Sun on the Great Lake Can Save the Mekong? Simple Feasibility Analysis of a Tonle Sap Floating Solar Project with Storage System

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INTRODUCTION

Already Cambodia's Great Lake (the Tonle Sap) and Vietnam's Mekong Delta are suffering harmful impacts from the suppression of the Mekong River's annual flood pulse, a consequence of the operation of hydroelectric dams far upstream in Yunnan, China, and on tributaries of the Mekong in Laos and Vietnam. Many more dams are planned; if they are built, Cambodia will see the end of the reverse flow that supports the enormously fecund flood pulse at the Tonle Sap. Subsequently, in the dry season, Vietnam will be starved of the fresh water that supports its delta ecosystem and food security.

This brief proposes an alternative approach, a floating solar power system on the Tonle Sap, built on a scale that will satisfy Cambodia's power needs at lower cost.

Can the Sun on the Great Lake Project Save the Mekong and Vietnam?

The answer is YES and the feasibility analysis in this report seeks to prove that a 25-year program for a 28 GW floating solar project with 4-hours battery storage will meet Cambodia's projected energy need to 2045 at the cost of $31 Billion USD.

The high cost of electricity in Cambodia

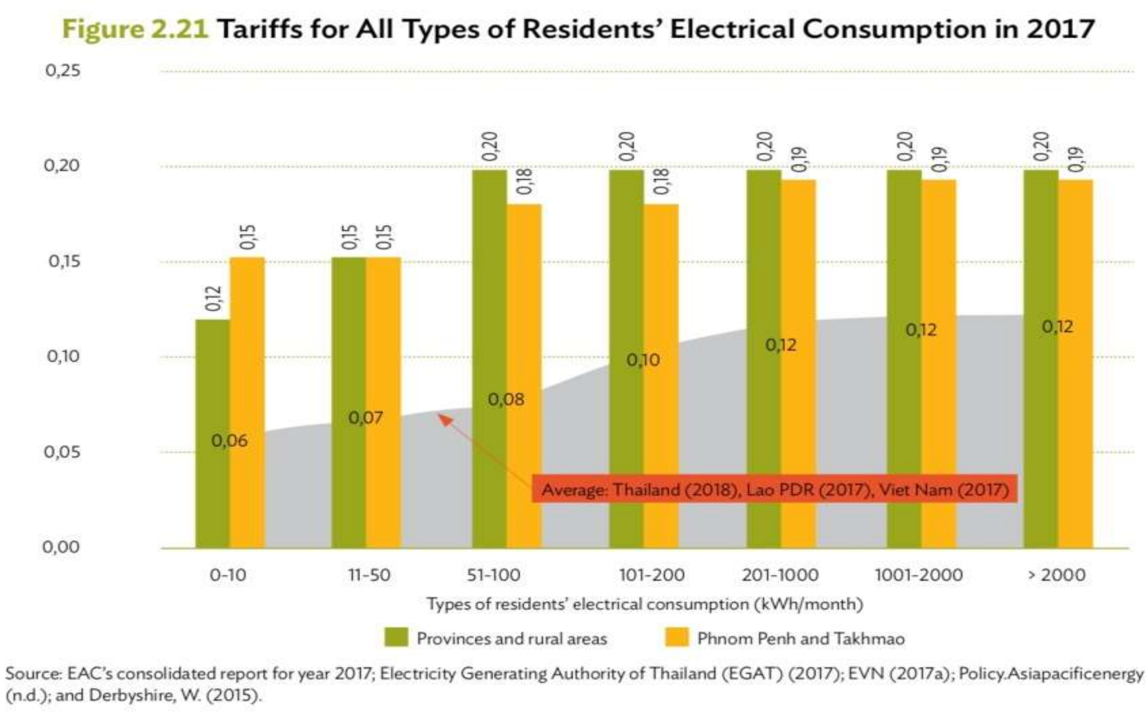

Figure 1. Electricity Prices[3]

Cambodia is the least developed and most energy-thirsty country in Southeast Asia. The price of electricity in Cambodia is the highest[1] in the region, ranging from $0.15 to $0.18 per kWh. In some rural areas the price reaches $0.50 to $1.00 per kWh.[2] By comparison, the price in Thailand ranges from $0.105 to $0.143 per kWh, and in Vietnam from $0.072 to $0.126 per kWh.

Hydroelectricity in C ambodia is not cheap

Cambodia's 2030 energy plan includes several new coal and gas fired power plants plus two giant hydroelectric projects—the run-of-river Stung Treng[4] (980 MW) and Sambor[5] (2600 MW) power plants on the Mekong mainstream. These two hydroelectric projects face strong objection from local communities and from Vietnam.

The International Rivers organization reports that: *The Sambor Dam would be a tragic and costly mistake for Cambodia. Cambodia's fisheries safeguard the food security of millions of subsistence fishers and contribute over 15% to the country's Gross Domestic Product (GDP).*[6]

The Natural Heritage Institute ("NHI"), a U.S.-based international research organization, studied the Sambor Dam project and recommended the Cambodian Government defer any commitment to Sambor Dam and, instead, pursue better alternatives. The NHI reports:

• *Out of a total sustainable fisheries yield in Vietnam and Cambodia of 1.2 million tonnes/year, 38% of all fish are migratory -- 70% of these would be affected because they have their spawning grounds above Sambor, and these will suffer a 100% reduction (because mitigation is not feasible). At a net value to fishermen of USD 1.50/kg, this represents a loss of USD 479 million/year.*

• *On the basis of productivity differences of paddy fields in An Giang province, between fields that receive 2.5cm/year sediment deposition or none, a total value of the sediment load at Sambor of USD 120 million/year is estimated. At a trapping efficiency of 62%, the Sambor reservoir would reduce this value by USD 74 million/year.*

The two hydropower projects together will hold back in their reservoirs 3.8 km3 water and permanently inundate 831 km2 of land. The Sambor and Stung Treng dams will inflict costly damage on the livelihoods of the surrounding population and offer them no compensation. What they produce for the people instead is expensive electricity with harmful effects.

It appears the N.H.I report may have turned Cambodia definitely away from hydropower. Cambodia has signed a 30-year Power Purchase Agreement[7] at 7.7 cents/kWh[8] with Sekong Power and Mineral Company Limited and Xekong Thermal Power Company Ltd from Laos for electricity from coal, a project which will take at least 4 years to construct.

What does this study offer Cambodia?

In July, 2019, the Director General of Electricité Du Cambodge ("EDC") said that he does not wish to see the Sambor and Stung Treng hydroelectric projects as part of Cambodia's future energy development plan.[9] He did not mention an alternative that will meet the country's power needs. Cambodia desperately needs an alternate energy source, and this situation prompts the author of this paper to explore the technical and economic feasibility of a floating solar power generation system (FSS) on the Tonle Sap Lake and propose it as an alternative to the hydroelectric projects and perhaps also some of the coal and gas plants in the current Cambodia energy plan (summarized in Figure 2 below).

Table 2.2 Aggressive Generation Development Plan (revised existing plan)

No.	Type	Capacity (MW)	Year	Total in 2030 (MW)
1	Coal/gas	-1,317	2021–2030: /10 years	1,056
2	Hydro	+3,526	2021–2030: /10 years	5,127
3	Biomass	+301	2031–2030: /10 years	486
4	Solar/wind	+368	2031–2030: /10 years	673

Source: Author (outcome of the dialogue with the Ministry of Mines and Energy).

Figure 2. Cambodia Energy Plan[10]

WHY CHOOSE THE TONLE SAP ("THE GREAT LAKE") for THE FLOATING SOLAR SYSTEM?

The Great Lake (also known as the Tonle Sap) offers overwhelming advantages for a floating solar energy plant:

1. The Great Lake is a huge, centrally located public surface near to Cambodia's capital, Phnom Penh, where 90% or electric demand is concentrated.
2. The Great Lake receives the highest level of solar irradiance in the Mekong River Basin[11].
3. Floating solar arrays produce 11%[12] to 16% more energy[13] than arrays sited on land.
4. Proximity to existing 230 kV national grids means that connection costs will be relatively low (see Figure 3).

Figure 3: Project Location and Cambodia National Grid

Figure 4: Typical floating solar system (14)

Figure 5: Typical Battery Storage Facility

Floating Solar Energy Project on Tonle Sap Lake	
25 yrs Energy Generation, GWh	533,597
Capex, Billion USD	31.04
Fixed O&M, Billion USD	3.71
Battery Replace, Billion USD	6.51
Total Cost, Billin USD	41.26
$/kWh	0.077
$/MWh	77.32
Saving for riparians, Billions/year	0.599
Total	14.975
Net cost	26.28
$/kWh	0.049
$/MWh	49.25

DESCRIPTION OF THE FLOATING SOLAR PLANT

Table 1: LCOE for this project is 7.73 cents/kWh and 4.93 cents/kWh if avoided loss is credited.

1. This proposed FSS is to be constructed in phases over 25 years on the Great Lake. The total capacity is 28.5 GW, with 88 GWh storage, generating 508 tWh in 25 years.
2. The entire project would cover a direct area of 330 km2, gross area of up to 400 km2, which is 15% of the Great Lake's dry season surface and about 2.4% of its wet season surface. At this

relatively small percentage of the Great Lake's total area, the impact of the project on aquatic life would be insignificant. It may even benefit the Great Lake by lessening algae growth and reducing the loss of oxygen.

3. The FSS requires 400 km2 of open water surface area but helps save 831 km2 of permanent land loss to the Sambor and Stung Treng reservoirs (if constructed). The FSS would preserve 15 Billion USD in the inland fisheries economy (as avoided loss to them).
4. The LCOE of 7.73 cents/kWh is slightly more than 7.7 cents/kWh Cambodia would pay for electricity generated at Laos' Xekong coal-fired power plant. The real LOCE to the Cambodia should only be 4.93 cents/kWh since the riparian population will not have to bear the losses associated with the hydroelectric plan.
5. Vietnam was disclosed to be the buyer of 70% electricity generated by the Sambor hydroelectric project,[14] a plant that may not be built. Vietnam's government can look hard at its own energy plan, where the fast-falling costs of renewable energies (including wind and tidal wave energy in addition to solar) should permit it to satisfy its needs more economically and with greatly reduced external costs.
6. Considering that there will be 28 job-years needed for each MWp[15], this project will support 500,000 job-years for Cambodian fishermen.
7. Considering the ecological importance of the environmental flow and the livelihoods of 30 million Mekong people, the next question is, will Cambodia and Vietnam's governments take a step back from hydropower and fossil fuels and formally investigate the feasibility of the floating solar energy as demonstrated in this report?

Based on this feasibility analysis, the Sun on the Lake project can save the Mekong for Cambodia and Vietnam. Solar energy requires that a smart grid and transmission network be put in place and in time to balance fluctuating demand, however solar plants can be constructed to supply electricity in matter of months and can be phased in as demand is confirmed, a feature that no other source can match.

About the Author

Long P. Pham has 40 years of experience as a Professional Mechanical Engineer in California, he is the founder of the Viet Ecology Foundation, an NGO's based in the US. Mr. Pham founded Moraes/Pham & Associates, Inc. and Advanced Technologies Consultant Inc. and serves as its Principal-in-Charge, directing Facility, Safety and Code Compliance projects for advanced semiconductor and pharmaceutical companies such as Hughes, Genentech, ASML Cymer, AMCC, ABOTT, Solar Turbines. He was the responsible design engineer for the HVAC system at the Orange County GWR Advanced Water Treatment Plant, the project is recognized as a significant engineering contribution of the Century that won the Orange County the prestigious international Centenary Award.[16]

Awards

- 1985 Engineer of the Year, American Institute of Plant Engineers, San Diego, CA.
- 1986 Award of Merit - Facility Management Excellence for Pioneering Semiconductor Safety, AIPE.
- 1987 Water Conservation Award – Best Industrial Water Conservation Project – San Diego County Water Authority.

- 2008 HVAC Engineering – California Recycled Water Project of the Year by American Society of Civil Engineers

Appendix 1

METHODOLOGY

The purpose of this study is to formulate a floating solar system with battery storage over the next 25 years that can meet the projected Cambodian demand for electricity in lieu of the planned hydroelectric and possibly some additional the thermoelectric plants. This study follows the following approach:

1. **Energy Demand**: The Asian Development Bank provided an energy forecast in GWh for Cambodia to 2030 [17]. Their data is further extrapolated to 2045, using trend line technique and polynomial function.
2. **Global Tilt Irradiance and Optimal Tilt Angle**: Utilize Global Solar Atlas Solar Calculator [18][19] on-line to select project coordination, determine energy generation potential based on the panel optimal tilt angle ("OPTA").
3. **Lake-use footprint**: The National Renewable Energy Laboratory provided Calculations Method for Solar Energy's direct (net) and total (gross) land-use footprint [20] in terms of acres/MWac and acres/GWh/year. They equate to capacity of 42.59 MW/km2 and energy generation of 88.9 GWh/km2/year direct land area. With 10% additional energy credit due to lower ambient floating surface, the energy generation level of 97 GWh/km2/year direct land area is used in this report. Note that Dau Tieng achieves 138 GWh/km2/year. A service factor 130% is applied to allow for service access to the floating panels.
4. **Solar panel degradation**: The direct area, km2 of solar panel required to harvest the GWh needed each year for the 25 years can then be calculated. SunPower report [21] that solar panel degradation to 78.8% in 25 years life.
5. **Floating solar system cost**: NHI estimated the cost of $900/kWp for their proposed 400 MW floating solar project on LSS2 reservoir, and the 1.17 GW Noor Abu Dahbi costs $769/kWp [22], for this project World Banks low cost figure $800/kWp [23] is used.
6. **Battery storage**: This project is initially to have a 2, then 3 and then 4-hours energy storage system. $4-Hour is the same practice as several recent energy storage projects for utilities in Hawaii [24], California PG&E [25] and Los Angeles LADWP [26].
7. This study uses NREL [27] published utility battery price of $375/kWh in 2020 decreasing to $110/kWh in 2045 for 4-hour lithium-ion systems.
8. This study allows battery cost to decrease 2% annually.
9. Battery storage facility and transmission network is included in battery cost.
10. Compare cost of energy between FSS and current hydroelectric and thermoelectric plans.
11. Estimate number of jobs generated by this project.

Appendix 2

FLOATING SOLAR PROJECT INPUT PARAMETERS

The following are parameters used in this report for analysis:

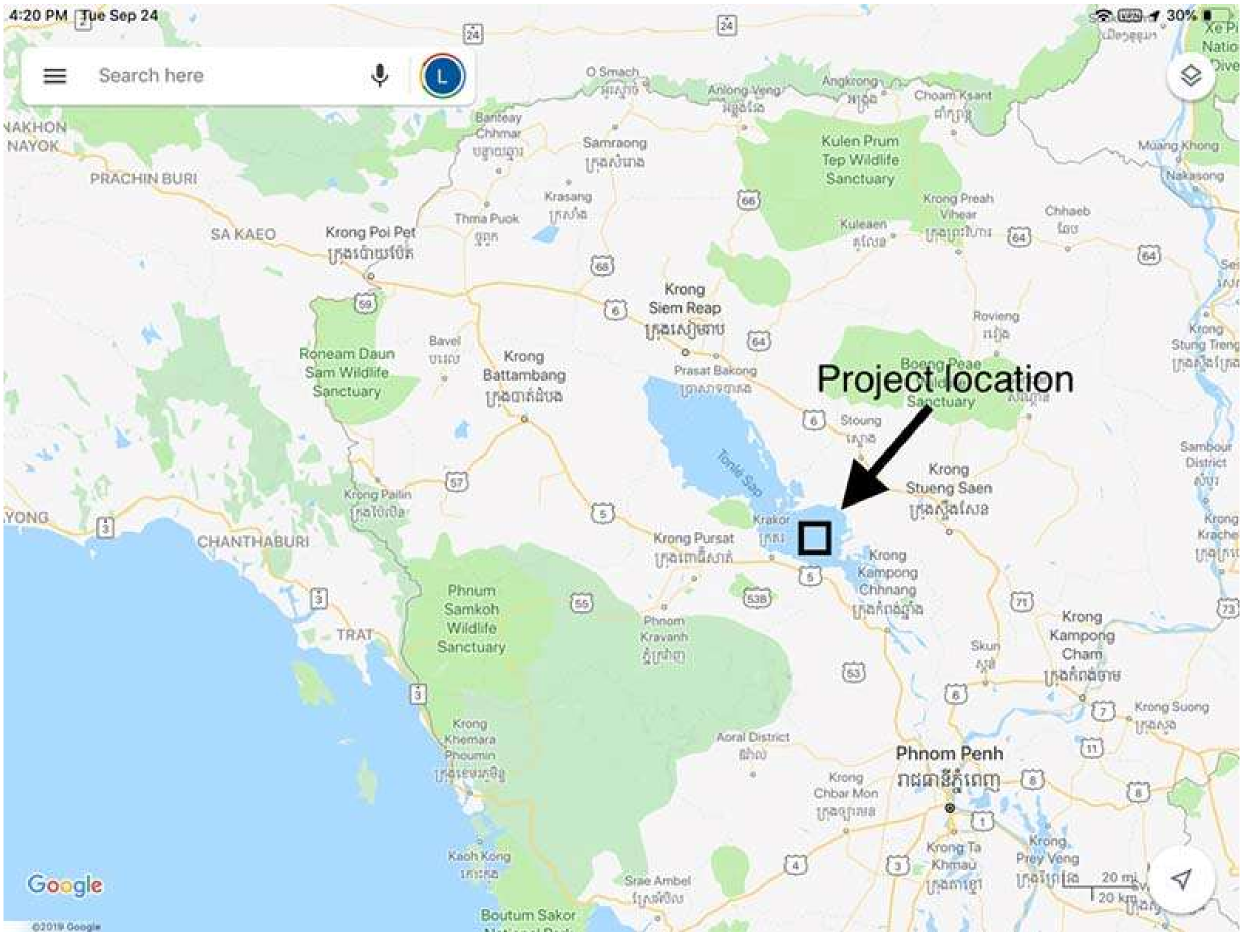

Figure 6: Floating Solar System Proposed Location and Size

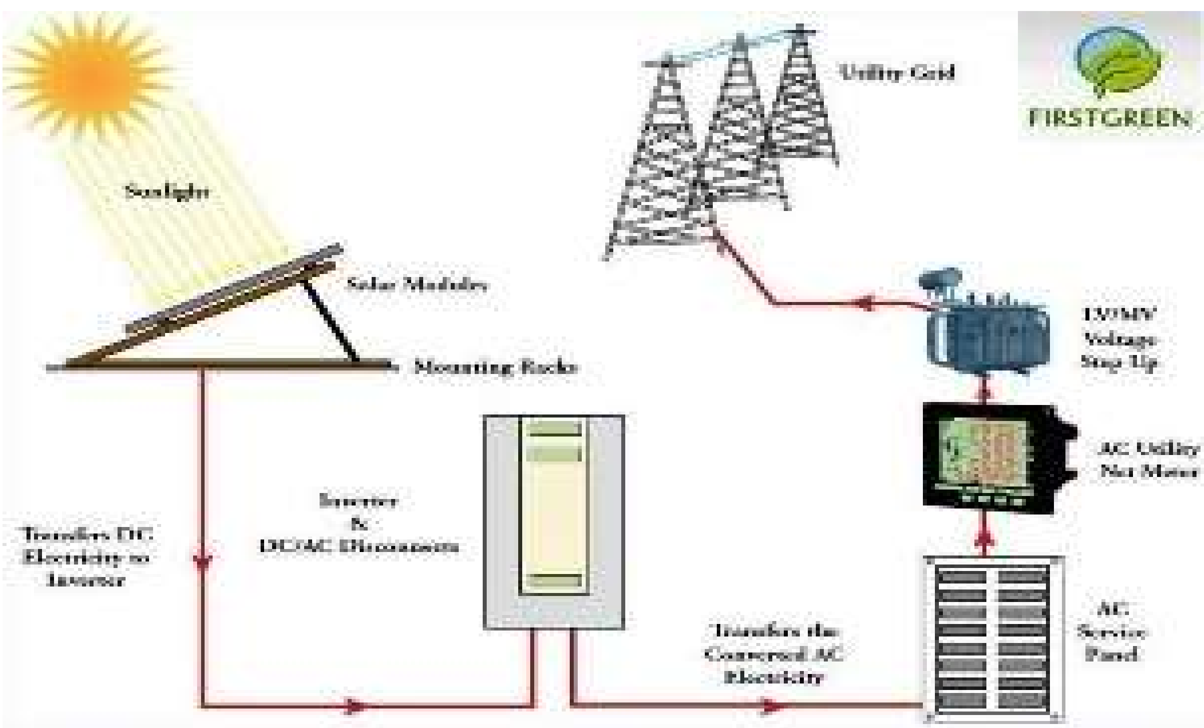

Figure 7: Typical Schematic Diagram Solar Power System

1. Projected harvestable solar energy is generated from World Bank Global Solar Atlas [28] for this report and presented in Figure 5. Photovoltaic output ("PVOUT") of 1567 kWh/kWp/yr, Global Horizontal Irradiance, GHI 2032 kWh/m2/year.
2.

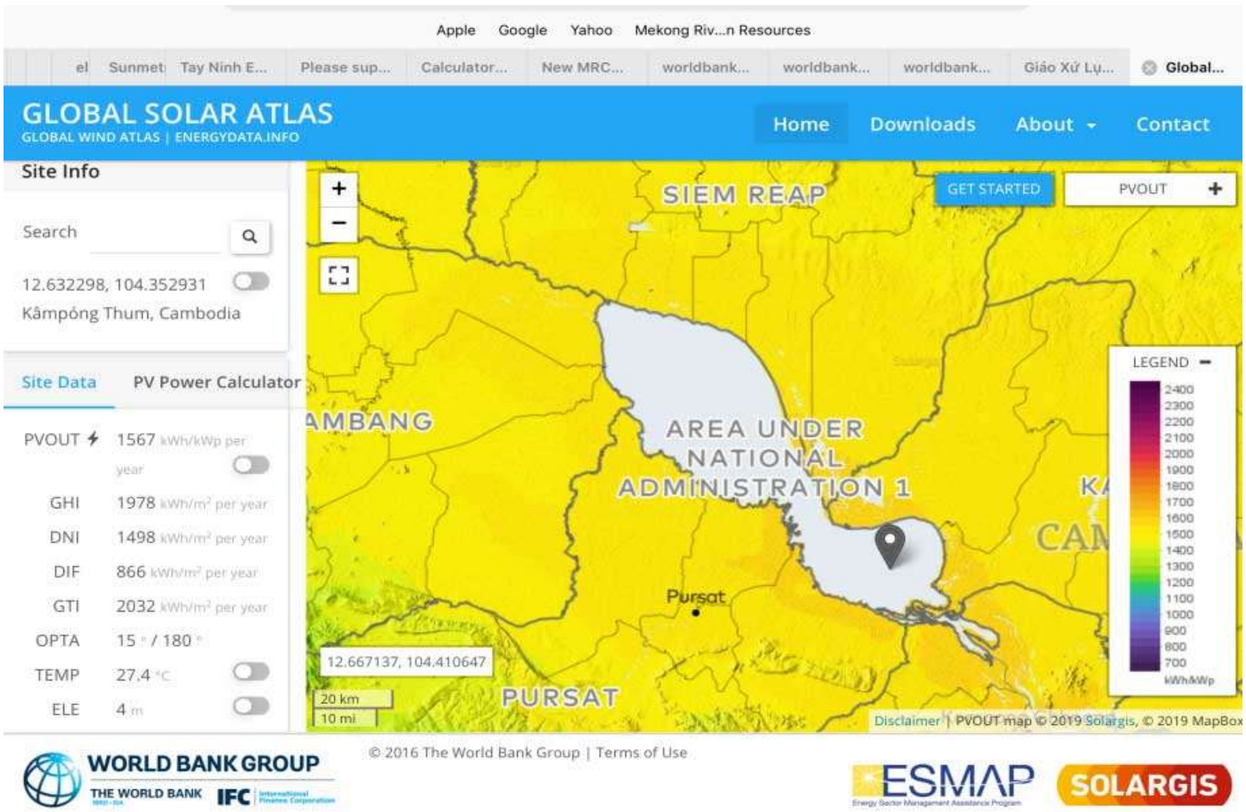

Figure 8: Tonle Sap Lake PVOUT Solar Resource 1567 kWh/kWp/year [29]

- The amount of the Great Lake's surface area required depends on the solar cell efficiency. The Global Solar Atlas model is based on a crystalline silicon (c-Silicon) module at about 17% efficiency. The OPTA is 20 degrees. A 20% extra area is allowed for service access allowance.
- The life span for the project is generally accepted to be 25 years.
- Solar panel degradation is 0.848% per year, to 78.8% [30] after 25 years is factored in this report.
- Capital expenditure for energy storage starts at $375/kWh for 2020 and gradually drops to $110/kWh (National Renewable Energy Laboratory [31] reports that the storage cost is $380/kWh).
- Battery is sized for 2, 3 and then 4 full load hours to provide dispatch ability.
- Battery is to be replaced in year 12.
- Fixed O&M cost is $10 Mil/GW/year [32].
- Capacity factor is 17%, although 20% is likely possible.
- Project to have 25 phases over 25 years.
- Generation is to produce enough energy to fully satisfy Cambodia's projected growth demand.
- Note that LCOE does not include financing issues, discount issues, future replacement, or disposal costs. Each of these would need to be included for a thorough analysis.

CALCULATIONS TABLE

Cambodia - Floating Solar Energy Project Potential on Tonle Sap Lake																					
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	R
Project	Phase	Year	Accum Lake Area used (km2)	Accum Solar (% Lake area)	Solar Area (% Lake)	Solar Area (km2)	Min reservoir area (km²)	Max reservoir area (km²)	Solar (GW)	Total (GW)	Cost Solar Mil/GW @2% Less/yr	Cost solar (Bil USD)	Cost Battery Mil/GW	Cost of Storage (Bil USD)	Storage hours	Replace battery Year 12 (Bil USD)	Fixed O&M $10 (Mil USD/GW/yr)	Capex Solar w Storage (Bil USD)	Total Solar Generation (GWh/yr)	Solar Capacity Added (GWh/yr)	Demand (GWh)
Tonle Sap Floating Solar and Storage System	1	2021	13	0.49%	0.49%	13.20			1.14	1.14	770	0.88	300	0.68	2.00		11	1.57	1,690	1690	
	2	2022	26	0.96%	0.49%	13.20			1.14	2.28	755	0.86	285	0.65	2.00		23	1.53	3,111	1690	
	3	2023	40	1.43%	0.49%	13.20			1.14	3.42	740	0.84	271	0.62	2.00		34	1.49	4,775	1690	
	4	2024	53	1.90%	0.49%	13.20			1.14	4.56	725	0.83	257	0.59	2.00		46	1.46	6,424	1690	
	5	2025	66	2.38%	0.49%	13.20			1.14	5.70	710	0.81	244	0.56	2.00		57	1.42	8,060	1690	
	6	2026	79	2.85%	0.49%	13.20			1.14	6.84	696	0.79	232	0.53	2.00		68	1.39	9,681	1690	
	7	2027	92	3.32%	0.49%	13.20			1.14	7.98	682	0.78	221	0.50	2.00		80	1.36	11,289	1690	
	8	2028	106	3.79%	0.49%	13.20			1.14	9.12	668	0.76	210	0.48	2.00		91	1.33	12,883	1690	
	9	2029	119	4.26%	0.49%	13.20			1.14	10.26	655	0.75	199	0.68	3.00		103	1.53	14,464	1690	
	10	2030	132	4.74%	0.49%	13.20			1.14	11.40	642	0.73	189	0.65	3.00		114	1.49	16,032	1690	
	11	2031	145	5.21%	0.49%	13.20			1.14	12.54	629	0.72	180	0.61	3.00		125	1.46	17,586	1690	
	12	2032	158	5.68%	0.49%	13.20			1.14	13.68	617	0.70	171	0.58	3.00		137	1.42	19,126	1690	
	13	2033	172	6.15%	0.49%	13.20	2,700	16000	1.14	14.82	604	0.69	162	0.55	3.00	0.55	148	1.95	20,654	1690	
	14	2034	185	6.62%	0.49%	13.20			1.14	15.96	592	0.68	154	0.53	3.00	0.53	160	1.89	22,169	1690	
	15	2035	198	7.10%	0.49%	13.20			1.14	17.10	580	0.66	146	0.50	3.00	0.50	171	1.83	23,671	1690	
	16	2036	211	7.57%	0.49%	13.20			1.14	18.24	569	0.65	139	0.48	3.00	0.48	182	1.78	25,160	1690	
	17	2037	224	8.04%	0.49%	13.20			1.14	19.38	557	0.64	132	0.60	4.00	0.60	194	2.03	26,637	1690	
	18	2038	238	8.51%	0.49%	13.20			1.14	20.52	546	0.62	125	0.57	4.00	0.57	205	1.97	28,101	1690	
	19	2039	251	8.98%	0.49%	13.20			1.14	21.66	535	0.61	119	0.54	4.00	0.54	217	1.91	29,553	1690	
	20	2040	264	9.46%	0.49%	13.20			1.14	22.80	525	0.60	113	0.52	4.00	0.52	228	1.86	30,992	1690	
	21	2041	277	9.93%	0.49%	13.20			1.14	23.94	514	0.59	108	0.49	4.00	0.49	239	1.81	32,419	1690	
	22	2042	290	10.40%	0.49%	13.20			1.14	25.08	504	0.57	102	0.47	4.00	0.47	251	1.76	33,835	1690	
	23	2043	304	10.87%	0.49%	13.20			1.14	26.22	494	0.56	97	0.44	4.00	0.44	262	1.71	35,238	1690	
	24	2044	317	11.34%	0.49%	13.20			1.14	27.36	484	0.55	92	0.42	4.00	0.42	274	1.67	36,629	1690	
	25	2045	330	11.82%	0.49%	13.20			1.14	28.50	474	0.54	88	0.40	4.00	0.40	285	1.62	38,008	1690	
								Total	28.50	Total	15267	17.40	Total	13.64	Total	6.51	3705	41.26	508188		

Table 2: Energy and Cost Calculations

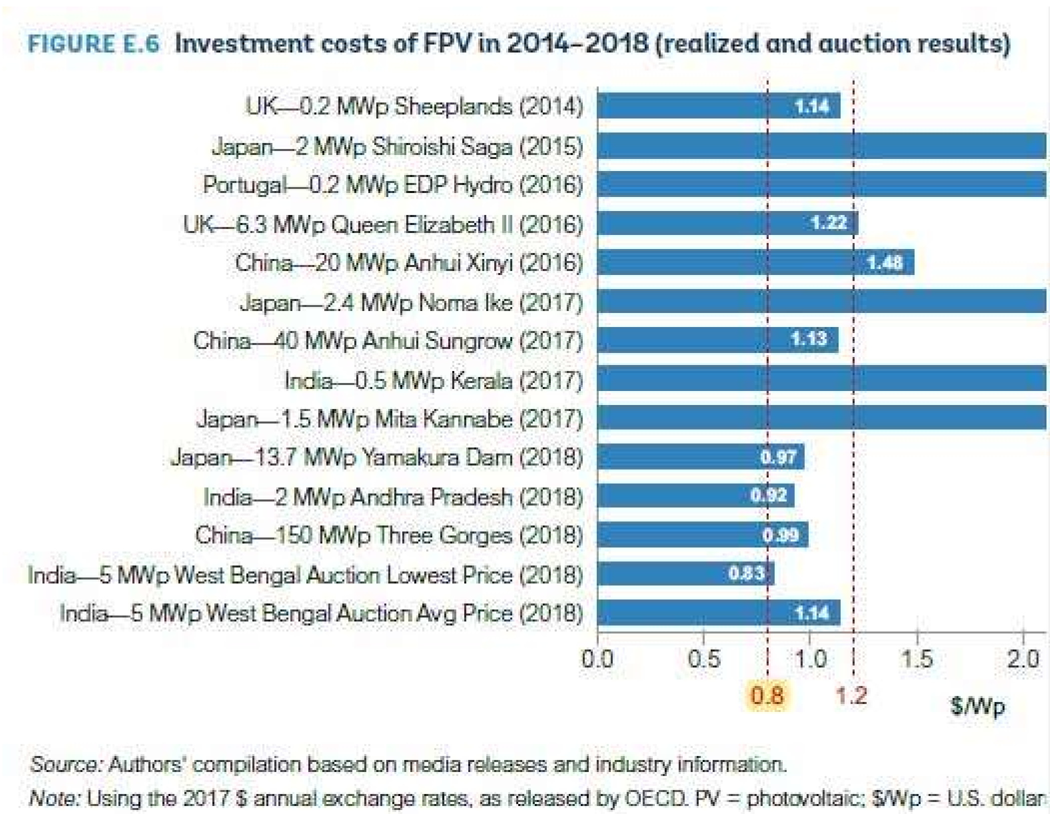

Figure 9: World Bank FPV Cost Projection [33]

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