%[19] or 11.0%.[20]

Moreover, for much of ASEAN, land-use competition is driving up the price of land and consequently the cost of land-based projects. A 100MW solar PV installation requires 250 acres or 100 hectares, equivalent to 1 sq. km. For example, in the Philippines land conversion can take up to three years because land must not have had any economic purpose for three years to be considered idle, which then allows it to be converted. Though securing water rights may be a concern for FPV developers, hybridizing with existing hydro plants could potentially expedite the permitting process.

The advantages of FPV21 over land-based solar PV include:

- Co-locating with existing hydro sites can double power output while reducing variability and utilizing existing transmission infrastructure
- PV and hydro together can act as firm capacity and thus are beneficial for areas where grids are too weak to absorb variable renewable energy (VRE) in isolation
- FPV can reduce evaporation from water reservoirs through shading
- FPV can also improve water quality in reservoirs
- FPV benefits from lower capital expenditure compared to conventional PV due to reduced site preparation requirements and low anchoring or mooring requirements
- FPV can be installed and deployed much more quickly because it is modular, an added benefit to countries with power capacity shortages
- FPV are more resilient to typhoons and high winds than land-based solar PV

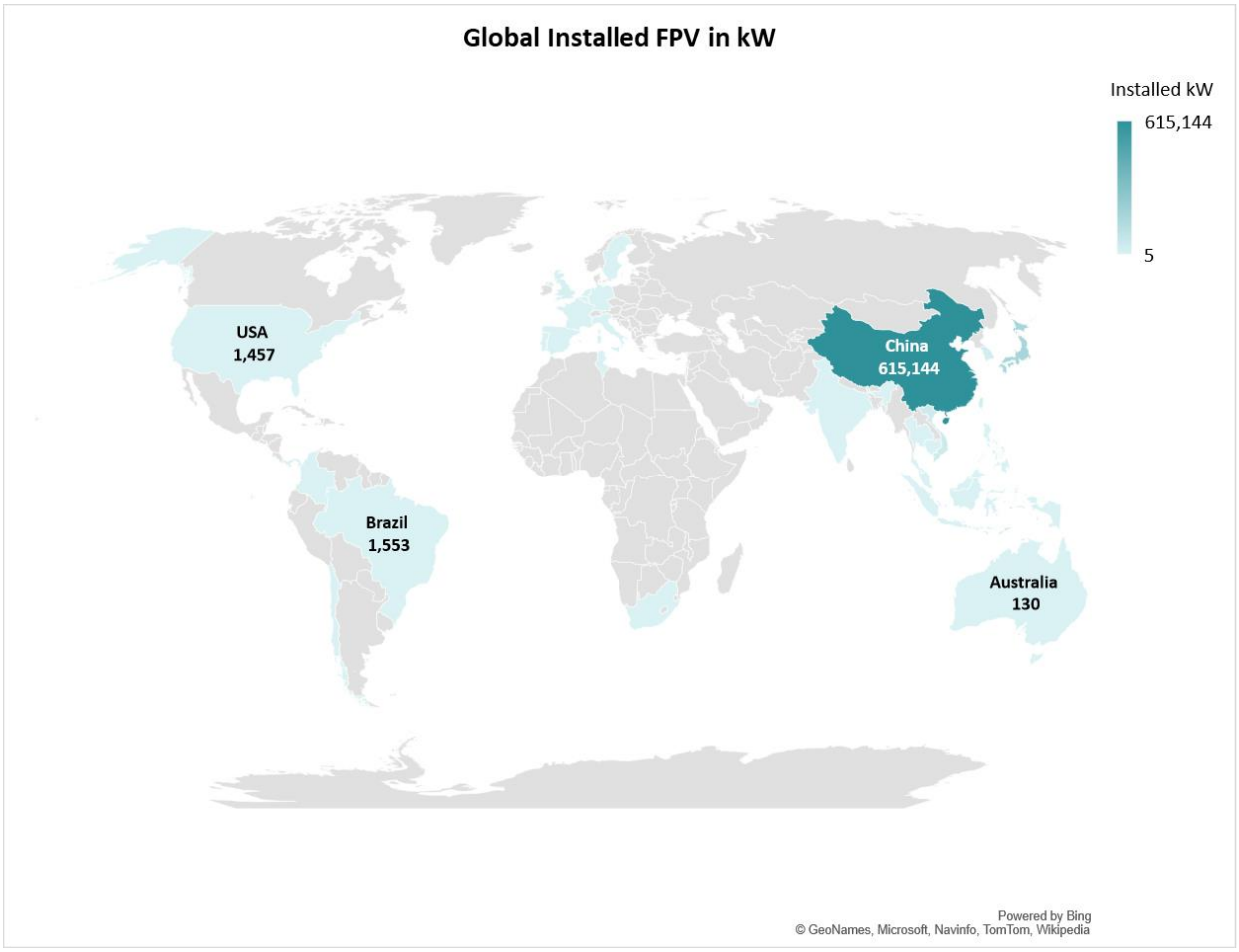
Floating Solar on the Rise in ASEAN

Asia leads Europe in deploying FPV. The first FPV system was built in 2007 in Aichi, Japan,[22] while China is the largest FPV player. At the end of 2018, both Japan and China had a combined FPV installed capacity of 1.3GW.[23] Most recently, India's largest power generation firm, National Thermal Power Corporation (NTPC),

[19] Renewable Energy World: Thailand planning massive floating solar power plants on hydropower dam reservoirs.
[20] Choi, Y.K. A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact. Int. J. Softw. Eng. Appl. 2014, 8, 75–84.
[21] World Bank Group, ESMAP and SERIS. 2019. Where Sun Meets Water: Floating Solar Market Report. Washington, DC: World Bank.
[22] World Bank Group, ESMAP and SERIS. 2019. Where Sun Meets Water: Floating Solar Market Report. Washington, DC: World Bank.
[23] pv tech: World Bank, SERIS take aim at floating PV hurdles with standardisation push.

confirmed it has 200MW of FPV under development across four sites, making it one of the largest developers in the world.[24] India is a country to watch for the rest of ASEAN as it continues to remove roadblocks and ensure policy stability to accelerate renewable energy, with renewable energy being two-thirds the cost of domestic coal.

Figure 3: Global Installed Floating PVs

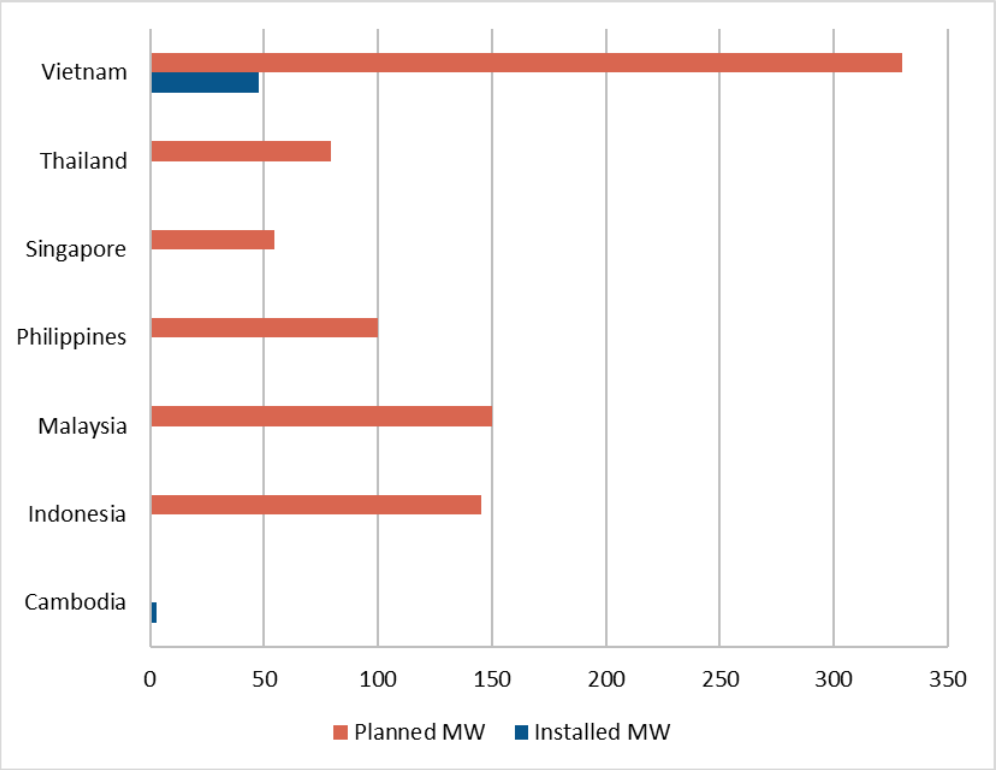


Source: IEEFA database.

Meanwhile, up to 2019, total installed capacity of FPVs among ASEAN countries was considered rather insignificant, mostly below 1MW, with the exception of Vietnam, which managed to install 47MW of FPV. This changed drastically in 2019 when at least five countries announced large-scale floating solar plans.

[24] Business Standard: ONGC, NTPC in pact to form JV for renewable energy biz.

Figure 4: ASEAN Countries FPV Installed vs Planned in MW



Source: IEEFA database.

The following is an FPV timeline for some ASEAN countries:

- February 2019: Singapore's Cleantech Solar announced the completion of a 9.8MW solar installation that includes a mix of rooftop solar and 2.8MW of FPV on a water reservoir to power Cambodian cement manufacturer Chip Mong Insee Cement Corporation (CMIC).[25]

- June 2019: Thailand's EGAT issued an invitation for 55.5MW of FPV on the Sirindhorn Dam, co-located with the existing 12MW Sirindhorn Hydropower Plant.[26]

- June 2019: Thailand's EGAT is also planning for a second FPV with a capacity of 24MW on the Ubol Ratana Dam.[27]

- July 2019: Singapore has been testing FPV since 2017 which led to the Singapore water authority, Public Utilities Board (PUB), interest to procure 50MW of FPV on the Tengeh Reservoir, with targeted operational date of 2021.[28] The generated electricity will power water treatment processes.[29]

[25] pv-magazine.com: Floating-solar-reaches-new-territories/.
[26] Pv-magazine.com: Thai-utility-EGAT launches-tender-for-58-5-mw-floating-project.
[27] pv-tech: EGAT readies tender for 45MW floating solar at Sirindhorn dam.
[28] pv-magazine.com: Singapore preps-SE Asia's largest public floating-solar tender.
[29] Straits Times: Floating solar panel systems to be ready at 2 reservoirs next year.

PUB is also in the process of implementing two smaller 1.5MW FPV systems on the Bedok and Lower Seletar reservoirs.[30]

- August 2019: Malaysia's Pestech, an electrical power technology company, has entered a partnership with China's inverter maker Sungrow to jointly develop FPV solutions in the region.[31]
- October 2019: Vietnam's Da Nhim–Ham Thuan–Da Mi (DHD), a subsidiary of national utility EVN, which owns and operates for hydro plants, managed to commission a 47.5MW of FPV[32], with a targeted increase of 330MW more[33], in an area where 1MW alone may be able to light 165 homes.[34]
- October 2019: Philippines' Meralco Powergen Corp, a subsidiary of the country's largest utility company in the Philippines, is looking to build 110MW of FPV in Laguna Lake.[35]
- October 2019: Chinese solar manufacturer Risen Energy Co. Ltd secured a contract to supply 150MW of PV modules to power a floating PV park[36].
- January 2020: In Thailand, a consortium comprised of Thailand's B Grimm Power Plc and Energy China was awarded a contract to build 45MW of FPV on the Sirindhorn Dam by EGAT. The deal was worth 842 million baht or USD 27 million, which translates to USD 600 per kW.[37]
- January 2020: Indonesia's state-owned PLN utility company, signed an FPV deal with UAE's Masdar for a targeted 145MW at USD 0.058 per kWh.[38]

Firm Renewable Energy: Hybridization with Existing Hydro Plants

Perhaps the most promising near-term opportunity for FPV in ASEAN will be in projects that co-locate with existing hydro sites that can increase power output while reducing variability and utilizing existing transmission infrastructure. In other words, this co-location can provide firm renewable energy to be dispatched as needed by the grid operator. According to the World Bank, "combining the dispatch of solar and hydropower could be used to smooth the variability of the solar output, while making better use of existing transmission assets, and this could be

[30] Renew Economy: Singapore plans huge 50MW floating solar project.
[31] pv-magazine: New alliance to expand floating PV in Southeast Asia.
[32] pv-tech: ADB finances Vietnam's first large-scale floating solar plant.
[33] ADB: Inside-Southeast-Asia's-first-large-scale-floating-solar-project.
[34] Renew Economy: Singapore plans huge 50MW floating solar project.
[35] Bworldonline.com: MGen eyes floating solar installation in Laguna Lake.
[36] Renewables Now: Risen Energy to equip 150-MW Malaysian floating PV park.
[37] Asia News Network: Thai-China consortium to build world's largest hydro-floating solar project for Thai electricity agency.
[38] Jakarta Post: UAE's Masdar to support development of Indonesia's largest solar power plant.

particularly beneficial in countries where grids are weak."[39]

Solar PV costs have fallen more than 80.0% since 2009 while the cost of electricity has fallen by almost 75.0% over 2010-2017 and continues to decline. At the same time, ASEAN solar capacity grew to 4.21GW in 2007-2017.[40]

Regional differences in the availability of fuel and resources will influence renewable energy prices and the relative attractiveness of FPV as a solution. Most ASEAN countries, excluding Indonesia, are net importers of fossil fuel. These countries would benefit from using domestic resources to reduce imports. Relying on imported fuels exposes the country to the price and foreign exchange volatility of global commodity markets. Table 3 shows coal and natural gas consumption, production, and imports in the ASEAN bloc.

Table 3: Fossil Fuel Domestic Production and Import Data in ASEAN (2017)

Country	Total Primary Coal Consumption (MMt)	Total Primary Coal Production (MMt)	Total Primary Coal Imports (MMt)	Natural Gas Consumption (BCM)	Natural Gas Production (BCM)	Natural Gas Imports (BCM)
Brunei Darussalam	0	0	0	3.94[cia]	12.85 [bp]	0[cia]
Cambodia	1,880	0	2,444	0[cia]	0[cia]	0[cia]
Indonesia	99,966	461,252	4,353	38.55 [bp]	72.87 [bp]	0[cia]
Lao PDR	12,905	13,573	12	0[cia]	0[cia]	0[cia]
Malaysia	33,567	2,906	34,057	41.79 [bp]	74.46 [bp]	2.02 [bp]
Myanmar	445	737	191	4.50[cia]	17.80 [bp]	0[cia]
Philippines	29,321	11,932	22,268	3.77 [bp]	3.06[cia]	0[cia]
Singapore	732	0	1,357	12.29 [bp]	0[cia]	4.14 [bp]
Thailand	38,479	16,259	22,189	50.08 [bp]	38.72 [bp]	5.24 [bp]
Vietnam	54,666	38,237	14,022	9.52 [bp]	9.52 [bp]	0[cia]
Total	271,960	544,895	100,893	164.44	229.28	11.40

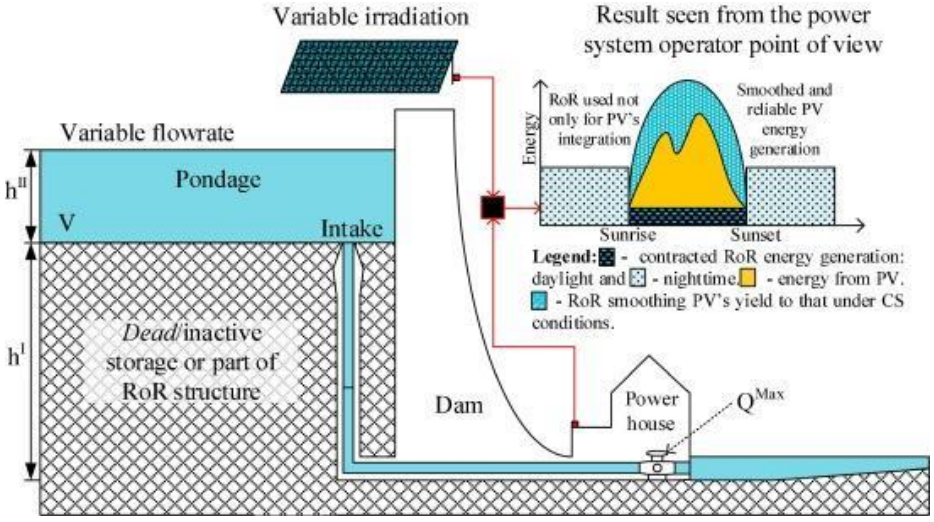
Note: 1 MMt (million metric tonne) = 1.1023 Mst (million short ton) BCM – billion cubic metres.
Sources: U.S. Energy Information Administration (Coal), BP and CIA World Factbook (LNG)

FPV's short development time is another plus. Thanks to the modular nature of FPV, it is possible to complete utility-scale installations in months where equivalent coal, hydro, and gas power could take more than three years and much longer for nuclear. FPV can help add positive system-balancing opportunities. For example, FPV can be used during the day while hydro can be used at night; blending of these technologies can reduce variability and translate into firm renewable energy that competes with baseload coal.

[39] World Bank Group: ESMAP and SERIS. 2019. Where Sun Meets Water: Floating Solar Market Report. Washington, DC.
[40] IRENA: Renewable Power Generation Costs in 2017, International Renewable Energy 2018.

Figure 5 illustrates the result of a hydro-floating solar hybrid from a system operator's point of view. The world's first hybrid solution (as illustrated in Figure 5) was in the Alto Rabagão dam in Portugal in 2017 by Ciel & Terre International (C&T) of France. It increased the plant's total capacity of 68 MWh by 220 kWp, (kilowatt peak) generating 332 megawatt hours, enough to power 100 homes for a year.[41] Another example is in the Sobradinho hydroelectric plant, located in the state of Bahia, Brazil. In 2019, 1MWp of solar designed by C&T was installed. C&T's partner, Companhia idrelétrica do São Francisco (CHESF) currently operates 12 hydroelectric plants with FPV potential of 52GWp if it used 10.0% of the surface of all reservoirs.[42]

Figure 5: Hydro-Floating Solar Hybrid Power Station as a Way to Smooth Power Output



Source: Jurasz, J., & Ciapała, B. Solar–hydro hybrid power station as a way to smooth power output and increase water retention. 2018.

Case Study #1: Floating Solar PV-Hydro Hybrid vs. Coal in the Philippines

With a growing focus on energy transition in emerging countries such as the Philippines, it is important that newer and more suitable renewable technologies are at the heart of system design processes. When considering options, it is not enough to focus on the economics of generation in isolation. Given the instability in the Luzon grid, it is vital that system-level solutions, using the levelized cost of electricity (LCOE) plus transmission line cost, are adopted.

FPV's ability to utilize existing grid infrastructure is a valuable advantage in areas where grids are too weak to absorb VRE in isolation. It can also improve the overall

[41] Futurism.com: The world's first power plant combining hydro-electricity and solar energy is now open.
[42] Powermag: Solar-hydro-hybridization – Ciel & Terre floating PV plan on Sobradinho Hydro-electric dam.

output of the hydropower unit because some facilities can also use lithium-ion batteries to store FPV-generated energy.

Table 4 shows options for FPV placement in the Luzon grid. The output of a hybridized FPV can supply incremental demand for 10MW to 150MW systems. Over a 15-year period, at a utilization rate of 18.0% and an investment of USD 800 per MW, FPV can deliver a price of USD 0.04 per kWh; this can be blended with the existing hydro plant or an energy storage unit. FPV electricity can be three times cheaper than power from new import coal-fired plants, which range from USD 0.076 to USD 0.14 per kWh.

Table 4: Options for the Luzon Grid

	Magat Dam, Hydro + New FPV	Ambuklao Dam, Hydro + New FPV	Laguna de Bay, New FPV	La Mesa Dam, New FPV	Ipo Dam, New FPV	Binga Dam, Hydro + New FPV	Angat Dam, New FPV	Caliraya Dam, Hydro + New FPV
Technology Type	FPV and existing hydro	FPV and existing hydro	FPV	FPV	FPV	FPV	FPV	FPV and existing hydro
Water Surface Area	11.7 km^2	7.5 km^{2*}	911.7 km^2	27 km^2	70 km^2	936 km^2	568 km^2	10.5 km^{2*}
Existing Hydro	360MW	105MW	-	-	-	140MW	-	728MW
Existing Hydro Utilisation	31.2%	36.1%	-	-	-	35.1%	-	30.0% (estimate only)
Existing Hydro Output	985,000 MWh	332,000 MWh	-	-	-	430,000 MWh	-	1,913,184 MWh

Note: FPV assumption: 100 watt-peak per square meter; $800k/M.
Source: Laguna de Bay Development Authority, National Power Corporation, SN Power, IEEFA calculations.

Case Study #2: Floating Solar PV-Hydro Hybrid Trumps Coal-fired Plant for Java-Bali Grid

There are many excellent opportunities to install floating solar PV on existing dams/reservoirs in Indonesia. Because its economy is based on agriculture, Indonesia has built and maintained a considerable number of inland water bodies such as dams and reservoirs. Data from the Ministry of Public Works and Public Housing (PWPH) shows there are some 231 big dams, 3,489 weirs, and 4,311 reservoirs across Indonesia, with a few dozen still under construction.[43] Most of

[43] Ministry of Public Works and Public Housing: Water Resources Data Centre.

them are used for irrigation, and nearly half have installed hydropower generation capacity.

PLN and Indonesian government ministries have discussed the idea of FPV on existing dams for years. Land-scarcity and relatively close grid connections are primary considerations. For Java, having the highest population density of all Indonesia's islands, land scarcity is a big issue and land prices have skyrocketed over the last 10 years.

A 5 kilowatt-peak (kWp) FPV pilot project was successfully installed on a government-owned man-made lake in 2016.[44] On March 2020, the Ministry of Public Works issued an updated Ministerial Regulation (no 6/2020) that allows FPVs to be installed on dams and reservoirs in Indonesia. But to minimize any environmental impact, only 5.0% of the surface can be used for FPVs.

Three Reasons That Combined FPV–Hydro Makes Sense for Indonesia

Potential: Following the new regulation capping water surface coverage at 5.0% for FPVs on dams, IEEFA compiled a list of existing big dams and reservoirs in Indonesia. From this list, we found potential of at least **3.8GW of FPVs** around Indonesia, and an existing 3.3GW of hydro installed on the same infrastructure.

Table 5: Potential FPVs in Indonesia on Existing Big Dams and Reservoirs

Island	Water Surface Area (hectare)	Floating Solar Potential (MW)	Existing Hydro (MW)
Java-Bali	46,054	2,303	1,867
Sumatra	6,253	313	753
Kalimantan	3,801	190	33
Sulawesi	18,829	941	237
West & East Nusa Tenggara	2,658	133	410
TOTAL	**77,595**	**3,880**	**3,299**

Source: Ministry of Public Works website, Water Resources Data Centre.

IEEFA notes that this is not a complete list of all the potential sites in Indonesia. In addition, the list does not include lakes and major rivers. This means **the total potential of FPVs could be much higher than 3.8GW**.

In addition, the Ministry of Public Works said in March 2020 there was potential for hydro on 46 of its existing dams and reservoirs. The Ministry of Energy and Mineral Resources has authorized the public works ministry to hold auctions to develop

[44] REC Group: REC's Floating Solar Installation Debuts in Indonesia Floating Solar Installation Debuts in Indonesia.

these potential hydro sites with a public private partnership scheme.[45] The more hydro capacity installed on existing dams, the more reliable it is for FPVs to be connected on the same grid. Developing hydro capacity on existing water bodies also presents far less environmental risk than building new hydropower from scratch.

Resilience: A combination of FPVs and hydropower could provide greater resilience to the system—especially during emergencies—compared with having many inflexible baseload coal-power plants**:**

In August 2019, Jakarta, Banten, West Java and some parts of Central Java province were hit by severe blackouts. Power was lost after a combination of faults resulting in cascading transmission lines trips that eventually caused power plants supplying electricity from the east to the west part of Java to disconnect. It took PLN, the state-owned utility, more than six hours to put the power back on. It was one of the longest blackouts for Java, Indonesia's most populous island, and probably also the most expensive for PLN.

The Java-Bali grid is a complex system, with more than 250 generation plants connected to 500 substations and a transmission system spread across 5000 kmc (circuit kilometres) of 500kV (kilovolt) and 7000 kmc of 150kV line.[46] The blackout showed clearly that the Java-Bali grid, despite being the most advanced interconnected system in the archipelago, was not resilient enough to reset quickly in an emergency.

FPVs and hydropower could provide greater resilience to the system—especially during emergencies—compared with multiple baseload coal-powered plants.

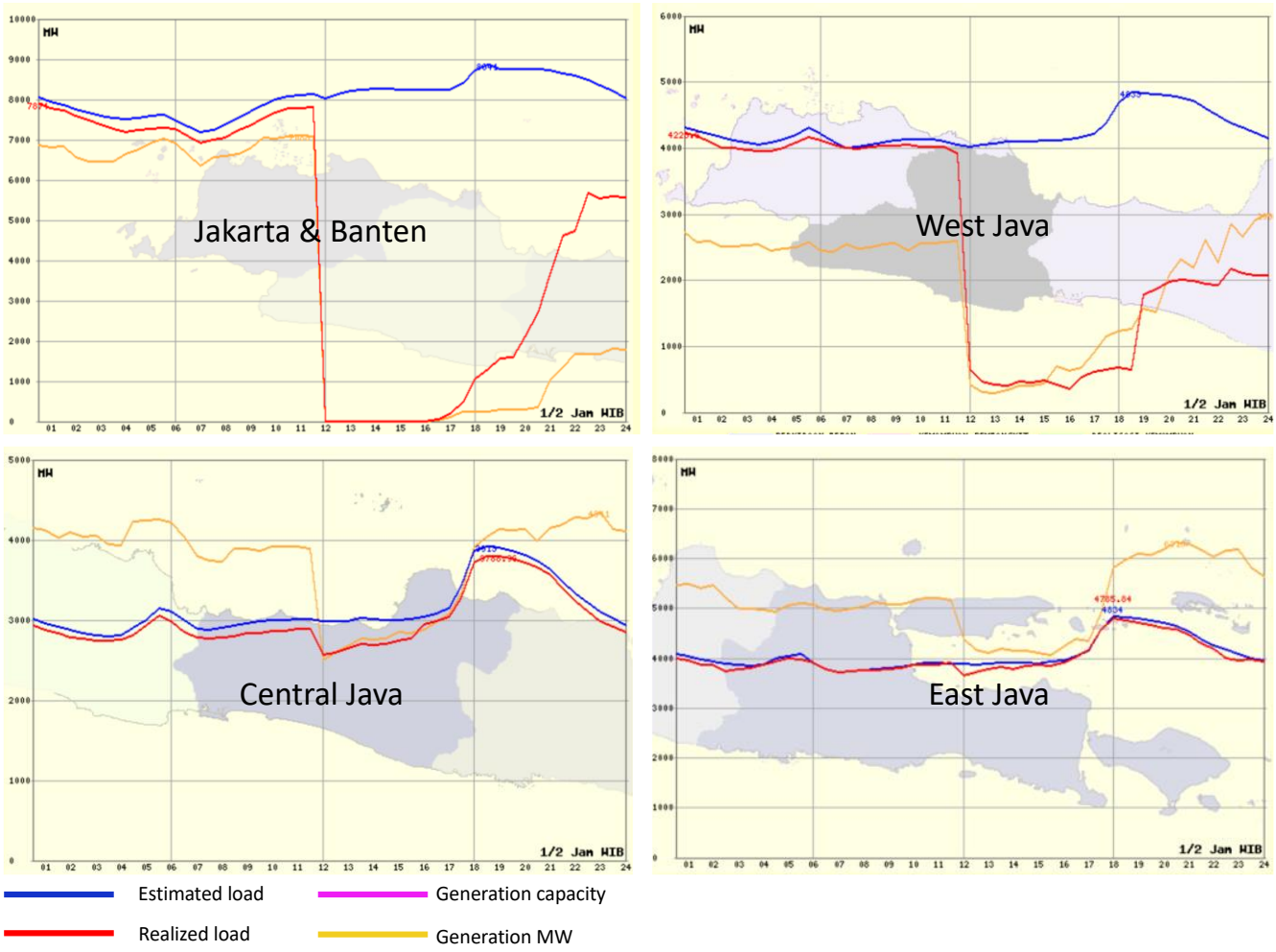
PLN had some difficulty restarting its generators after the system collapsed. Finding the right balance of supply and demand to achieve the necessary frequency in such a complex interconnected system was extremely difficult. It appears that there was not enough flexible generation capacity to begin a black start (often called a cold start) to reactivate the system.

The concentration of inflexible coal-fired power that dominates the Java-Bali system made matters worse, because of the time it took for major coal-burning plants to resume operation. Coal-fired plants need time to reach operational temperature before they can run at full baseload capacity.[47]

[45] Economi.bisnes.com: List of Potential Dams for Power Plants.
[45] Republika, PLN: Complex Java-Bali system.
[47] CNBC Indonesia: The Story Behind the Java-Bali Blackout in August 2019.

More flexible generation methods such as hydro and diesel would usually be used to restore system shutdowns. Lately however, utility companies globally have also started to rely on utility scale battery storage system for black start options.

Figure 6: Java-Bali System Condition – Blackout as at 4th August 2019



Source: PLN P2B.

The demand curve above clearly shows that when the circuit failed, its protection system immediately responded by separating the Central and East Java system from the West Java and Jakarta system. The two eastern provinces managed to avoid a complete shutdown, while Jakarta, Banten and West Java almost immediately lost all power.

The August 2019 blackout was made worse by the fact that there is more generation capacity in East and Central Java (shown by the yellow line) than in the western provinces. Jakarta, Banten and West Java in particular, had higher demand than supply in their area, creating a gap that was usually met by power transmitted from the eastern part of Java.

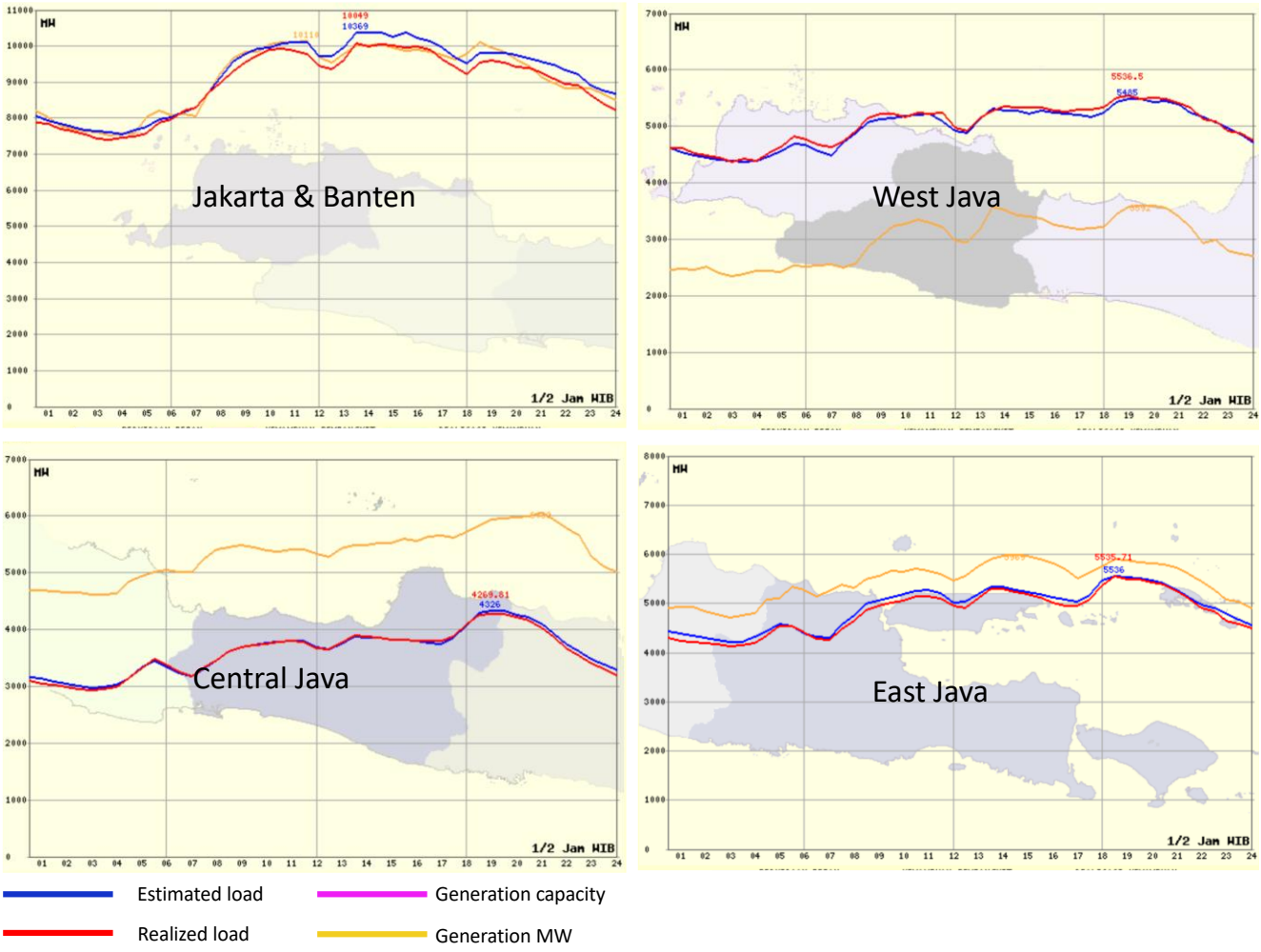
To be fair to PLN, the blackout did not have a single cause. Multiple factors led to the unfortunate failures of the 500kV line, including insufficient control of trees under the super high voltage cables. A series of mishaps during maintenance work caused a breakdown of system operations and coordination.

The supply-demand imbalance in the Java-Bali grid also made the emergency worse for the western provinces because they cannot operate independently as island grids.

The blackout offers a simple lesson for power operators and system designers: The importance of a strong island grid, even within an interconnected system, cannot be overestimated. Strong island grids with balanced power supply and demand ensure greater resilience for the whole system, especially during a wide-area outage.

Instead of adding more coal capacity, co-locating FPVs with existing hydropower could be a good option for a land-scarce island such as Java. In addition to providing more flexible power, it would augment the load profiles of Jakarta and West Java which show that on normal business days, power demand peaks at around 2 pm. Because Indonesia's most intense sunshine occurs from 10 am to 2 pm, the two modes of power generation would complement one another.

Figure 7: Java-Bali System Normal Condition – as at 4 February 2020



Source: PLN P2B.

Economics: Combined FPVs and existing hydropower would be more cost-effective than adding more inflexible coal-powered plants to the Java-Bali grid.

Even before the COVID-19 outbreak, the Java-Bali grid already had severe overcapacity and a high reserve margin of up to 30.0%. In the wake of the pandemic and its lockdowns, recession looms over the economy, threatening job losses and industry closures that translate to heavily curtailed demand for power.

PLN conceded recently that it expected electricity demand to fall 9.7% below its initial target for 2020. In response, PT PJB—a wholly owned PLN subsidiary—said it would use cheaper, lower quality, coal to fuel its power plants, changing its feedstock from 4,500kCal/kg coal to low-grade 4,000kCal/kg. PJB President Director Iwan Agung said the low-grade coal was acceptable because Java faced an

oversupply of electricity.[48]

What the President Director did not acknowledge, however, is the additional harm cheap coal causes the environment. Burning low-grade coal means increased emissions because more of it is needed to build up steam. Moreover, lower grade coal easily catches fire in storage, creating safety hazards.

Over the next two years, about 4,000MW of new coal-fired power will come online in the Java-Bali grid. An additional 4,000MW is also planned out to 2024.[49] These installations may well become wasteful and expensive baseload capacity in the system, particularly in the wake of the severe drop in demand caused by COVID-19. Combining FPVs and existing hydropower could add more resilience than coal because they are not burdened by fluctuating fuel prices and costly logistics.

Based on the list of big dams and reservoirs on Java island, IEEFA calculates that developing FPVs combined with existing hydropower on these water bodies could be more cost competitive than new thermal generation plants.

Assuming a 5.0% water surface area used for FPVs, there is a potential of 1.9GW of FPVs for Java island. Meanwhile, the installed hydropower on these water bodies amounts to 2.5GW. Even after taking a conservative capacity factor (CF) for each technology, and using the real PPA price of new coal and FPV capacity, plus an average PPA price for existing hydropower, IEEFA found that the combined price per kWh of FPVs and existing hydro could be as low as USD 0.05/kWh, against the current price of new coal-fired power averaged at USD 0.06/kWh.[50]

[48] Jakarta Post.: Energy, utility companies cut costs to survive slumping demand. May 2020.
[49] PLN RUPTL 2019.
[50] The capacity actor for a coal-burning power plant is based on average real CF of Suralaya, Suralaya-8, Lontar, Pelabuhan Ratu, Priok and Cilegon in 2017. Tariff for CFPP is based on the tariff for Cirebon 2 and Tanjung Jati-A CFPP, both at 5.5 US cents/kWh. CF for FPVs is using common conservative approach for solar power plants in Indonesia (range usually starts from 15-20%). CF for hydro takes on the lower end of hydro CF in Java island, based on PT PJB and PT Indonesia Power 2017 statistics. Price for FPVs mirrors the latest 145MW Cirata FPV PPA which is USD 5.8 cents/kWh, while the price for hydro is taken as an average of USD 4.5 cents/kWh. It is worth noting that the tariff at older hydro generators such as the Jatiluhur plant is much lower at 2.07 US cents/kWh.

Table 6: Combination of FPV + Existing Hydro on Dams and Reservoirs in Java Island

	Location	Water Surface Area (hectare)	Floating Solar Potential (MW)	Existing Hydro (MW)
Bendungan Saguling	West Java	4,869	243.5	715.2
Bendungan Cirata	West Java	6,200	310.0	1008.0
Bendungan Juanda (Jatiluhur)	West Java	7,780	389.0	187.5
Bendungan Cileunca	West Java	180	9.0	
Bendungan Jatigede	West Java	260	13.0	110.0
Bendungan Mrica	Central Java	1,250	62.5	184.5
Bendungan Garung	Central Java	67	3.4	26.4
Bendungan Sempor	Central Java	275	13.8	1.1
Bendungan Wadaslintang	Central Java	1,320	66.0	16.0
Bendungan Pejengkolan	Central Java	5	0.2	1.4
Bendungan Kedung Ombo	Central Java	4,500	225.0	22.5
Bendungan Wonogiri	Central Java	7,360	368.0	12.4
Bendungan Logung	Central Java	174	8.7	0.5
Bendungan Tlogo Ngebel	East Java	143	7.2	
Bendungan Pondok	East Java	380	19.0	2.3
Bendungan Soelorenjo	East Java	400	20.0	4.7
Bendungan Sengguruh	East Java	237	11.9	29.0
Bendungan Wlingi	East Java	4	0.2	54.0
Bendungan Sutami (Karangkates)	East Java	1,500	75.0	103.0
Bendungan Wonorejo	East Java	380	19.0	6.0
Bendungan Bening	East Java	570	28.5	0.7
Bendungan Tugu	East Java	25	1.3	0.4
Bendungan Tukul	East Java	45	2.2	0.6
Bendungan Karian	Banten	68	3.4	1.8
Bendungan Sindang Heula	Banten	129	6.5	0.4
Total			**1,900**	**2,488**
		Coal (4GW)	**FPV (1.9 GW)**	**Hydro (2.5GW)**
Capacity factor		70%	18%	40%
Output (MWh) per annum		24,528,000	2,995,205	8,717,847
Price USD cents per kWh *(taken from signed PPA)		5.5	5.8	4.5
Price paid by PLN per annum		134,904,000	17,372,189	39,380,618.66
Final price USD cents per kWh (combined FPV+hydro)		**5.5**		**4.8**

Source: Department of Public Works data on major dams in Indonesia, Water Resource Data Centre Indonesia, IEEFA calculation.

It is worth noting that Java has many weirs, smaller reservoirs and lakes not listed in the table above. In addition, there is also the long-awaited 1,040MW

pumped-storage hydro in Upper Cisokan that it is expected to be commissioned in 2020. This first pumped-storage hydropower plant in Indonesia will act as a valuable balance to stabilize the system.

Case Study #3: Floating Solar PV-Storage Hybrid in the Mekong River, Cambodia

The current price of electricity in Cambodia is one of the highest in the region ranging from USD 0.15 to USD 0.18 per kWh, after the Philippines which ranges from USD 0.18 to USD 0.20 per kWh in the main grid. The rural parts of Cambodia have prices between USD 0.50 to USD 1.00, similar to the small islands and isolated areas in the Philippines.[51] The Government of Cambodia has approved the construction of import coal-fired power plants in the Koh Kong and Oddar Meanchey provinces by 2025, with total capacity of 965 MW and a starting budget of USD 1.665 billion.[52]

Cambodia's 2030 energy plan includes two hydroelectric projects, Stung Treng with 980MW capacity and Sambor with 2,600MW capacity in the Mekong mainstream. However, these projects may be stopped by opposition from local communities that depend on the Mekong for their livelihood and opposition from the Government of Vietnam.[53] The Mekong Delta is Vietnam's most agriculturally productive region for rice, aquaculture and fruit. The hydro plants will not only jeopardise the millions of subsistence fishers that contribute 15.0% of Cambodia's GDP[54], the hydro barrage could also put at risk a river delta that produces enough food for 200 million people. A contraction in in agricultural output on this scale poses a fair degree of risk to global food security, according to Future Directions International.[55]

Instead of relying on options that unnecessarily expose Cambodian households and industry to volatile imported fuel prices, it would be wise for Phnom Penh to note Cambodia's most recent success in a solar park auction, which attracted 26 initial bidders including global investors and yielded a final bid of USD 0.04 per kWh.[56] A study by Viet Ecology Foundation found an FPV potential of 28GW that could be co-located with battery storage to firm up low-cost renewable energy.[57] Cambodia would only need to consider far less than half the FPV potential co-located with battery storage to replace the coal-fired and hydropower plants.

A less ambitious alternative was proposed by Cambodia's National Heritage Institute (NHI) for the Lower Se San 2 reservoir hydropower project. NHI found that leveraging the existing hydropower plants and reservoirs in Cambodia with floating

[51] pv magazine: How solar could save the Mekong, December 3, 2019.
[52] IEA Coal Center: Cambodia: National Assembly Approves Two Coal-fired Power Plants.
[53] pv magazine: How solar could save the Mekong, December 3, 2019.
[54] pv magazine: How solar could save the Mekong, December 3, 2019.
[55] Future Directions International, The Mekong Delta: Land Subsidence Threatens Vietnam's Food Basket, July 18, 2019.
[56] IEEFA, Paying Less for More - How Auctions Can Transform the Philippines Power Sector.
[57] pv magazine: How solar could save the Mekong, December 3, 2019.

solar could produce levelized costs of electricity (LCOE) of 7.5 US cents/kWh, without any subsidies or concessional financing.[58] That LCOE is comparable to the costs of building new dams on the Mekong mainstream, and still less than half what Cambodian customers currently pay.[59]

To start, the Government of Cambodia could run an auction for FPV (with storage), following a similar process to their previously successful solar park auction. Being a close ally of China, the Cambodian government should not find it difficult to achieve concessional financing from China for this type of project. Especially considering Chinese solar panel manufacturers are now fighting a tough market to sell their products at scale to the United States, after the heated debate on trade sanctions and the higher tariff imposed by the US government.

Conclusion: A Market Opportunity to Fast-Track Grid-Level Solutions

For Southeast Asian countries such as Thailand, Vietnam, and Indonesia the decision to install FPVs would be based primarily on the economics of existing grid infrastructure and the issue of land scarcity. Focusing on the economics of generation assets in isolation does not make sense because of the need to invest in transmission lines. A grid-level solution, considering the cost of generation plus transmission requirements, is key. It is possible to get competitively priced generation through technology-specific auctions of power, and Southeast Asia stands to benefit.

[58] Cambodia NHI: Sustainable Hydropower Development Alternatives for the Mekong.
[59] Mongabay: Floating solar power along the dammed-up Mekong River.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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