Advanced Energy Partnership for Asia

ENABLING FLOATING SOLAR PHOTOVOLTAIC (FPV) DEPLOYMENT

FPV Technical Potential Assessment for Southeast Asia

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List of Acronyms

ASEAN	Association of Southeast Asian Nations
EIA	United States Energy Information Administration
FPV	floating solar photovoltaic
GW	gigawatt
GWh	gigawatt-hour
GRanD	Global Reservoir and Dam Database
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
MW	megawatt
NREL	National Renewable Energy Laboratory
PV	photovoltaic
RDMA	Regional Development Mission for Asia
RE	renewable energy
SAM	System Advisor Model
SE Asia	Southeast Asia
SERIS	Solar Energy Research Institute of Singapore
TWh	terawatt-hour
USAID	United States Agency for International Development

Executive Summary

Southeast Asia (SE Asia) is a region with growing energy demand and increasing development of floating solar photovoltaic (FPV) systems, which can help meet countries' renewable energy (RE) and energy security goals. The Association of Southeast Asian Nations (ASEAN) has set a regional target of 35% RE in installed power capacity by 2025 (ASEAN 2022), and FPV is an increasingly popular option to help meet this objective. For instance, FPV development can avoid some of the challenges faced by ground-mount PV such as competing land use, and can take advantage of the significant existing and planned hydropower capacity in the region via co-location and hybridization.

This study uses a high-level geospatial assessment methodology to estimate the technical potential for monofacial and bifacial FPV on reservoirs and natural waterbodies in the 10 countries within ASEAN. Technical potential consists of the suitable waterbody area for FPV development (km^2), the capacity of FPV that could be installed on this suitable area (MW), and the annual energy that could be generated from these installations (GWh/year). This first-of-its-kind FPV technical potential assessment for SE Asia can help policymakers and planners better understand the role that FPV could play in meeting regional energy demand and could ultimately help inform investment decisions. High-level results for FPV technical potential in SE Asia, under a variety of assumptions, are visualized in Figure ES-1 for reservoirs and Figure ES-2 for natural waterbodies.

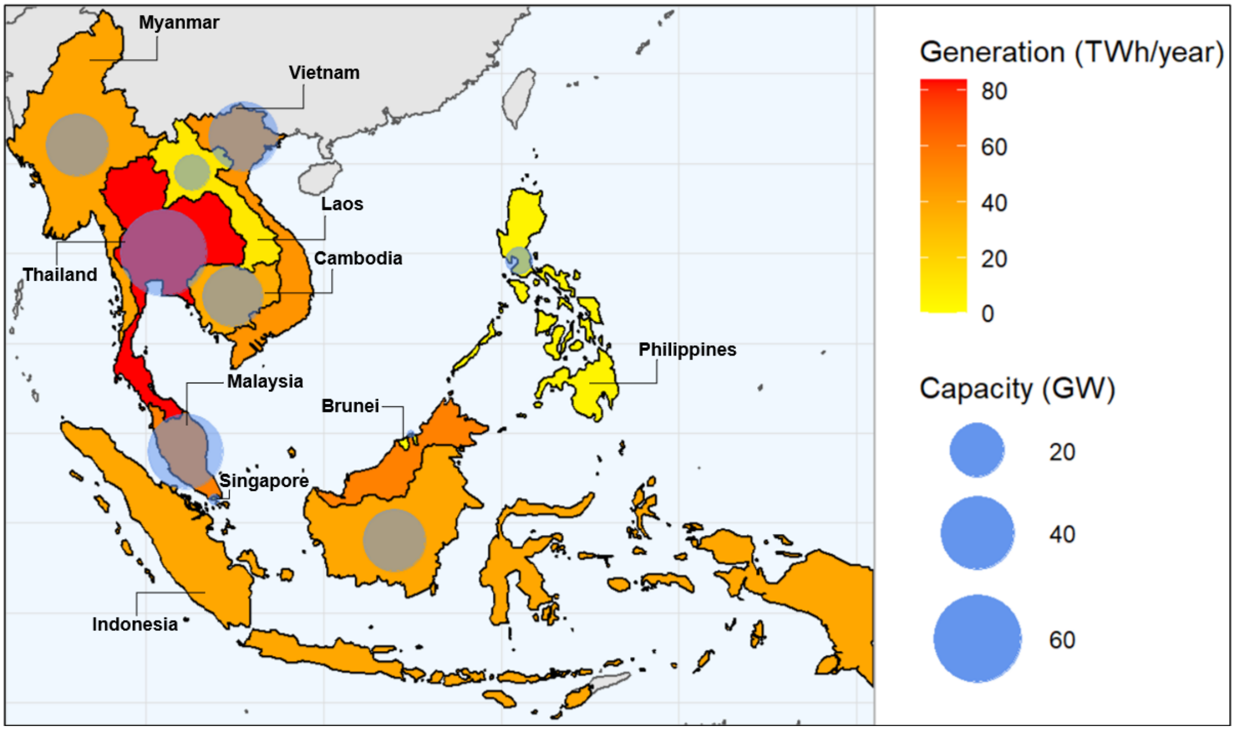

Figure ES-1. FPV generation and capacity technical potential for reservoirs in SE Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

A total of 7,301 waterbodies were included in the final dataset for SE Asia, which excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. Of this total, there were 88 reservoirs (including hydropower and non-hydropower) and 7,213 natural waterbodies. For the region, FPV technical potential ranges from 134–278 GW on reservoirs and 343–768 GW on natural waterbodies based on the methodology, assumptions, available data, and distance-from-shore sensitivities that are described in greater detail throughout the report. For monofacial FPV, average net capacity factors range from 15.6–16.0% and vary by country and waterbody type.

In our median sensitivity case (50 m minimum distance-from-shore and 1,000 m maximum distance-from-shore), this translates to roughly 825 GW of FPV potential across both waterbody types examined. Under current policies, the installed capacity of renewables in ASEAN countries is expected to reach 235 GW by 2030, with 81 GW of utility-scale solar, and 1,311 GW by 2050, with 841 GW of utility-scale solar (IRENA and ASEAN Centre for Energy 2022). Thus, FPV can play an important role in the region's renewable energy buildout.

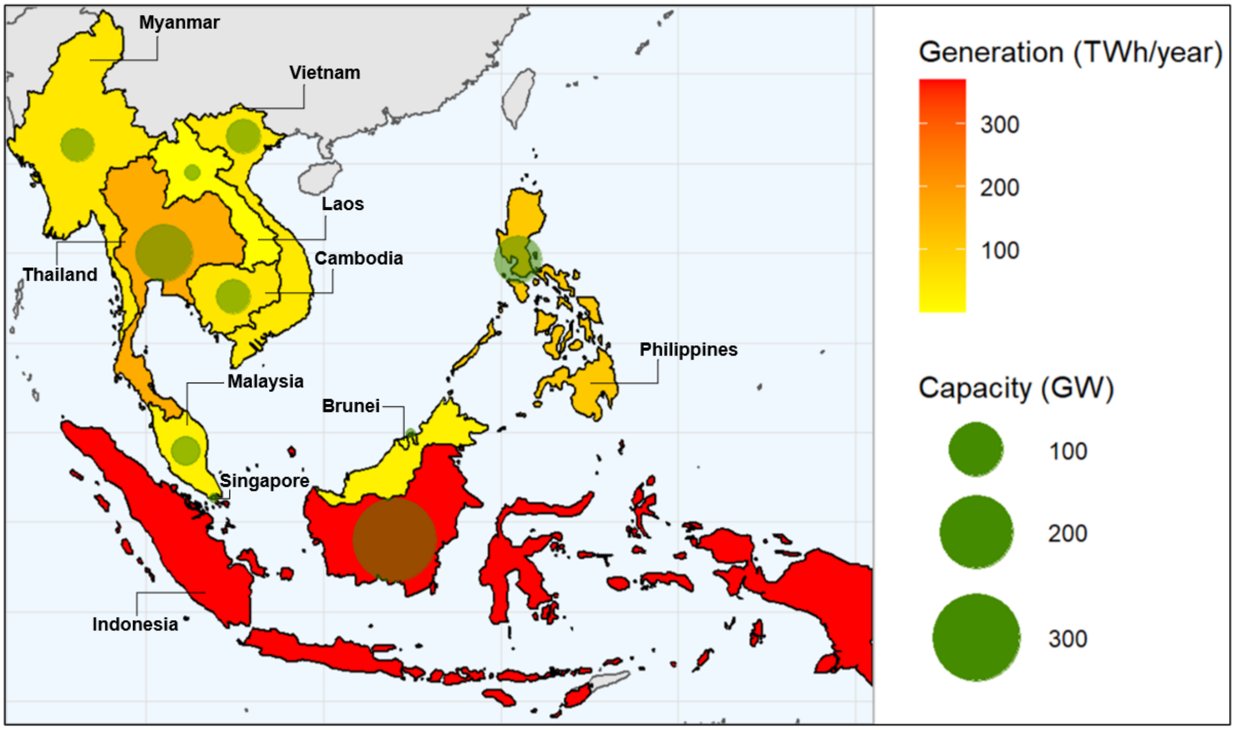

Figure ES-2. FPV generation and capacity technical potential for natural waterbodies in SE Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

Country-specific results for FPV technical potential are discussed in the report and differ in level of detail based on available data. For instance, transmission line data was only available for Cambodia, Laos, Myanmar, the Philippines, Thailand, and Vietnam. For these countries, a second set of results for technical potential was also generated by excluding waterbodies more than 25 km from a transmission line; although for sites with large FPV technical potential, a 25 km distance from the transmission line might not be a barrier to development. This transmission line filter does not significantly impact the technical potential results for reservoirs, and the impact for natural waterbodies varies by country.

Though this work focuses on SE Asia, the methodology for calculating FPV technical potential might also be applicable for countries in other regions, with adaptations. Due to data limitations, these results can be viewed as a conservative, upper-bound estimate of FPV technical potential in the region. Site-specific data on wind and waves, bathymetry, seasonal variation in water levels, and sedimentation were not available on a scale that would allow for consistent and reproduceable country- and region-wide geospatial analysis. Rather, this study is intended as a starting point for further analysis and to provide some data-driven insights to help clarify the potential role of FPV in meeting SE Asia's electricity demand, sustainability targets, and energy security objectives.

The primary intended audiences for this work include:

1. Decision makers within energy ministries and utilities considering the potential for FPV to support broader energy and development goals
2. Energy system modelers tasked with exploring and quantifying the potential value that FPV installations may provide within a specific energy system
3. Developers that might be interested in building FPV in the SE Asia region

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1 Introduction

Southeast Asia (SE Asia) is a region with growing energy demand and increasing development of floating solar photovoltaic (FPV) systems. FPV has emerged as a renewable energy (RE) option that can help meet countries' energy security and RE objectives, particularly for those with abundant solar and reservoir resources. The Association of Southeast Asian Nations (ASEAN) has a regional target to achieve a 35% share of RE in installed power capacity by 2025, and individual countries have set their own ambitious RE and decarbonization objectives (ASEAN 2022). FPV is an increasingly popular solution to help meet these goals, as it can avoid some of the challenges faced by ground-mount PV such as competing land use, and can take advantage of the significant existing and planned hydropower capacity in the region via co-location and hybridization.

This study uses a high-level geospatial assessment methodology to estimate the technical potential for FPV in the 10 countries within ASEAN, displayed in Figure 1. Technical potential refers to the achievable generation from a technology given various environmental, topographical, and land-use constraints. It provides an upper-bound estimate for a given RE resource and typically precedes more detailed economic and market potential analyses (Lopez et al. 2012). FPV technical potential assessments typically characterize the suitable waterbody area for FPV development (km^2), the capacity of FPV that could be installed on this suitable area (measured in megawatts (MW)), and the annual energy that could be generated from these installations (measured in gigawatt (GW) hours per year (GWh/year)). This first-of-its-kind upper-bound estimate of FPV technical potential for SE Asia can help policymakers, planners, and decision makers better understand the role that FPV could play in meeting regional energy demand.

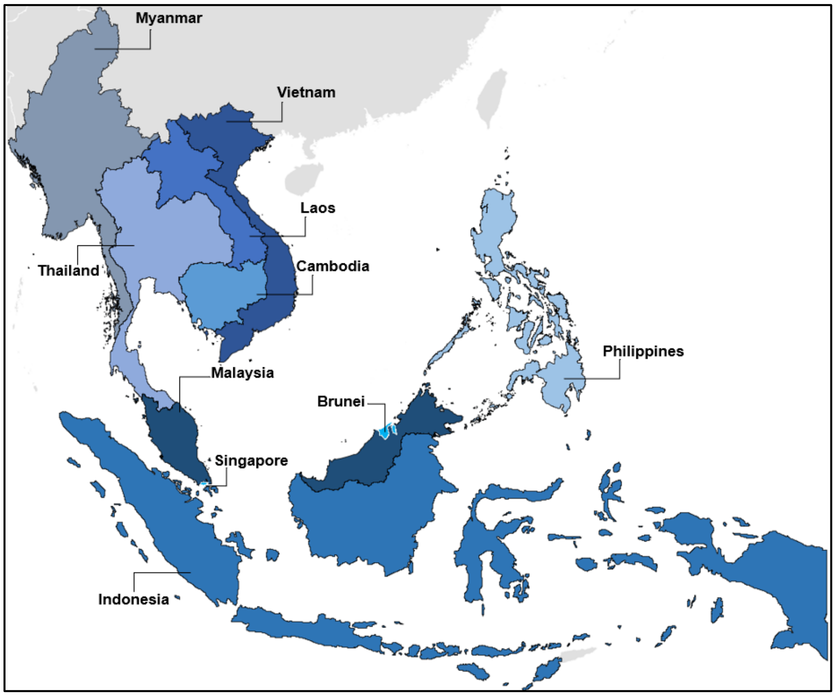

Figure 1. Countries included in the FPV technical potential assessment

This report begins with a brief background on FPV technology and overview of relevant prior research (Section 1.1 and Section 1.2). We then discuss the methodology and assumptions for the study (Section 2), as well as the findings for suitable waterbody area, capacity, and generation (Section 3). Finally, we conclude with a discussion of the different scenarios assessed and the relevance of these results for both the entire region and individual SE Asian countries (Section 4), along with considerations for next steps and future work (Section 5). Detailed country results are provided in the accompanying Appendix.

1.1 FPV Background

FPV systems are a growing application of solar photovoltaics (PV) in which the technology is sited on waterbodies such as lakes, reservoirs, and water treatment ponds (Acharya and Devraj 2019). The solar panels, which are the same as those used in ground-mount or rooftop installations, are mounted to floating structures and can be installed as stand-alone systems or systems hybridized with hydropower dams (Figure 2). More information on FPV can be found in the Floating Solar Handbook for Practitioners (World Bank Group, Energy Sector Management Assistance Program, and Solar Energy Research Institute of Singapore 2019). FPV can have numerous benefits such as reduced land-use, increased ease of installation, reduced water evaporation, and increased panel efficiency (Gadzanku et al. 2021a).

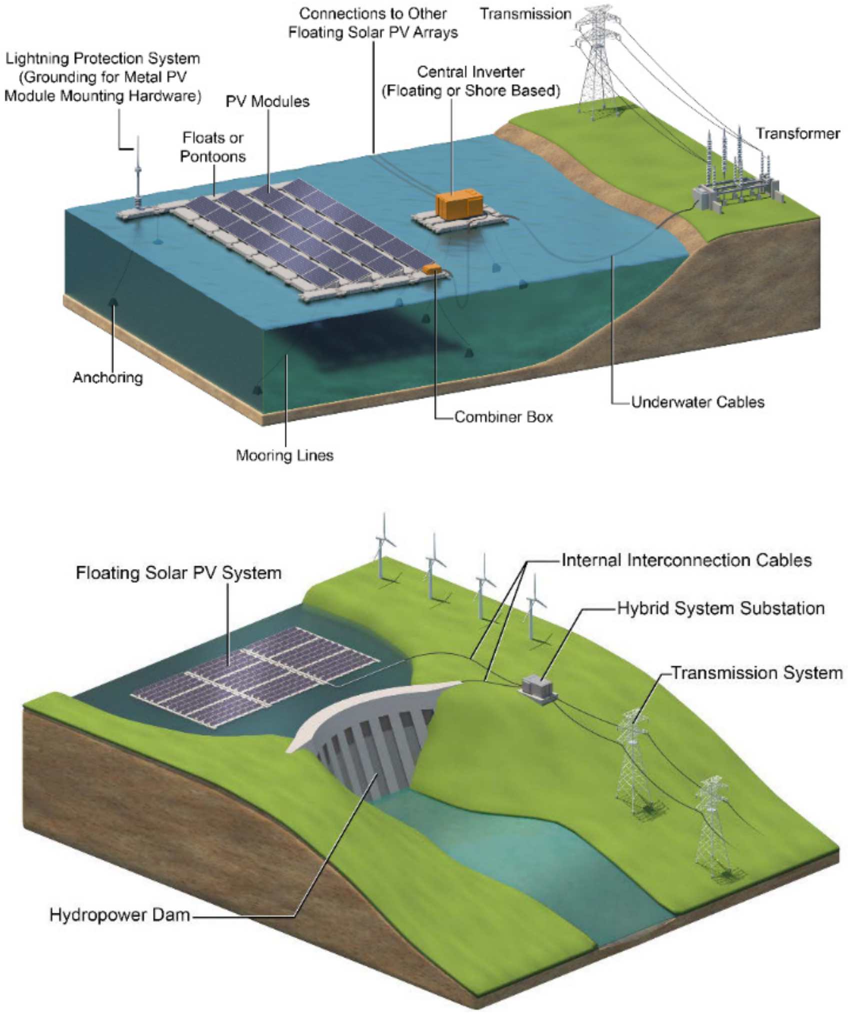

Figure 2. Representative schematics of stand-alone FPV (top) and hybrid FPV-hydropower (bottom) systems

Source: Lee et al. (2020)

1.2 Relevant Prior Research

Previous technical potential assessments for FPV have been conducted at a global scale (Lee et al. 2020; Jin et al. 2023), focused on specific countries or regions such as the United States (Spencer et al. 2019), Spain (Lopez et al. 2022), Brazil (Campos Lopes et al. 2022), the European Union (Kakoulaki et al. 2023) and Africa (Gonzalez Sanchez et al. 2021), or focused on specific sites (Agrawal et al. 2022; Popa et al. 2021). These technical potential assessments primarily focus on artificial waterbodies – mainly hydropower reservoirs, with some focus on non-hydropower reservoirs (e.g., other artificial waterbodies such as drinking water reservoirs or water treatment ponds). Hydropower reservoirs are promising sites for FPV development due to existing electric grid infrastructure and various operational benefits, such as lower PV curtailment when transmission is congested and more optimal use of limited water resources (Gadzanku et al. 2022). There has been a limited focus on FPV sited on natural waterbodies such as inland lakes, partly due to concerns about potential ecological impacts (Exley et al. 2022). Recently, there has also been more development of FPV sited offshore or near shore in saltwater (Vo et al. 2021).

The FPV technology in these prior assessments has been generally limited to fixed-tilt monofacial panels. However, there is growing research and interest into FPV systems that utilize bifacial panel and tracking technologies (Hasan and Dincer 2020; Widayat et al. 2020; Ziar et al. 2020), both of which have become increasingly common in the land-based solar PV industry. Bifacial panels can absorb sunlight from both sides, thereby increasing the power output of the PV installation. Tracking technologies, which can be 1-axis or 2-axis, allow the panels to adjust their tilt and orientation throughout the day in order to maximize solar irradiation exposure and consequently energy production.

Due to limited land availability, substantial pre-existing and planned hydropower development, abundant RE resources, and ambitious RE targets, SE Asian countries have significant interest in FPV. Several countries in the region, including Indonesia, Vietnam, and Thailand, are deploying both stand-alone and hybrid FPV systems. However, barriers to FPV deployment in the region remain. These include economic, environmental, cultural, regulatory, or technical barriers that potential adopters may face (Gadzanku et al. 2021b).

This study builds off previous research by conducting an FPV technical potential assessment for SE Asia and expanding the waterbody types considered by including non-hydropower reservoirs and inland natural waterbodies, in addition to hydropower reservoirs. This study also expands the FPV technology types considered by including bifacial PV panels in addition to monofacial panels. Finally, the study uses high temporal and spatial resolution solar irradiance data specifically developed for the SE Asia region that was not available for previous technical potential assessments (Figure 3). This study does not conduct an economic analysis of FPV, though FPV system cost estimates for select countries and the United States can be found in Chopra and Sagardoy (2021) and Ramasamy and Margolis (2021), respectively.

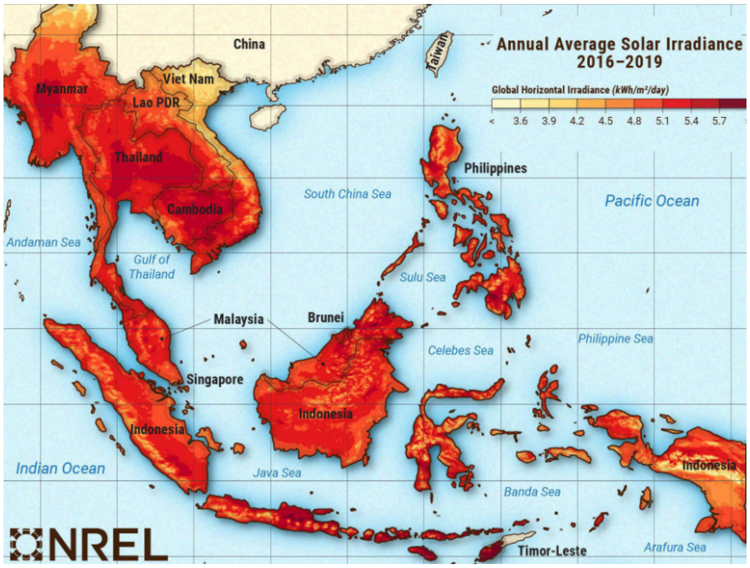

Figure 3. High-resolution solar resource data available for SE Asia

Source: Maclaurin et al. (2022)

2 Methods

2.1 Data Collection

This study required data on waterbodies, supporting infrastructure, and energy resources. We built off the data gap assessment conducted in Lee et al. (2020), narrowing the geographic scope to focus on SE Asia and expanding the waterbody scope to include non-hydropower reservoirs (e.g., reservoirs for agriculture, drinking water, recreation, or other purposes not related to electricity generation) and natural waterbodies (e.g., lakes), in addition to hydropower reservoirs (i.e., reservoirs used for electricity generation). We also used updated datasets where available. Table 1 summarizes the inputs and the data sources used.

Table 1. Data Availability for FPV Technical Potential Assessment in SE Asia

Input	Data Available?	Data Source(s) Used	Countries Covered	Data Provided
Waterbodies				
Hydropower reservoirs	Yes	Global Reservoir and Dam Database (GRanD)	ASEAN	Spatial location and extent of waterbody
Non-hydropower reservoirs	Yes	GranD	ASEAN	Spatial location and extent of waterbody
Natural waterbodies	Yes	HydroLAKES Database	ASEAN	Spatial location and extent of waterbody
Bathymetry	No	N/A	N/A	Waterbody depth, including seasonal variations
Sedimentation	No	N/A	N/A	Rate of sediment deposits to estimate site's FPV viability
Waves	No	N/A	N/A	Wave height and frequency to estimate impact on panels
Wind	No	N/A	N/A	Wind speed and direction to estimate wind loads on panels
Protected areas	Yes	RE Data Explorer	ASEAN	National parks, conservation areas, wildlife sanctuaries, etc.
Supporting Infrastructure				
Transmission lines	Yes	RE Data Explorer, Stimson Mekong Infrastructure Tracker	Cambodia, Laos, Myanmar, the Philippines, Thailand, Vietnam	Spatial locations of transmission network
Major roads	Yes	RE Data Explorer	ASEAN	Spatial locations of major roads
Energy Resource				
Solar resource	Yes	RE Data Explorer	ASEAN	Global horizontal irradiance, direct normal irradiance, etc.
Water resource	No	N/A	N/A	Historical annual variations in water resource across seasons

Data on protected areas, transmission lines, major roads, and solar resources are aggregated from various primary sources and can be downloaded from RE Data Explorer, a geospatial visualization and analysis tool developed by USAID and NREL. Additional transmission line data is sourced from the Mekong Infrastructure Tracker (Stimson Center 2020). Data on hydropower and non-hydropower reservoirs is from the Global Reservoir and Dam Database (GDW 2019), and data on natural waterbodies is from the HydroLAKES Database (Messager et al. 2016). The Global Reservoir and Dam Database (GranD) is considered to have reliable data on reservoir primary use, although the quality of attribute data on the type of reservoir can vary significantly across countries and the GranD dataset might not align completely with other sources of data on waterbodies such as the Mekong Infrastructure Tracker. However, we used this dataset to remain consistent with the methodology in Lee et al. (2020) and because it covers all the ASEAN countries.

Data not available include wind and wave information, bathymetry, seasonal variation in water levels, and sedimentation data for all waterbody types, along with transmission data for certain countries. The analysis did not consider reservoir attributes in detail, which can be a focus of future analysis. The solar resource data is based off satellite measurements and is available from 2015–2019, with a 10-minute temporal resolution and a 2 km x 2 km spatial resolution. Details on how this dataset was developed can be found in Maclaurin et al. (2022).

2.2 Scenario Development

Based on the available data (Table 1) and discussions with various stakeholders, we developed scenarios for the technical potential assessment using different combinations of waterbody types and FPV technologies. Two different waterbody types (reservoirs and natural inland waterbodies) are paired with two different FPV technology types (fixed tilt: monofacial and fixed tilt: bifacial) for a total of four technical potential scenarios. Reservoirs include both hydropower and non-hydropower reservoirs. A summary of the waterbody and FPV technology types included and excluded from the scenarios is displayed in Figure 4.

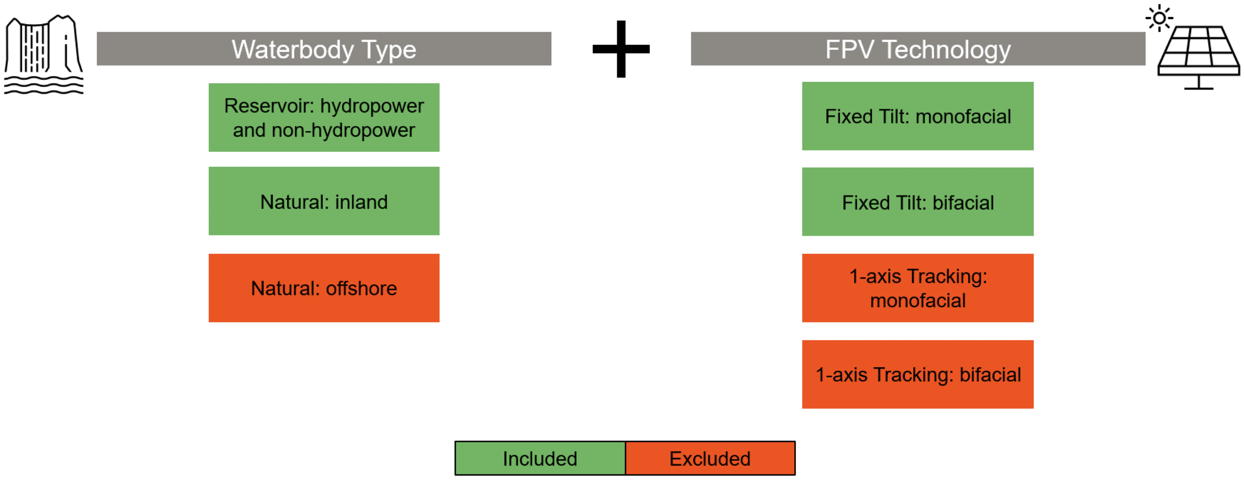

Figure 4. Waterbody and FPV technology types included in analysis scenarios

FPV installations, which typically use monofacial panels, are an emerging application for bifacial technology. If bifacial panels are used, the downward-facing panel can catch sunlight that is reflected off the surface of the water or the floating platform, which could potentially be amplified with installed reflective devices, thus increasing the electricity output of the FPV plant (Hasan and Dincer 2020; Widayat et al. 2020; Ziar et al. 2020). FPV developers usually seek to minimize the size and cost of the floating platform by increasing the power density of the installation. Using bifacial panels, along with packing the panels more tightly, could help accomplish this objective. Generally, the module prices for bifacial PV panels are higher than that of monofacial panels. For instance, an analysis by Clean Energy Associates estimates that a bifacial module's price could be approximately 3.3% higher than a monofacial module's price (Balyon 2021). Exact price differences depend on the PV panel manufacturer and the country. Further analysis is needed to assess the trade-offs between increased generation versus increased module price for bifacial PV compared to monofacial PV panels. Such a techno-economic analysis is beyond the scope of this report.

One-axis tracking FPV was excluded from the scenarios following discussions with stakeholders, who generally viewed this technology as less relevant for the SE Asia region based on geographic and cost considerations (i.e., one-axis tracking PV technology provides a smaller increase in energy production over fixed-tilt PV in regions closer to the equator compared to regions further from the equator, and this smaller increase in energy production might not be enough to offset the increased capital costs of tracking systems). Offshore FPV was excluded from the scenarios due to a lack of both sufficient data and an established methodology for assessing its technical potential. However, offshore FPV technical potential could be an area for future research given that it is an emerging technology with growing interest in the region.

2.3 Technical Potential Calculation

This section describes the methodology used for calculating FPV technical potential. The results from this assessment, for each of the scenarios described in Section 2.2, are presented in Section 3.

2.3.1 FPV Suitable Area

In the dataset, we exclude waterbodies in protected areas and make assumptions about the area developable for FPV based on distances from the shore and major roads, and in some cases, transmission lines. Though waterbodies in protected areas could sometimes differ from protected waterbodies, we did not have sufficient data to distinguish between the two and we thus treat them as equivalent in the interest of caution. For all waterbody types, we apply sensitivities for minimum (0, 50, and 100 m) and maximum (500, 1,000, and 2,000 m) distances from shore to estimate a range for the suitable area for FPV installation. The minimum distance-from-shore assumptions serve to remove waterbody areas that are potentially too shallow for FPV development, given the lack of inland bathymetry data, and the maximum distance-from-shore assumptions serve to limit potentially prohibitive costs for installation and operation (Lee et al. 2020). The distance-from-shore filters (e.g., 50 m minimum distance-from-shore) typically exclude a majority of very small waterbodies in the dataset. These filters also serve to prevent covering an entire waterbody with PV panels, as stakeholder input and knowledge on existing installations confirmed that this rarely occurs for real world projects, especially those located on large multi-purpose waterbodies.

For all waterbodies, we assume a maximum distance from major roads of 50 km as a proxy for site development limitations. Therefore, any waterbody that is further than 50 km from the nearest major road, as defined within the RE Data Explorer datasets, is excluded from the technical potential analysis because we estimate that the site development costs would be too high for a developer to undertake. The sources for data on major roads vary by country but are all consolidated and listed within RE Data Explorer's Data Library. This data does not capture smaller access roads that span over 50 km to connect to the closest major road, which might exist for certain reservoirs and potentially even natural waterbodies. Nonetheless, this filter serves as a simple way to estimate a threshold for site development costs in the absence of site-specific data, though sites with higher generation potential may warrant higher development costs.

Because transmission data was not available for all countries, as indicated in Table 1, we do not apply a maximum distance-from-transmission filter in the default results contained in this report to ensure a consistent basis of comparison. However, for the countries that do have transmission data publicly accessible (Cambodia, Laos, Myanmar, the Philippines, Thailand, and Vietnam), we discuss the implications of removing waterbodies that are greater than 25 km from the nearest transmission line on FPV technical potential in Section 4.2. The 25 km assumption is based off the methodology described in Lee et al. (2020). However, the FPV development prospects for sites with sufficiently large technical potential capacities might not be hindered by a 25 km distance from the nearest transmission line. The distance from transmission at which a site will be deemed developable or not will depend on the specific location, transmission development costs, and the developer; considering these factors fall under market and economic potential assessments, which are beyond the scope of this study. Altogether, these assumptions limit the suitable area for FPV development for each waterbody type examined, given the lack of site-specific data.

2.3.2 FPV Capacity and Generation

Within the suitable areas for FPV development, we calculate potential of both capacity (MW) and annual generation (GWh/year). The technical potential capacity is the product of an assumed power density of 100 MW/km^2 for both types of FPV technology and the suitable waterbody area (km^2) discussed in Section 2.3.1. The technical potential generation is the product of capacity and a modeled annual average solar energy resource capacity factor for either fixed-tilt monofacial or bifacial FPV. The capacity factors are modeled in NREL's System Advisor Model (SAM) and PVWatts Calculator using all years of the solar resource data described in Section 2.1 and assumptions for the FPV technology. More detailed information about SAM and PVWatts is in Blair et al. (2018) and Dobos (2014), respectively. Both capacity and generation estimates can help planners assess the role that FPV could play in their power systems.

FPV systems can generate more energy compared to similar land-based systems because the ambient air temperature over waterbodies is typically lower than the ambient air temperature over land or rooftops for a variety of reasons, and PV panels generally produce more power at lower operating temperatures (Dörenkämper et al. 2021). Therefore, the energy generation estimates produced in the aforementioned calculation are increased by 3% in order to capture the cooling effect of water, based on the lower bound of the modeled results in Dörenkämper et al. (2021) and the conservative assumptions used in Ramasamy and Margolis (2021). The precise energy generation gains for a certain site due to the cooling effect of water depend on specific weather conditions and the floating platform design, among other factors.

A selection of the FPV technology assumptions used in SAM is shown in Table 2. The tilt of 11 degrees is from Spencer et al. (2019), and the power density of 100 MW/km^2 is from Lee et al. (2020). The monofacial FPV capacity factors are inflated by a factor of 1.05 (5%) to obtain the assumed capacity factors for a bifacial panel, based on the findings of Hasan and Dincer (2020), who modeled efficiency gains of between 2.8–11.9% for bifacial panels mounted on a platform covered with reflective aluminum sheets. This increase in capacity factor corresponds to an increase in expected energy generation.

Table 2. Select FPV Technology Assumptions

Assumption	Fixed Tilt: Monofacial and Bifacial
Azimuth (degrees)	180 for waterbodies north of the equator; 0 for waterbodies south of the equator
Tilt (degrees)	11
Power density (MW/km^2)	100

The power density of 100 MW/km^2 is higher than typical assumptions used for ground-mount PV because panels in FPV installations are usually packed more tightly compared to ground-mount installations, resulting in more power per surface area (Gadzanku et al. 2021a). In ground-mount PV installations, a typical ground cover ratio is 0.4, meaning that the PV panels take up 40% of the total PV development area from a "bird's eye" view. For FPV projects, where the developable area is a larger percentage of the overall cost due to the costs of installing the floating platforms and associated structural components, the panels are packed more tightly together. Thus, a higher ground cover ratio of 0.7 was used to reflect the higher packing density of panels in FPV projects. This results in a higher power density and a lower required area for a given installed capacity, but also a lower capacity due to higher self-shading from shadows cast onto neighboring panels. This is ameliorated somewhat in FPV development by the fact that lower fixed tilt angles are typically used compared to ground-mount PV in order to reduce the wind loading, and these lower fixed tilt angles also result in less self-shading. If bifacial panels are used in an FPV project, these lower fixed tilt angles could result in lower energy gains from bifacial panels because there is less available surface area on the panel's backside. Hence, the inflation factor of 1.05 described above is reasonable because this value is approximately equal to the lower quartile of the range found in Hasan and Dincer (2020).

3 Findings

The results in this section are aggregated for all countries in SE Asia. Detailed country-specific results can be found in the Appendix. The results presented do not account for site-specific constraints to FPV development or economic factors. Rather, the assumptions, scenarios, and sensitivities considered provide a conservative, upper-bound estimate for FPV technical potential in the region and in specific countries given the data available.

As discussed in Section 2, waterbodies located within protected areas and waterbodies located more than 50 km from the nearest major road are excluded from the technical potential assessment. These results do not reflect a filter for distance-from-transmission. As noted earlier, the implications of a distance-from-transmission filter (25 km) will be discussed in Section 4.2 for countries that have such data available.

A total of 7,301 waterbodies were included in the final dataset for SE Asia after the filters were applied, a breakdown of which is shown in Table 3. Of this total, there were 88 reservoirs (including hydropower and non-hydropower) and 7,213 natural waterbodies. Generation estimates are conservative and do not consider the potential upside of using higher efficiency panels. 677 waterbodies were removed from the dataset with the distance-from-road filter and 1,149 additional waterbodies were removed with the protected area filter.

Table 3. Breakdown of Waterbody Types Included in Final Dataset

Countries	Waterbody Type		
	Reservoir	Natural	All Waterbodies
Brunei	0	18	18
Cambodia	1	430	431
Indonesia	19	1,839	1,858
Laos	3	74	77
Malaysia	10	381	391
Myanmar	15	558	573
Philippines	3	1,157	1,160
Singapore	1	6	7
Thailand	14	1,850	1,864
Vietnam	22	900	922
All Countries	88	7,213	7,301

3.1 Summary of Regional Results

Table 4 displays the results for suitable area, capacity, and generation potential for FPV development by waterbody type and shore distance sensitivity (minimum and maximum distance-from-shore), aggregated for all countries in SE Asia. Our results show that the average net capacity factor, which accounts for inverter losses, does not change significantly between the waterbody types and various distance sensitivities for monofacial panels (the average net capacity factor varied from 15.6–16.0%). We also considered bifacial fixed tilt panels, and based on previous analysis, we assume that the average net capacity factor increases by a factor of 1.05 (i.e., increasing to 16.4–16.8%).

Table 4. Results for all SE Asian Countries

Waterbody Type	Sensitivities		Results		
			Fixed Tilt: Monofacial		
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Capacity (MW)	Generation (GWh/year)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	2,222	222,169	308,456
		1,000	2,784	278,352	386,999
		2,000	2,784	278,352	386,999
	50 (Median)	500	1,743	174,333	242,753
		1,000	2,292	229,194	319,526
		2,000	2,584	258,386	360,279
	100 (Far from Shore)	500	1,343	134,278	187,494
		1,000	1,879	187,850	262,536
		2,000	2,160	216,040	301,964
Natural Waterbodies	0 (Close to Shore)	500	6,547	654,719	910,827
		1,000	7,676	767,643	1,062,381
		2,000	7,676	767,643	1,062,381
	50 (Median)	500	4,831	483,136	671,729
		1,000	5,954	595,365	822,318
		2,000	7,007	700,724	960,197
	100 (Far from Shore)	500	3,427	342,697	475,860
		1,000	4,542	454,183	625,415
		2,000	5,592	559,219	762,848
All Suitable Waterbodies	0 (Close to Shore)	500	8,769	876,888	1,219,283
		1,000	10,460	1,045,995	1,449,379
		2,000	10,460	1,045,995	1,449,379
	50 (Median)	500	6,575	657,468	914,483
		1,000	8,246	824,559	1,141,844
		2,000	9,591	959,110	1,320,476
	100 (Far from Shore)	500	4,770	476,975	663,354
		1,000	6,420	642,033	887,951
		2,000	7,753	775,259	1,064,812

3.2 Summary of Country-Specific Results

Table 5 displays the results for suitable area, capacity, and generation potential for FPV development by waterbody type and country. These results reflect the median distance-from-shore sensitivity (50 m minimum shore distance and 1,000 m maximum shore distance) and are visualized in Figure 5 for reservoirs and Figure 6 for natural waterbodies. Again, the average net capacity factor is assumed to increase by a factor of 1.05 for bifacial FPV, translating to higher potential generation.

Table 5. Results for Individual SE Asian Countries

Waterbody Type	Countries	Results			
		Fixed Tilt: Monofacial			
		Suitable Waterbody Area (km^2)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	Brunei	0	0	0	N/A
	Cambodia	262	26,170	37,475	16.3%
	Indonesia	278	27,792	39,741	16.3%
	Laos	79	7,885	10,473	15.2%
	Malaysia	424	42,449	55,145	14.8%
	Myanmar	280	28,027	40,352	16.4%
	Philippines	37	3,736	5,134	15.7%
	Singapore	1	102	124	13.8%
	Thailand	576	57,645	83,781	16.6%
	Vietnam	354	35,386	47,300	15.3%
Natural Waterbodies	Brunei	3	340	459	15.4%
	Cambodia	351	35,081	51,113	16.6%
	Indonesia	2,719	271,897	369,059	15.5%
	Laos	37	3,745	5,341	16.3%
	Malaysia	216	21,560	28,017	14.8%
	Myanmar	338	33,800	49,492	16.7%
	Philippines	788	78,838	108,615	15.7%
	Singapore	3	287	351	14.0%
	Thailand	1,142	114,158	164,373	16.4%
	Vietnam	357	35,659	45,499	14.6%
All Suitable Waterbodies	Brunei	3	340	459	15.4%
	Cambodia	613	61,251	88,588	16.5%
	Indonesia	2,997	299,689	408,800	15.6%
	Laos	116	11,631	15,814	15.5%
	Malaysia	640	64,009	83,163	14.8%
	Myanmar	618	61,827	89,844	16.6%
	Philippines	826	82,575	113,749	15.7%
	Singapore	4	389	475	13.9%
	Thailand	1,718	171,803	248,154	16.5%
	Vietnam	710	71,045	92,799	14.9%

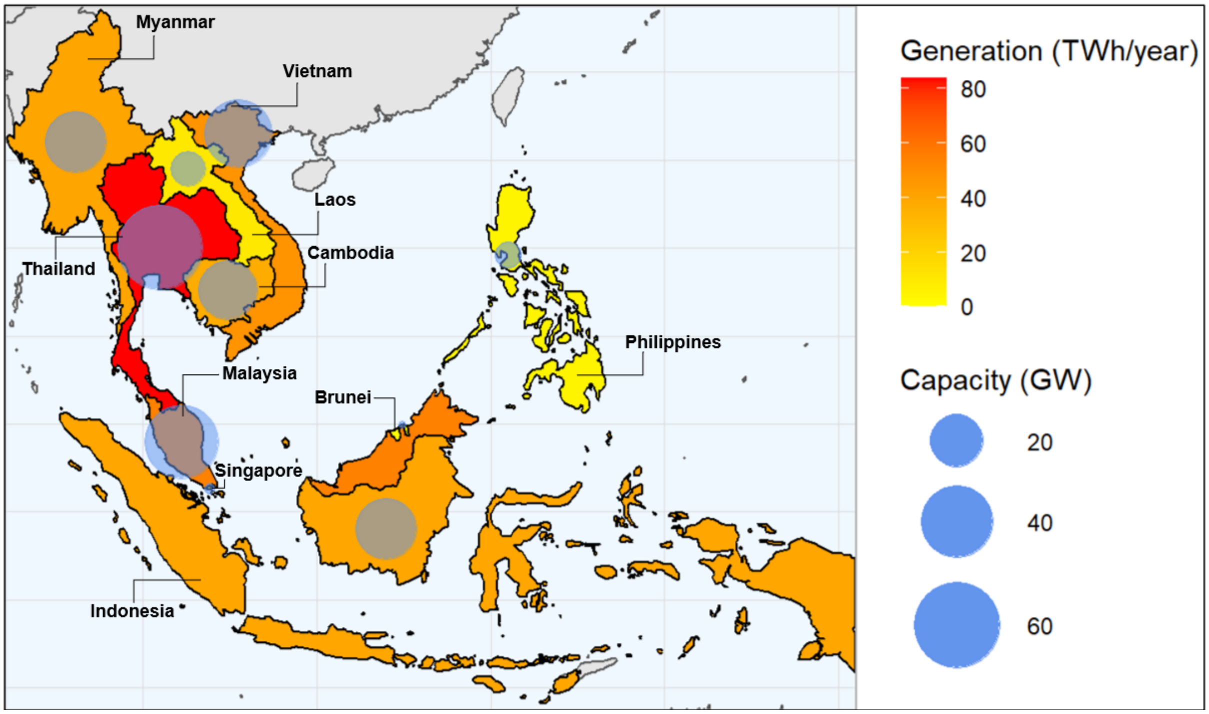

Figure 5. FPV generation and capacity technical potential for reservoirs in SE Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

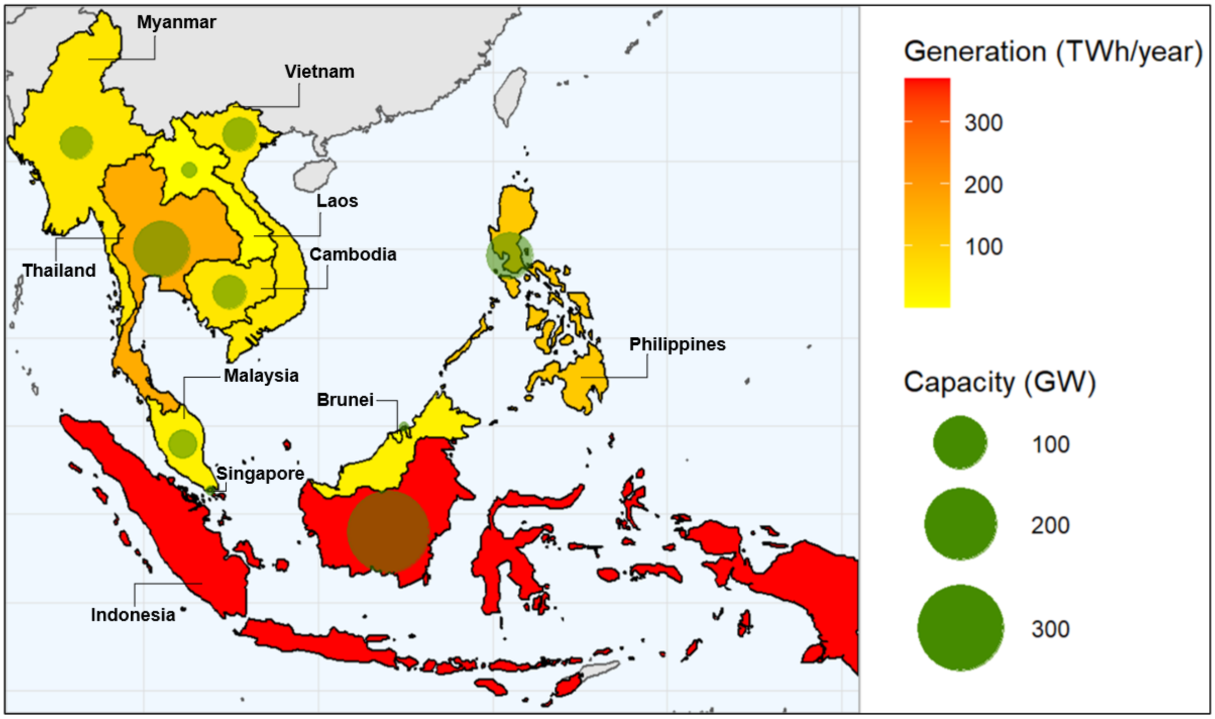

Figure 6. FPV generation and capacity technical potential for natural waterbodies in SE Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore and 1,000-m maximum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas. These results do not reflect a filter for distance-from-transmission.

4 Discussion

4.1 SE Asia Context

As noted in the introduction, the SE Asia region is experiencing significant economic growth, leading to a projected increase in overall electricity demand estimated at 3% per year through 2050 (IEA 2022). This anticipated growth, which differs by country, is largely driven by increased use of consumer appliances and equipment and increased end-use electrification in the buildings, industrial, and transportation sectors. Thus, countries face the task of affordably meeting rising electricity demand while reducing emissions and ensuring energy security (IEA 2022). Some of these priorities have been shaped and impacted by the COVID-19 pandemic and geopolitical events, which could impact achievement of various RE goals (IEA 2022). Additionally, an estimated 5% of the regional population lacks access to electricity, and efforts to achieve universal electrification will continue in the coming years.

Renewables, mostly hydropower, accounted for approximately 25% of power generation in the region as of 2020, with natural gas and coal largely accounting for the rest (IEA 2022). Given the regional target of 35% installed capacity of renewables by 2025, significant deployment of renewables is needed. Hydropower plays an important role in these efforts, and might continue to do so, in addition to solar and wind. Due to its solar resource potential, significant existing hydropower capacity, and planned additions of hydropower and solar PV, the region is well placed to deploy FPV in both stand-alone and hybrid configurations. This study assessed two main scenarios for FPV technical potential in SE Asia: waterbody type (reservoirs and natural waterbodies) and FPV technology type (monofacial and bifacial). Differences among SE Asian countries in terms of electricity sector targets, installed RE capacity, the role of hydropower, and FPV technical potential are discussed in section 4.2.

4.1.1 Waterbody Type

The technical potential assessment identified 7,301 waterbodies—88 reservoirs and 7,213 natural waterbodies—as potentially suitable for FPV deployment in SE Asia. Overall, FPV technical potential ranges from 134–278 GW on reservoirs and 343–768 GW on natural waterbodies, based on the methodology, assumptions, available data, and distance-from-shore sensitivities outlined in Section 2. In our median sensitivity case (50 m minimum distance-from-shore and 1,000 m maximum distance-from-shore), this translates to roughly 825 GW of FPV. Under current policies, the installed capacity of renewables in ASEAN countries is expected to reach 235 GW by 2030, with 81 GW of utility-scale solar, and 1,311 GW by 2050, with 841 GW of utility-scale solar (IRENA and ASEAN Centre for Energy 2022). Thus, FPV can play an important role in the region's renewable energy buildout.

4.1.2 FPV Technology Type

The technical potential capacity results for each waterbody type and country are the same for monofacial and bifacial FPV because the same power density assumption is used for both technology types (100 MW/km^2), as discussed in Section 2.3.2. However, the capacity factors are different, leading to different estimated electricity generation results. As a simplifying assumption, the capacity factors for bifacial FPV were estimated by increasing the capacity factor results for monofacial FPV by a factor of 1.05. The rationale for this assumption is described in Section 2.3.2.

4.2 Country-Specific Results

This section discusses the results within the context of each ASEAN country. Detailed modeled results for each country are in the Appendix. Geography, waterbody type, and data availability shape the estimated technical potential across the countries. Overall, the modeled technical potential for FPV on natural waterbodies is higher than that of reservoirs. However, the actual developable capacity on natural waterbodies might be significantly lower due to site-specific constraints and environmental impact considerations. Considering waterbody types, the FPV technical potential is higher on reservoirs in Laos and Malaysia and higher on natural waterbodies in Brunei, Cambodia, Indonesia, Myanmar, the Philippines, Singapore, and Thailand. In Vietnam, the technical potential is roughly equivalent across waterbody types.

Considering geography, Brunei and Singapore are much smaller than other ASEAN countries and have a lower number of available reservoirs; thus, their technical potential results are a magnitude smaller. The technical potential impacts of excluding waterbodies that are more than 25 km from the nearest transmission line, for countries that have this data publicly available (Cambodia, Laos, Myanmar, the Philippines, Thailand, and Vietnam), will be discussed in the subsequent subsections. As mentioned earlier, all default results in tables and figures exclude transmission filters in order to ensure a consistent basis of comparison. Though the overall results indicate that the transmission distance filter does not have a significant impact on the technical potential capacity for reservoirs, the impact for natural waterbodies varies by country as discussed below.

4.2.1 Brunei

Brunei largely generates electricity from natural gas (78%) and coal (21%), but has a target of generating 30% of its electricity from renewables by 2035 (Abu Bakar 2021; IEA 2022). Unlike most of its neighbors in SE Asia, Brunei does not have installed capacity or significant potential for hydropower, and therefore has little opportunity to hybridize existing hydropower with FPV. In the dataset analyzed, Brunei has zero FPV technical potential on artificial reservoirs. The assessment identified 18 natural waterbodies as potentially suitable for future development of FPV. On these waterbodies, FPV technical potential capacity ranges from 137–669 MW depending on the distance-from-shore assumptions, compared to a total installed electricity generation capacity of 1.2 GW in 2021 (IRENA 2022a). When the minimum distance-from-shore assumption is fixed at 50 m, FPV technical potential capacity is constant at 340 MW, regardless of the maximum distance-from-shore assumption (Figure 7), indicating smaller-sized natural waterbodies.

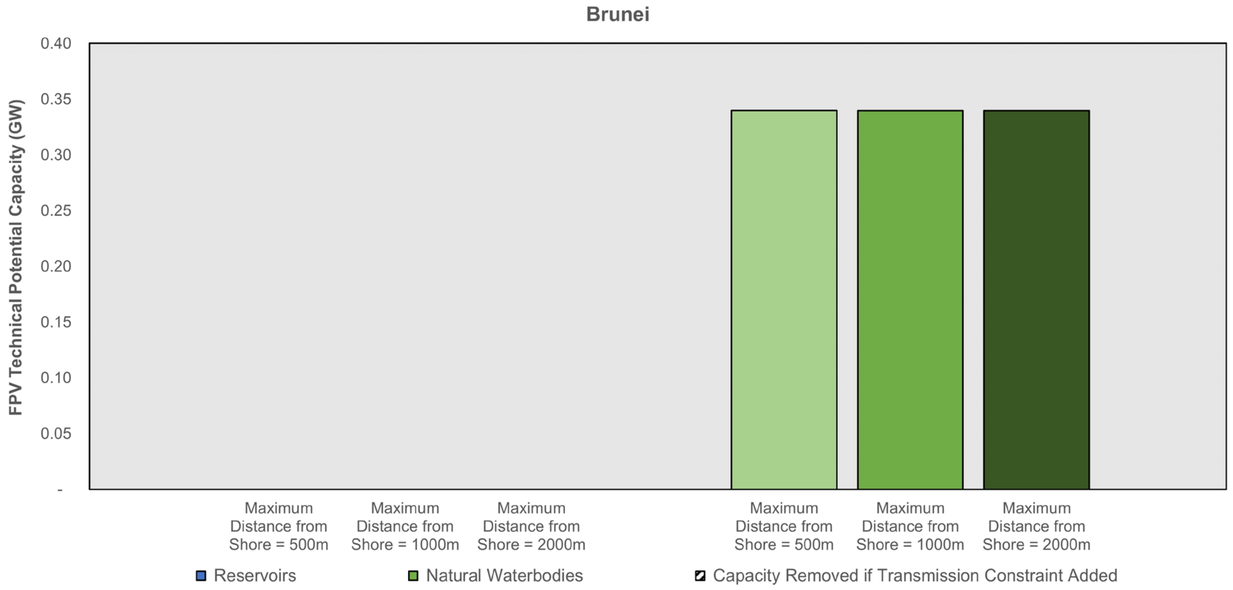

Figure 7. FPV technical potential capacity in Brunei

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

These estimates do not include filters for distance from existing transmission, as transmission data was not available for Brunei. The calculated FPV technical potential of 137–669 MW is smaller than the 2.3 GW of potential estimated by Brunei's Ministry of Energy at nine potential sites, including four reservoirs and five lakes (Abu Bakar 2021). When the road distance and protected area filters are removed, our results indicate a maximum of 1.3 GW of FPV technical potential, still lower than the Ministry of Energy estimate.

4.2.2 Cambodia

Cambodia is targeting a 2030 installed capacity mix of 55% hydropower, 6.5% biomass, and 3.5% solar, with fossil fuels comprising the remaining 35% (IEA 2022). Increased RE deployment will also support the country's electrification efforts, as electricity access stood at 86% in 2020 (IRENA 2022b). Hydropower is the main source of electricity, supplying approximately 45% of overall generation as of 2020 (IRENA 2022b). However, with recent droughts and related unreliability in reservoir water levels, this significant hydropower dependency has raised energy security concerns (Cheang 2018; Hutt 2019). These concerns were highlighted in 2019, when a particularly dry stretch from May to June led to power outages in the country (Phoumin 2019).

Our analysis estimates that Cambodia has 15–29 GW and 22–46 GW of FPV technical potential on reservoirs and natural waterbodies respectively, compared to a total installed electricity generation capacity of 3.1 GW in 2021 (IRENA 2022b). The reservoir analysis may be an underestimate because other data suggests at least nine suitable reservoirs in Cambodia (Kingdom of the Netherlands 2018), compared to the two listed in our dataset. Of these two, one reservoir was excluded from our analysis because it is located in a protected area. This discrepancy might be caused by the datasets used for waterbody types and potential misattribution of waterbody type within those datasets. When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity is unchanged for reservoirs and decreases by 1.9–3.1% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 8).

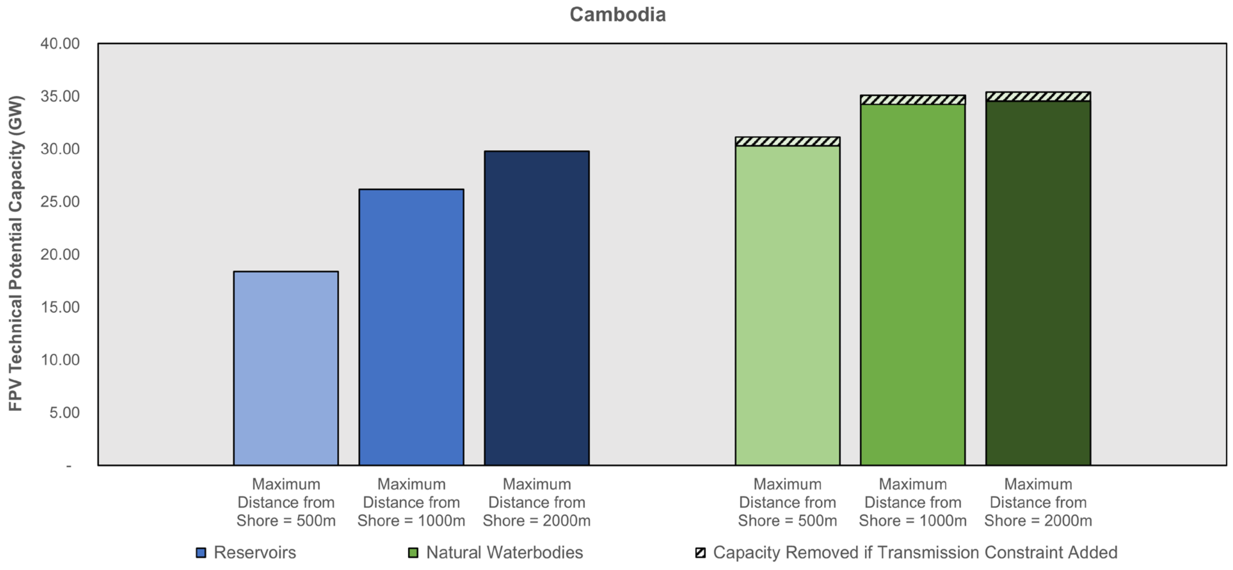

Figure 8. FPV technical potential capacity in Cambodia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.3 Indonesia

Indonesia has abundant RE resources and an ambitious target to achieve net-zero emissions by 2060. In the near term, Indonesia has identified energy efficiency and electrification as high priorities alongside a more concerted effort to increase deployment of renewables (Darghouth et al. 2020; IEA 2022a). Indonesia's current power generation mix consists of coal (60%), natural gas (18%), renewables such as hydropower, geothermal, and biofuels (17%), and oil (3%). Indonesia has significant wind and solar resources, but these generation technologies have not yet been deployed widely. PT Perusahaan Listrik Negara is Indonesia's state-owned utility and plans to add roughly 21 GW of renewables between 2021 and 2030, accounting for just over half of new capacity additions. Of this total planned capacity, hydropower accounts for 4.9 GW and solar PV accounts for 2.5 GW (Clean Energy Finance and Investment Mobilisation 2021). Currently, Indonesia's largest RE source is hydropower, which generated approximately 7% of the country's electricity in 2020 (IEA 2022a).

Indonesia's significant hydropower resources were reflected in our analysis, which identified 1,858 waterbodies (19 reservoirs and 1,839 natural waterbodies) as potentially suitable for FPV. Based on our technical potential results, this translates to a range of 170–364 GW of FPV capacity, which is significantly greater than both the planned RE additions over the next decade and the total installed electricity generation capacity of 74 GW in 2021 (IRENA 2022c). A comparison of technical potential capacity for natural waterbodies versus reservoirs, when the minimum distance-from-shore assumption is fixed at 50 m, is shown in Figure 9. This technical potential range is an upper-bound estimate as we did not have access to transmission constraint data for Indonesia. Nevertheless, these results show a promising opportunity for FPV to significantly contribute to Indonesia's decarbonization efforts. In fact, construction is underway on a 145-MW FPV plant in the country that will be one of the largest in SE Asia (Bellini 2021) and ACWA Power recently secured a contract with PT Perusahaan Listrik Negara to build two FPV projects with a total capacity of 110 MW (Power Technology 2022).

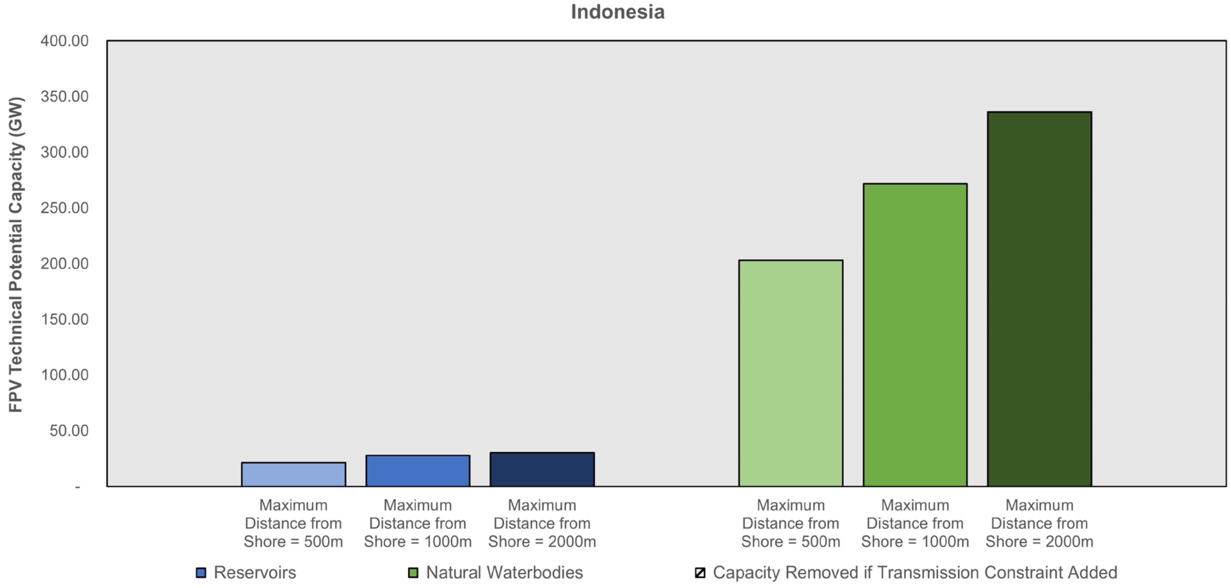

Figure 9. FPV technical potential capacity in Indonesia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.4 Laos

Like many of its neighbors, Laos is experiencing rapid growth in electricity demand. Laos has been working to expand its transmission network, and 95% of the population has access to the grid (XinhuaNet 2020). Laos struggles with an inefficient transmission and distribution system, however, with an estimated 13% of supply lost during transport to end users. In urban areas, demand can easily outstrip supply, and electricity can become unreliable during peak periods (World Bank 2015). Laos' generation mix is dominated by hydropower, which accounts for approximately 73% of overall generation (ADB 2019). Laos is aiming to achieve 30% of total energy consumption from renewables by 2025 (Grantham Research Institute on Climate Change and the Environment). Most of the hydropower plants in Laos have seasonal storage reservoirs, rather than being run-of-river dams, and thus can take a few years to reach full capacity. Laos' geography is mountainous and forested, which can hinder the development of utility-scale solar projects. However, this constraint has led to consideration of FPV, which could potentially help Laos cover the shortfall in electricity production from hydropower during the dry season. Laos is also a major exporter of electricity to neighboring countries such as Thailand during the wet season, and FPV sited on existing hydropower can be a viable option to further bolster this cross-border electricity trade (Weatherby et al., 2022).

Our analysis suggests that unlike most other ASEAN countries, Laos has a higher FPV technical potential on reservoirs compared to natural waterbodies. This is likely due to its significant domestic hydropower resources. On the three reservoirs included in the dataset, Laos has 5–10 GW of FPV technical potential. This is likely an underestimate, as the Mekong Infrastructure Tracker identifies 19 reservoirs in Laos over 15 km^2 in size with transmission connections (Stimson Center 2020). Currently, a 240-MW FPV project is being planned at Laos' second-largest hydropower reservoir, Nam Theun 2. On natural waterbodies, Laos has approximately 2–5 GW of FPV technical potential. This combined FPV technical potential (9–15 GW) is sizable compared to the country's overall installed capacity, which was 10 GW as of 2021 (IRENA 2022d). When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity is unchanged for reservoirs and decreases by 8.4–10.1% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 10).

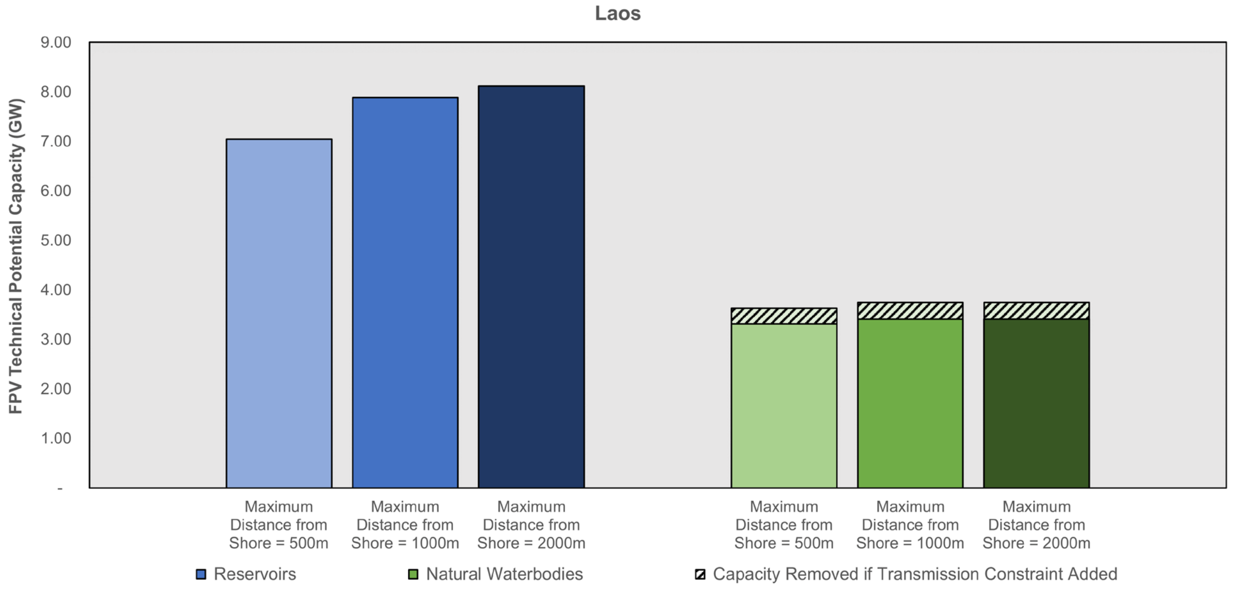

Figure 10. FPV technical potential capacity in Laos

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.5 Malaysia

Malaysia experienced significant economic growth in the last decade, and subsequently consumer spending per capita increased almost fivefold. These trends are expected to increase the country's electricity demand. To meet some of this demand, Malaysia plans to increase RE capacity to 4 GW by 2030 (IEA 2019). Malaysia has a target of 31% installed electricity generation capacity from renewables by 2025 (IEA 2022). As of 2020, 16% of electricity generation was from renewables, predominantly hydropower at 15% (IRENA 2022e). The country is also the fifth-largest exporter of liquefied natural gas in the world as of 2019, although oil and natural gas discoveries are decreasing (EIA 2021). Malaysia is working to discover more oil and gas by introducing enhanced oil recovery practices both on and offshore and is pursuing new deep-water developments. However, as a result of declining domestic reserves, Malaysia is expected to become more dependent on fuel imports. Coal power generation has increased in Malaysia over the past several years due to policies that encouraged fuel switching from natural gas to coal because of the declining gas production. However, the government announced plans to stop building new coal power plants and accelerate the retirement of existing capacity (Lee 2021).

Results from this assessment indicate that, similar to Laos, Malaysia has a higher potential for FPV on reservoirs (23–54 GW) compared to natural waterbodies (13–30 GW). As of 2021, the total installed electricity generation capacity was 39 GW in Malaysia (IRENA 2022e). A comparison of technical potential capacity for natural waterbodies versus reservoirs, when the minimum distance-from-shore assumption is fixed at 50 m, is shown in Figure 11. A separate study looking at six specific locations in Malaysia indicates that FPV could generate around 14.5 GWh/year (Jamalludin et al. 2019). This analysis expands on that result and looks at all feasible waterbodies in the country, indicating that FPV could generate 47–109 GWh/year as an upper-bound estimate. However, these results do not account for site-specific constraints or economic considerations, and transmission data was not available for Malaysia.

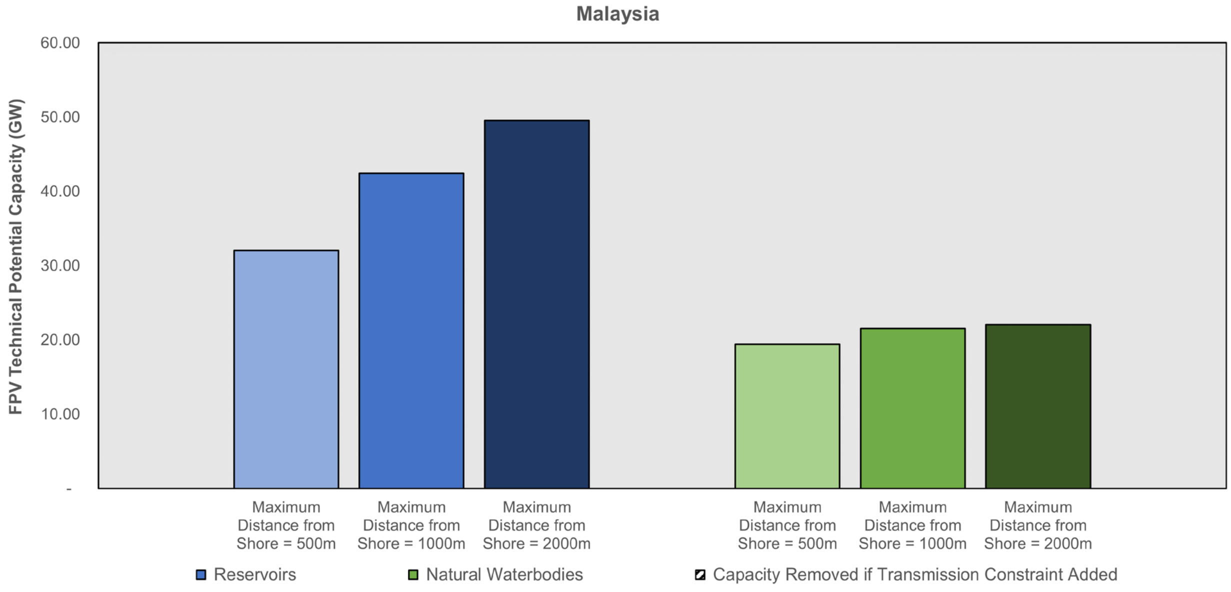

Figure 11. FPV technical potential capacity in Malaysia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.6 Myanmar

Myanmar has a goal of 20% installed electricity generation capacity from renewables by 2025 (IEA 2022). The increased renewables deployment will support its electrification efforts (i.e., achieving universal electricity access by 2030, up from 70% currently) and ability to meet growing electricity demand (i.e., demand is increasing annually by approximately 15–17%). Myanmar's 2015 Energy Master Plan seeks to increase the share of hydropower from 50% of electricity generation in 2021 to 57% in 2030, increase coal to 30%, decrease natural gas to 8%, and increase wind and solar to 5% (IEA 2017; IRENA 2022f). The country has substantial wind and solar potential (Export.gov 2019). These resources can help alleviate the severe power shortages that have resulted from aging power plants, inadequate electricity transmission infrastructure, and droughts impacting hydropower production (EIA 2019). As of 2018, the Government of Myanmar had six hydropower plants under construction and 51 in the pre-construction phase (Aung 2021).

Our analysis suggests that Myanmar has lower FPV technical potential on reservoirs (18–35 GW) than it does on natural waterbodies (21–47 GW). This combined potential is an order of magnitude larger than Myanmar's total electricity generation capacity, which was approximately 7.6 GW as of 2021 (IRENA 2022f). Given the proposed expansion of hydropower, the technical potential on reservoirs is poised to increase, and, therefore, FPV-hydropower hybrid plants could be an additional option to meet Myanmar's future RE targets. When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity decreases by 1.7–2.1% for reservoirs and decreases by 9.7–16.2% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 12).

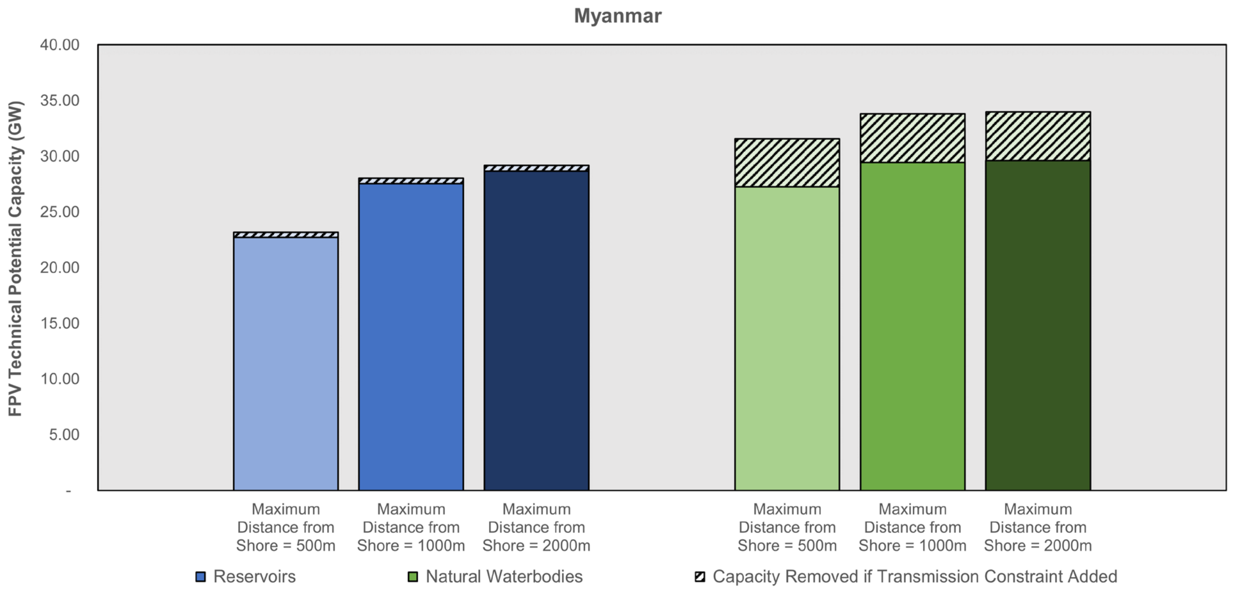

Figure 12. FPV technical potential capacity in Myanmar

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.7 Philippines

The Philippines has several electricity sector priorities, such as meeting growing electricity demand, achieving universal electricity access by 2022, installing 15 GW of renewables by 2030, and ceasing new coal development beyond specific projects already in the pipeline. Electricity demand in the Philippines has grown faster than the grid has been able to meet it, particularly on the island of Luzon, which contains the capital city of Manila. During the summer months of 2019, Luzon's grid had frequent "yellow" alerts, which are notifications that electricity customers could experience brownouts due to insufficient supply (Amoguis 2019).

In 2019, the Philippines brought its first FPV project online, and construction on other projects commenced in the ensuing years (T&D World 2019). The technical potential assessment identified a much higher capacity range for FPV on natural waterbodies (42–103 GW) compared to reservoirs (2–5 GW). As of 2021, the total installed electricity generation capacity was 28 GW in the Philippines (IRENA 2022g). Like in all other countries, FPV development on natural waterbodies in the Philippines would require additional guidelines around assessing possible environmental impacts. However, the potential remains significant compared to the current overall installed electricity generation capacity. When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity is unchanged for reservoirs and decreases by 1.7–5.2% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 13).

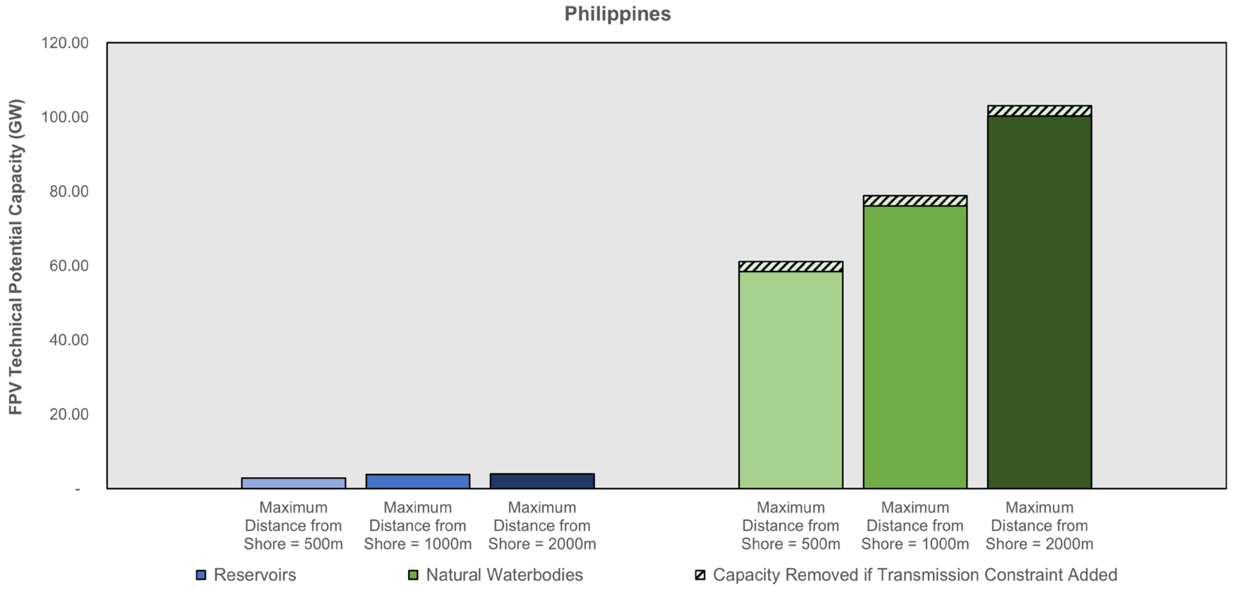

Figure 13. FPV technical potential capacity in the Philippines

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.8 Singapore

Singapore's RE plans include installing 2 GW of solar PV capacity by 2030 and supplying 30% of its energy needs with low-carbon electricity imports by 2035 (Koons 2022). Singapore's power sector is heavily reliant on natural gas, which generated 95% of the country's electricity in 2020, compared to 1% for solar PV (IEA 2022b). FPV provides an RE option in a land-constrained country, technical expertise which can be exported, and a potential investment opportunity in neighboring countries which could be sold back to Singapore as clean energy given its electricity import goals (Tani 2022). Furthermore, Singapore has pioneered the development of FPV through the Solar Energy Research Institute of Singapore (SERIS), which is located within the National University of Singapore. SERIS houses the world's largest FPV testbed, at 1 MW, which allows researchers to assess environmental impacts, energy yields, structural performance, and other important FPV topics (Reindl 2020).

Our dataset identified one reservoir and six natural waterbodies for Singapore, with the technical potential ranging from 67–153 MW on the reservoir and 206–381 MW on the natural waterbodies, compared to a total installed electricity generation capacity of 12 GW in 2021 (IRENA 2022h). A comparison of technical potential capacity for natural waterbodies versus reservoirs, when the minimum distance-from-shore assumption is fixed at 50 m, is shown in Figure 14. These estimates do not include filters for distance from existing transmission, as transmission data was not available for Singapore. Greater FPV potential for Singapore might exist offshore, which was outside the scope of this analysis. Offshore and nearshore FPV is garnering significant interest in Singapore in particular, and the nation has built a 5-MW FPV system off its coast to study the impacts of tides, waves, the corrosive environment, and biofouling on this technology (Reindl 2020).

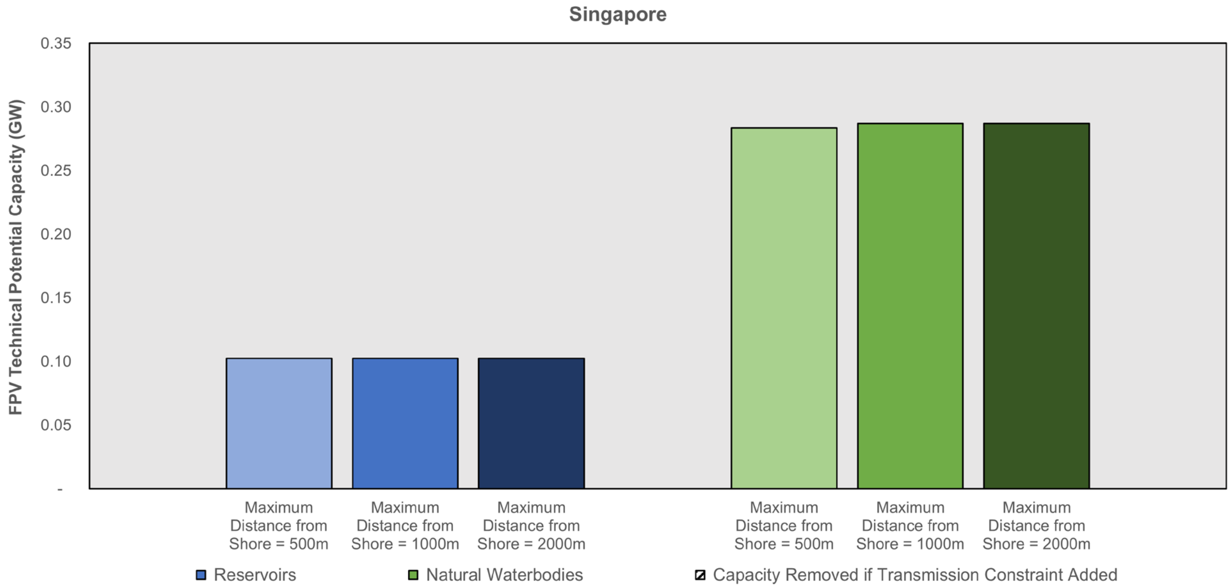

Figure 14. FPV technical potential capacity in Singapore

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.9 Thailand

Thailand has experienced steady economic growth over the past two decades, accompanied by a rise in energy demand and greater dependence on fossil fuels. However, Thailand has a goal to achieve carbon neutrality by 2050. Furthermore, Thailand has limited fossil fuel reserves and imports a large portion of energy from neighboring countries (EIA 2019). To meet these carbon neutrality goals and bolster its energy security, Thailand has established an interim target for renewables to account for 36% of installed power capacity and 20% of generation by 2037 (IEA 2022).

As part of this effort, Thailand is planning to build over 2.7 GW of FPV on nine different hydroelectric reservoirs by 2037 (Thanthong-Knight 2019). Our analysis suggests significant FPV technical potential of 33–65 GW on reservoirs and 68–152 GW on natural waterbodies, compared to a total installed electricity generation capacity of 55 GW in 2021 (IRENA 2022i). The average net capacity factor values for the different waterbody types were similar, at approximately 16.5%. When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity decreases by 1.8–2.5% for reservoirs and decreases by 3.9–5.9% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 15).

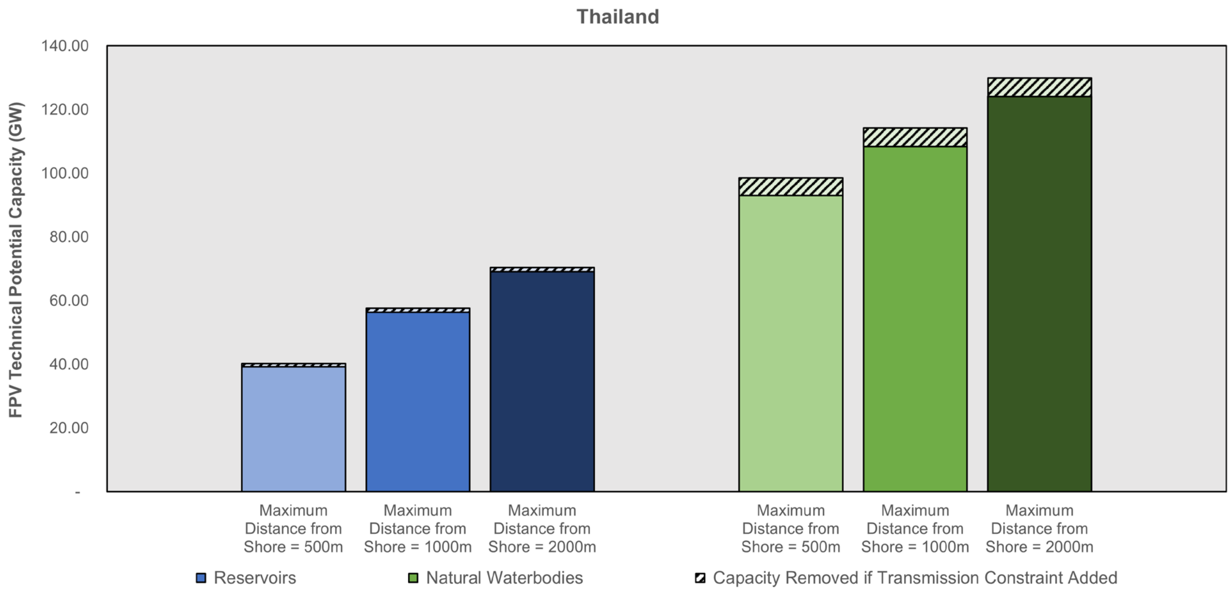

Figure 15. FPV technical potential capacity in Thailand

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

4.2.10 Vietnam

In 2020, Vietnam's electricity generation came primarily from coal (50%), hydropower (30%), and natural gas (15%) (IEA 2022c). Vietnam has the highest solar and wind capacity among ASEAN nations, as solar PV capacity reached 16.5 GW in 2020. However, the sharp rise in installed capacity of variable renewables has led to significant curtailment due to insufficient grid infrastructure (Le 2022). Vietnam seeks to deploy 31–38 GW of solar and wind capacity by 2030 as part of its broader ambition to reach carbon neutrality by 2050 (Reuters 2022). FPV hybridized with existing hydropower could take advantage of existing transmission lines and help avoid some of the curtailment issues the country has been experiencing.

Vietnam's significant share of hydropower provides an opportunity for stand-alone and hybrid FPV. In our dataset, Vietnam contained the highest number of reservoirs for FPV at 22. Across these reservoirs, we estimate an FPV technical potential of 21–46 GW. These results are similar to the technical potential found on natural waterbodies (21–54 GW). As of 2021, the total installed electricity generation capacity was 76 GW in Vietnam (IRENA 2022j). Recently, local authorities have approved the construction of two FPV projects in the Quynh Luu district with a combined capacity of 450 MW (Enerdata 2022). When the transmission filter is applied (excluding waterbodies further than 25 km from the nearest transmission line), the technical potential capacity is unchanged for reservoirs and decreases by less than 0.5% for natural waterbodies, depending on the distance-from-shore assumptions (Figure 16).

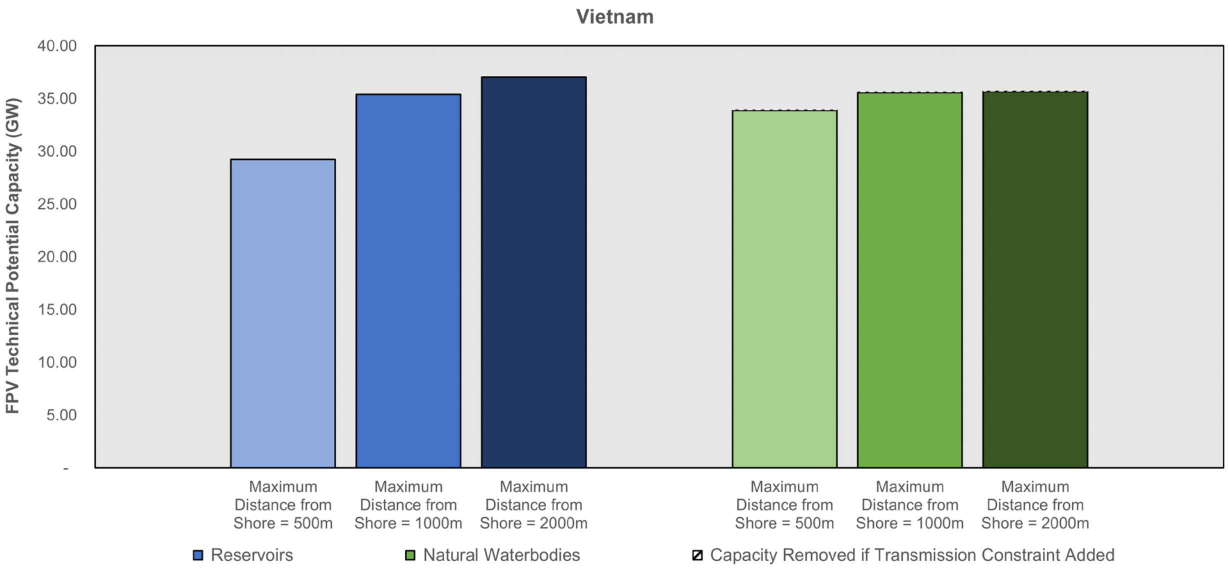

Figure 16. FPV technical potential capacity in Vietnam

Note: These results assume fixed-tilt monofacial FPV panels, with a 50-m minimum distance-from-shore buffer. The dataset excludes waterbodies that are more than 50 km from major roads and waterbodies that are within protected areas.

5 Conclusion

FPV deployment is growing rapidly in the SE Asia region. This report presents a detailed technical potential assessment of FPV in SE Asia alongside a breakdown of technical potential for each ASEAN country based on waterbody type and PV technology, leveraging high-quality solar resource data. The study provides regional context on FPV potential, expands on previous work by including non-hydropower reservoirs and natural waterbodies, and sheds light on upper bounds for FPV potential in individual countries.

Overall, these findings indicate significant technical potential for FPV in each country and across the region. Several countries have ambitious RE targets, mainly focused on solar, hydropower, and wind deployment. FPV presents an additional RE option that can leverage existing infrastructure, especially existing hydropower capacity, and support ongoing and increasingly ambitious decarbonization efforts in the region. Detailed market and economic technical potential assessments will be needed to further assess the FPV opportunities in each country. For specific sites, detailed site-specific analysis will need to be conducted given the lack of bathymetry, wind, wave, and sediment data at a regional level.

There are many opportunities for future technical research in this field. We did not examine offshore FPV potential or use a detailed representation of bifacial FPV. Furthermore, we did not examine technical potential for a combination of FPV and aquaculture, known as "AquaPV." This could be particularly relevant to SE Asia, given its large aquaculture industry. All these topic areas are viable next steps for future research.

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Appendix

Brunei Results

Waterbody Type	Sensitivities		Results						
				Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	0	0	0	N/A	0	0	N/A
		1,000	0	0	0	N/A	0	0	N/A
		2,000	0	0	0	N/A	0	0	N/A
	50 (Median)	500	0	0	0	N/A	0	0	N/A
		1,000	0	0	0	N/A	0	0	N/A
		2,000	0	0	0	N/A	0	0	N/A
	100 (Far From Shore)	500	0	0	0	N/A	0	0	N/A
		1,000	0	0	0	N/A	0	0	N/A
		2,000	0	0	0	N/A	0	0	N/A
Natural Waterbody	0 (Close to Shore)	500	7	669	905	15.4%	669	950	16.2%
		1,000	7	669	905	15.4%	669	950	16.2%
		2,000	7	669	905	15.4%	669	950	16.2%
	50 (Median)	500	3	340	459	15.4%	340	481	16.2%
		1,000	3	340	459	15.4%	340	481	16.2%
		2,000	3	340	459	15.4%	340	481	16.2%
	100 (Far From Shore)	500	1	137	184	15.3%	137	193	16.1%
		1,000	1	137	184	15.3%	137	193	16.1%
		2,000	1	137	184	15.3%	137	193	16.1%
All Suitable Waterbodies	0 (Close to Shore)	500	7	669	905	15.4%	669	950	16.2%
		1,000	7	669	905	15.4%	669	950	16.2%
		2,000	7	669	905	15.4%	669	950	16.2%
	50 (Median)	500	3	340	459	15.4%	340	481	16.2%
		1,000	3	340	459	15.4%	340	481	16.2%
		2,000	3	340	459	15.4%	340	481	16.2%
	100 (Far From Shore)	500	1	137	184	15.3%	137	193	16.1%
		1,000	1	137	184	15.3%	137	193	16.1%
		2,000	1	137	184	15.3%	137	193	16.1%

Cambodia Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	216	21,590	30,917	16.3%	21,590	32,463	17.2%
		1,000	294	29,382	42,074	16.3%	29,382	44,178	17.2%
		2,000	294	29,382	42,074	16.3%	29,382	44,178	17.2%
	50 (Median)	500	184	18,379	26,318	16.3%	18,379	27,634	17.2%
		1,000	262	26,170	37,475	16.3%	26,170	39,349	17.2%
		2,000	298	29,809	42,686	16.3%	29,809	44,820	17.2%
	100 (Far From Shore)	500	153	15,326	21,947	16.3%	15,326	23,044	17.2%
		1,000	231	23,118	33,104	16.3%	23,118	34,759	17.2%
		2,000	268	26,757	38,315	16.3%	26,757	40,230	17.2%
Natural Waterbody	0 (Close to Shore)	500	425	42,491	61,976	16.7%	42,491	65,074	17.5%
		1,000	465	46,460	67,737	16.6%	46,460	71,123	17.5%
		2,000	465	46,460	67,737	16.6%	46,460	71,123	17.5%
	50 (Median)	500	311	31,145	45,399	16.6%	31,145	47,669	17.5%
		1,000	351	35,081	51,113	16.6%	35,081	53,669	17.5%
		2,000	354	35,390	51,562	16.6%	35,390	54,140	17.5%
	100 (Far From Shore)	500	217	21,748	31,677	16.6%	21,748	33,260	17.5%
		1,000	257	25,651	37,342	16.6%	25,651	39,209	17.4%
		2,000	260	25,959	37,790	16.6%	25,959	39,679	17.4%
All Suitable Waterbodies	0 (Close to Shore)	500	641	64,081	92,892	16.5%	64,081	97,537	17.4%
		1,000	758	75,841	109,811	16.5%	75,841	115,301	17.4%
		2,000	758	75,841	109,811	16.5%	75,841	115,301	17.4%
	50 (Median)	500	495	49,524	71,717	16.5%	49,524	75,303	17.4%
		1,000	613	61,251	88,588	16.5%	61,251	93,017	17.3%
		2,000	652	65,199	94,248	16.5%	65,199	98,960	17.3%
	100 (Far From Shore)	500	371	37,074	53,624	16.5%	37,074	56,305	17.3%
		1,000	488	48,769	70,446	16.5%	48,769	73,968	17.3%
		2,000	527	52,715	76,105	16.5%	52,715	79,910	17.3%

Indonesia Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	273	27,341	39,150	16.3%	27,341	41,108	17.2%
		1,000	340	34,000	48,604	16.3%	34,000	51,034	17.1%
		2,000	340	34,000	48,604	16.3%	34,000	51,034	17.1%
	50 (Median)	500	212	21,246	30,444	16.4%	21,246	31,967	17.2%
		1,000	278	27,792	39,741	16.3%	27,792	41,728	17.1%
		2,000	304	30,406	43,411	16.3%	30,406	45,581	17.1%
	100 (Far From Shore)	500	163	16,282	23,335	16.4%	16,282	24,501	17.2%
		1,000	227	22,727	32,492	16.3%	22,727	34,117	17.1%
		2,000	253	25,282	36,079	16.3%	25,282	37,883	17.1%
Natural Waterbody	0 (Close to Shore)	500	2,604	260,425	357,115	15.7%	260,425	374,971	16.4%
		1,000	3,296	329,563	448,455	15.5%	329,563	470,878	16.3%
		2,000	3,296	329,563	448,455	15.5%	329,563	470,878	16.3%
	50 (Median)	500	2,031	203,115	278,210	15.6%	203,115	292,120	16.4%
		1,000	2,719	271,897	369,059	15.5%	271,897	387,511	16.3%
		2,000	3,362	336,217	451,573	15.3%	336,217	474,152	16.1%
	100 (Far From Shore)	500	1,539	153,920	210,464	15.6%	153,920	220,987	16.4%
		1,000	2,223	222,322	300,785	15.4%	222,322	315,824	16.2%
		2,000	2,864	286,435	383,012	15.3%	286,435	402,163	16.0%
All Suitable Waterbodies	0 (Close to Shore)	500	2,878	287,766	396,265	15.7%	287,766	416,078	16.5%
		1,000	3,636	363,563	497,059	15.6%	363,563	521,912	16.4%
		2,000	3,636	363,563	497,059	15.6%	363,563	521,912	16.4%
	50 (Median)	500	2,244	224,361	308,654	15.7%	224,361	324,087	16.5%
		1,000	2,997	299,689	408,800	15.6%	299,689	429,240	16.4%
		2,000	3,666	366,622	494,984	15.4%	366,622	519,733	16.2%
	100 (Far From Shore)	500	1,702	170,202	233,799	15.7%	170,202	245,488	16.5%
		1,000	2,450	245,049	333,277	15.5%	245,049	349,941	16.3%
		2,000	3,117	311,717	419,092	15.3%	311,717	440,046	16.1%

Laos Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	90	9,031	11,974	15.1%	9,031	12,573	15.9%
		1,000	99	9,945	13,191	15.1%	9,945	13,851	15.9%
		2,000	99	9,945	13,191	15.1%	9,945	13,851	15.9%
	50 (Median)	500	70	7,044	9,353	15.2%	7,044	9,821	15.9%
		1,000	79	7,885	10,473	15.2%	7,885	10,997	15.9%
		2,000	81	8,113	10,777	15.2%	8,113	11,316	15.9%
	100 (Far From Shore)	500	54	5,428	7,216	15.2%	5,428	7,576	15.9%
		1,000	62	6,200	8,244	15.2%	6,200	8,656	15.9%
		2,000	64	6,402	8,514	15.2%	6,402	8,939	15.9%
Natural Waterbody	0 (Close to Shore)	500	52	5,228	7,452	16.3%	5,228	7,825	17.1%
		1,000	53	5,349	7,625	16.3%	5,349	8,006	17.1%
		2,000	53	5,349	7,625	16.3%	5,349	8,006	17.1%
	50 (Median)	500	36	3,629	5,176	16.3%	3,629	5,435	17.1%
		1,000	37	3,745	5,341	16.3%	3,745	5,608	17.1%
		2,000	37	3,745	5,341	16.3%	3,745	5,608	17.1%
	100 (Far From Shore)	500	24	2,363	3,371	16.3%	2,363	3,539	17.1%
		1,000	25	2,473	3,526	16.3%	2,473	3,703	17.1%
		2,000	25	2,473	3,526	16.3%	2,473	3,703	17.1%
All Suitable Waterbodies	0 (Close to Shore)	500	143	14,259	19,426	15.6%	14,259	20,397	16.3%
		1,000	153	15,294	20,816	15.5%	15,294	21,857	16.3%
		2,000	153	15,294	20,816	15.5%	15,294	21,857	16.3%
	50 (Median)	500	107	10,674	14,530	15.5%	10,674	15,256	16.3%
		1,000	116	11,631	15,814	15.5%	11,631	16,605	16.3%
		2,000	119	11,859	16,118	15.5%	11,859	16,924	16.3%
	100 (Far From Shore)	500	78	7,791	10,587	15.5%	7,791	11,116	16.3%
		1,000	87	8,672	11,770	15.5%	8,672	12,359	16.3%
		2,000	89	8,875	12,040	15.5%	8,875	12,642	16.3%

Malaysia Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	430	43,042	56,091	14.9%	43,042	58,896	15.6%
		1,000	542	54,154	70,392	14.8%	54,154	73,912	15.6%
		2,000	542	54,154	70,392	14.8%	54,154	73,912	15.6%
	50 (Median)	500	321	32,063	41,784	14.9%	32,063	43,873	15.6%
		1,000	424	42,449	55,145	14.8%	42,449	57,902	15.6%
		2,000	495	49,535	64,223	14.8%	49,535	67,434	15.5%
	100 (Far From Shore)	500	230	22,975	29,926	14.9%	22,975	31,422	15.6%
		1,000	327	32,663	42,382	14.8%	32,663	44,501	15.6%
		2,000	391	39,060	50,578	14.8%	39,060	53,107	15.5%
Natural Waterbody	0 (Close to Shore)	500	278	27,787	36,333	14.9%	27,787	38,149	15.7%
		1,000	299	29,921	39,019	14.9%	29,921	40,970	15.6%
		2,000	299	29,921	39,019	14.9%	29,921	40,970	15.6%
	50 (Median)	500	194	19,438	25,347	14.9%	19,438	26,614	15.6%
		1,000	216	21,560	28,017	14.8%	21,560	29,418	15.6%
		2,000	221	22,055	28,625	14.8%	22,055	30,057	15.6%
	100 (Far From Shore)	500	128	12,791	16,611	14.8%	12,791	17,441	15.6%
		1,000	149	14,898	19,263	14.8%	14,898	20,226	15.5%
		2,000	154	15,394	19,871	14.7%	15,394	20,864	15.5%
All Suitable Waterbodies	0 (Close to Shore)	500	708	70,828	92,424	14.9%	70,828	97,045	15.6%
		1,000	841	84,075	109,412	14.9%	84,075	114,882	15.6%
		2,000	841	84,075	109,412	14.9%	84,075	114,882	15.6%
	50 (Median)	500	515	51,501	67,131	14.9%	51,501	70,488	15.6%
		1,000	640	64,009	83,163	14.8%	64,009	87,321	15.6%
		2,000	716	71,591	92,848	14.8%	71,591	97,491	15.5%
	100 (Far From Shore)	500	358	35,766	46,537	14.9%	35,766	48,864	15.6%
		1,000	476	47,562	61,645	14.8%	47,562	64,727	15.5%
		2,000	545	54,454	70,449	14.8%	54,454	73,972	15.5%

Myanmar Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	298	29,752	42,869	16.4%	29,752	45,013	17.3%
		1,000	347	34,706	49,962	16.4%	34,706	52,460	17.3%
		2,000	347	34,706	49,962	16.4%	34,706	52,460	17.3%
	50 (Median)	500	232	23,181	33,410	16.5%	23,181	35,081	17.3%
		1,000	280	28,027	40,352	16.4%	28,027	42,369	17.3%
		2,000	292	29,155	41,958	16.4%	29,155	44,056	17.2%
	100 (Far From Shore)	500	177	17,704	25,520	16.5%	17,704	26,796	17.3%
		1,000	224	22,448	32,319	16.4%	22,448	33,935	17.3%
		2,000	235	23,526	33,855	16.4%	23,526	35,547	17.2%
Natural Waterbody	0 (Close to Shore)	500	448	44,802	65,526	16.7%	44,802	68,802	17.5%
		1,000	471	47,087	68,830	16.7%	47,087	72,272	17.5%
		2,000	471	47,087	68,830	16.7%	47,087	72,272	17.5%
	50 (Median)	500	316	31,555	46,248	16.7%	31,555	48,560	17.6%
		1,000	338	33,800	49,492	16.7%	33,800	51,967	17.6%
		2,000	340	33,975	49,737	16.7%	33,975	52,224	17.5%
	100 (Far From Shore)	500	210	20,994	30,843	16.8%	20,994	32,385	17.6%
		1,000	232	23,201	34,034	16.7%	23,201	35,736	17.6%
		2,000	234	23,377	34,279	16.7%	23,377	35,993	17.6%
All Suitable Waterbodies	0 (Close to Shore)	500	746	74,554	108,395	16.6%	74,554	113,814	17.4%
		1,000	818	81,793	118,792	16.6%	81,793	124,732	17.4%
		2,000	818	81,793	118,792	16.6%	81,793	124,732	17.4%
	50 (Median)	500	547	54,736	79,658	16.6%	54,736	83,641	17.4%
		1,000	618	61,827	89,844	16.6%	61,827	94,336	17.4%
		2,000	631	63,130	91,695	16.6%	63,130	96,280	17.4%
	100 (Far From Shore)	500	387	38,697	56,363	16.6%	38,697	59,182	17.5%
		1,000	456	45,650	66,353	16.6%	45,650	69,671	17.4%
		2,000	469	46,903	68,133	16.6%	46,903	71,540	17.4%

Philippines Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	38	3,821	5,238	15.6%	3,821	5,500	16.4%
		1,000	47	4,682	6,427	15.7%	4,682	6,749	16.5%
		2,000	47	4,682	6,427	15.7%	4,682	6,749	16.5%
	50 (Median)	500	29	2,876	3,945	15.7%	2,876	4,143	16.4%
		1,000	37	3,736	5,134	15.7%	3,736	5,391	16.5%
		2,000	39	3,903	5,364	15.7%	3,903	5,632	16.5%
	100 (Far From Shore)	500	21	2,144	2,944	15.7%	2,144	3,091	16.5%
		1,000	30	3,003	4,130	15.7%	3,003	4,337	16.5%
		2,000	32	3,169	4,360	15.7%	3,169	4,578	16.5%
Natural Waterbody	0 (Close to Shore)	500	851	85,064	118,145	15.9%	85,064	124,052	16.6%
		1,000	1,029	102,881	142,187	15.8%	102,881	149,296	16.6%
		2,000	1,029	102,881	142,187	15.8%	102,881	149,296	16.6%
	50 (Median)	500	611	61,131	84,725	15.8%	61,131	88,962	16.6%
		1,000	788	78,838	108,615	15.7%	78,838	114,045	16.5%
		2,000	1,031	103,071	141,031	15.6%	103,071	148,082	16.4%
	100 (Far From Shore)	500	419	41,891	57,876	15.8%	41,891	60,770	16.6%
		1,000	595	59,473	81,590	15.7%	59,473	85,669	16.4%
		2,000	837	83,656	113,938	15.5%	83,656	119,635	16.3%
All Suitable Waterbodies	0 (Close to Shore)	500	889	88,886	123,382	15.8%	88,886	129,552	16.6%
		1,000	1,076	107,563	148,614	15.8%	107,563	156,045	16.6%
		2,000	1,076	107,563	148,614	15.8%	107,563	156,045	16.6%
	50 (Median)	500	640	64,007	88,671	15.8%	64,007	93,104	16.6%
		1,000	826	82,575	113,749	15.7%	82,575	119,436	16.5%
		2,000	1,070	106,973	146,395	15.6%	106,973	153,714	16.4%
	100 (Far From Shore)	500	440	44,035	60,820	15.8%	44,035	63,861	16.6%
		1,000	625	62,476	85,720	15.7%	62,476	90,006	16.4%
		2,000	868	86,825	118,298	15.6%	86,825	124,213	16.3%

Singapore Results

Waterbody Type	Sensitivities			Results					
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	2	153	185	13.8%	153	195	14.5%
		1,000	2	153	185	13.8%	153	195	14.5%
		2,000	2	153	185	13.8%	153	195	14.5%
	50 (Median)	500	1	102	124	13.8%	102	131	14.5%
		1,000	1	102	124	13.8%	102	131	14.5%
		2,000	1	102	124	13.8%	102	131	14.5%
	100 (Far From Shore)	500	1	67	81	13.8%	67	85	14.5%
		1,000	1	67	81	13.8%	67	85	14.5%
		2,000	1	67	81	13.8%	67	85	14.5%
Natural Waterbody	0 (Close to Shore)	500	4	378	463	14.0%	378	486	14.7%
		1,000	4	381	467	14.0%	381	490	14.7%
		2,000	4	381	467	14.0%	381	490	14.7%
	50 (Median)	500	3	284	347	14.0%	284	364	14.7%
		1,000	3	287	351	14.0%	287	369	14.7%
		2,000	3	287	351	14.0%	287	369	14.7%
	100 (Far From Shore)	500	2	206	252	14.0%	206	265	14.7%
		1,000	2	209	256	14.0%	209	269	14.7%
		2,000	2	209	256	14.0%	209	269	14.7%
All Suitable Waterbodies	0 (Close to Shore)	500	5	531	648	13.9%	531	680	14.6%
		1,000	5	534	652	13.9%	534	685	14.6%
		2,000	5	534	652	13.9%	534	685	14.6%
	50 (Median)	500	4	386	471	13.9%	386	495	14.6%
		1,000	4	389	475	13.9%	389	499	14.6%
		2,000	4	389	475	13.9%	389	499	14.6%
	100 (Far From Shore)	500	3	273	333	13.9%	273	350	14.6%
		1,000	3	276	337	13.9%	276	354	14.6%
		2,000	3	276	337	13.9%	276	354	14.6%

Thailand Results

Waterbody Type	Sensitivities		Results						
				Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	478	47,787	69,500	16.6%	47,787	72,975	17.4%
		1,000	654	65,401	95,072	16.6%	65,401	99,826	17.4%
		2,000	654	65,401	95,072	16.6%	65,401	99,826	17.4%
	50 (Median)	500	402	40,191	58,442	16.6%	40,191	61,364	17.4%
		1,000	576	57,645	83,781	16.6%	57,645	87,970	17.4%
		2,000	703	70,332	102,193	16.6%	70,332	107,303	17.4%
	100 (Far From Shore)	500	331	33,055	48,053	16.6%	33,055	50,455	17.4%
		1,000	503	50,331	73,135	16.6%	50,331	76,791	17.4%
		2,000	629	62,868	91,328	16.6%	62,868	95,895	17.4%
Natural Waterbody	0 (Close to Shore)	500	1,359	135,875	196,817	16.5%	135,875	206,658	17.4%
		1,000	1,516	151,611	218,815	16.5%	151,611	229,756	17.3%
		2,000	1,516	151,611	218,815	16.5%	151,611	229,756	17.3%
	50 (Median)	500	985	98,535	142,532	16.5%	98,535	149,659	17.3%
		1,000	1,142	114,158	164,373	16.4%	114,158	172,592	17.3%
		2,000	1,299	129,916	185,923	16.3%	129,916	195,219	17.2%
	100 (Far From Shore)	500	680	68,030	98,203	16.5%	68,030	103,113	17.3%
		1,000	835	83,535	119,877	16.4%	83,535	125,871	17.2%
		2,000	992	99,227	141,338	16.3%	99,227	148,405	17.1%
All Suitable Waterbodies	0 (Close to Shore)	500	1,837	183,662	266,317	16.6%	183,662	279,633	17.4%
		1,000	2,170	217,012	313,887	16.5%	217,012	329,581	17.3%
		2,000	2,170	217,012	313,887	16.5%	217,012	329,581	17.3%
	50 (Median)	500	1,387	138,726	200,974	16.5%	138,726	211,023	17.4%
		1,000	1,718	171,803	248,154	16.5%	171,803	260,562	17.3%
		2,000	2,002	200,248	288,116	16.4%	200,248	302,522	17.2%
	100 (Far From Shore)	500	1,011	101,085	146,256	16.5%	101,085	153,569	17.3%
		1,000	1,339	133,866	193,011	16.5%	133,866	202,662	17.3%
		2,000	1,621	162,095	232,666	16.4%	162,095	244,300	17.2%

Vietnam Results

Waterbody Type	Sensitivities		Results						
	Minimum Shore Distance (m)	Maximum Shore Distance (m)	Suitable Waterbody Area (km^2)	Fixed Tilt: Monofacial			Fixed Tilt: Bifacial		
				Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)	Capacity (MW)	Generation (GWh/year)	Average Net Capacity Factor (%)
Reservoirs (including hydropower and non-hydropower reservoirs)	0 (Close to Shore)	500	397	39,651	52,531	15.1%	39,651	55,157	15.9%
		1,000	459	45,930	61,090	15.2%	45,930	64,145	15.9%
		2,000	459	45,930	61,090	15.2%	45,930	64,145	15.9%
	50 (Median)	500	292	29,250	38,932	15.2%	29,250	40,878	16.0%
		1,000	354	35,386	47,300	15.3%	35,386	49,665	16.0%
		2,000	370	37,031	49,543	15.3%	37,031	52,020	16.0%
	100 (Far From Shore)	500	213	21,297	28,472	15.3%	21,297	29,896	16.0%
		1,000	273	27,293	36,650	15.3%	27,293	38,483	16.1%
		2,000	289	28,909	38,854	15.3%	28,909	40,797	16.1%
Natural Waterbody	0 (Close to Shore)	500	520	52,000	66,097	14.5%	52,000	69,402	15.2%
		1,000	537	53,719	68,340	14.5%	53,719	71,757	15.2%
		2,000	537	53,719	68,340	14.5%	53,719	71,757	15.2%
	50 (Median)	500	340	33,965	43,286	14.5%	33,965	45,451	15.3%
		1,000	357	35,659	45,499	14.6%	35,659	47,774	15.3%
		2,000	357	35,728	45,595	14.6%	35,728	47,874	15.3%
	100 (Far From Shore)	500	206	20,618	26,379	14.6%	20,618	27,698	15.3%
		1,000	223	22,284	28,558	14.6%	22,284	29,986	15.4%
		2,000	224	22,353	28,654	14.6%	22,353	30,087	15.4%
All Suitable Waterbodies	0 (Close to Shore)	500	917	91,652	118,628	14.8%	91,652	124,559	15.5%
		1,000	996	99,650	129,431	14.8%	99,650	135,902	15.6%
		2,000	996	99,650	129,431	14.8%	99,650	135,902	15.6%
	50 (Median)	500	632	63,215	82,218	14.8%	63,215	86,329	15.6%
		1,000	710	71,045	92,799	14.9%	71,045	97,439	15.7%
		2,000	728	72,759	95,138	14.9%	72,759	99,895	15.7%
	100 (Far From Shore)	500	419	41,915	54,852	14.9%	41,915	57,594	15.7%
		1,000	496	49,577	65,208	15.0%	49,577	68,469	15.8%
		2,000	513	51,262	67,508	15.0%	51,262	70,883	15.8%