STAReBEI Project: Floating Solar, Global Market & Potential

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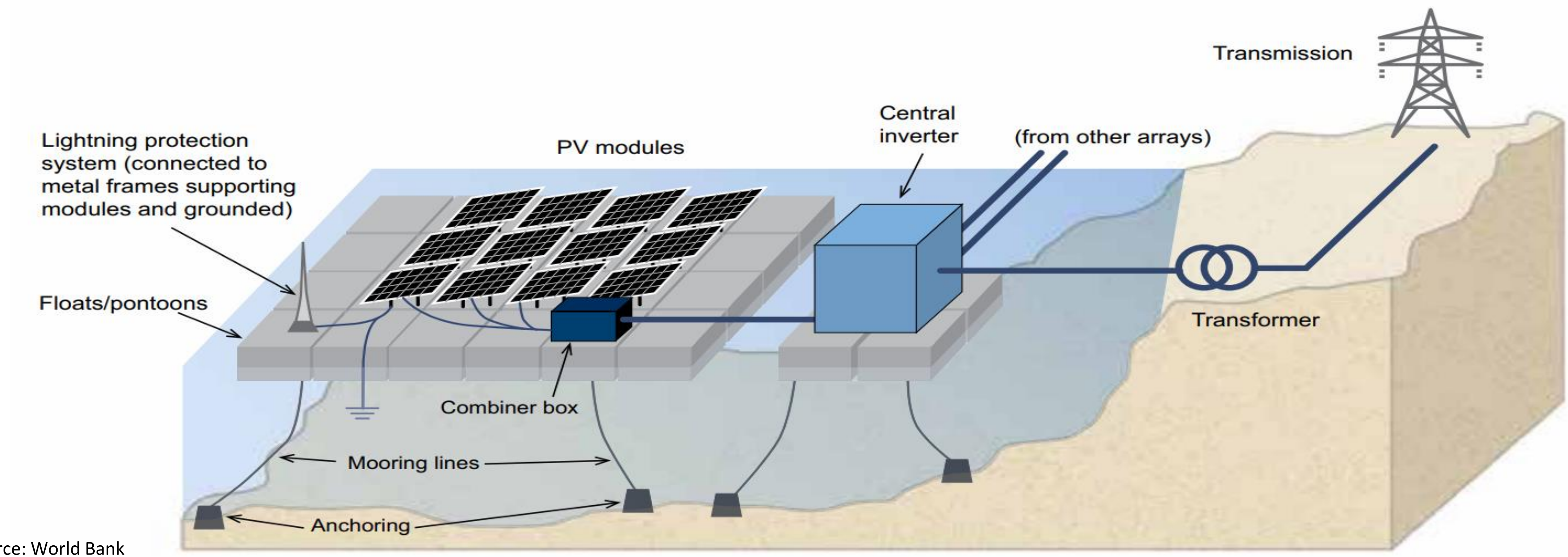


Source: World Bank

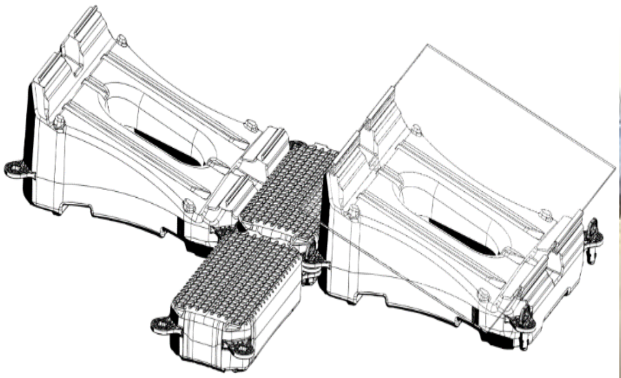
Floating Solar PV

- Similar to ground-mounted system with the addition of the floating structure and the anchoring and mooring system
- Typically developed on artificial water reservoirs due to the gentler environmental conditions. FPV configurations are highly site-specific, installation techniques vary greatly depending on location. Costs dependent on the complexity of the waterbody and local environment
- FPV developers relied on making ground-mounted PV components work in the aquatic environment, but developers are starting to make FPV-specific components

Pure-float

- Currently the most popular configuration in the market
- Mainly used due its scalability + Easy and quick to installation
- Configuration used by: Sungrow and Ciel & Terre

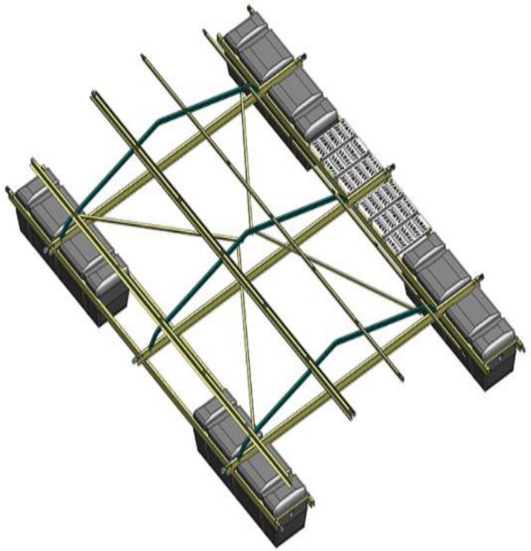
Source: Ciel &Terre



Floating metal structure

- Attaches the PVs onto pontoons or pipes to create buoyancy or uses metal structures to support the PV panels
- More similar to configurations seen on land-based systems
- Configuration used by: Zimmermann/Baywa r.e.

Source: Baywa r.e.



FPV Advantages

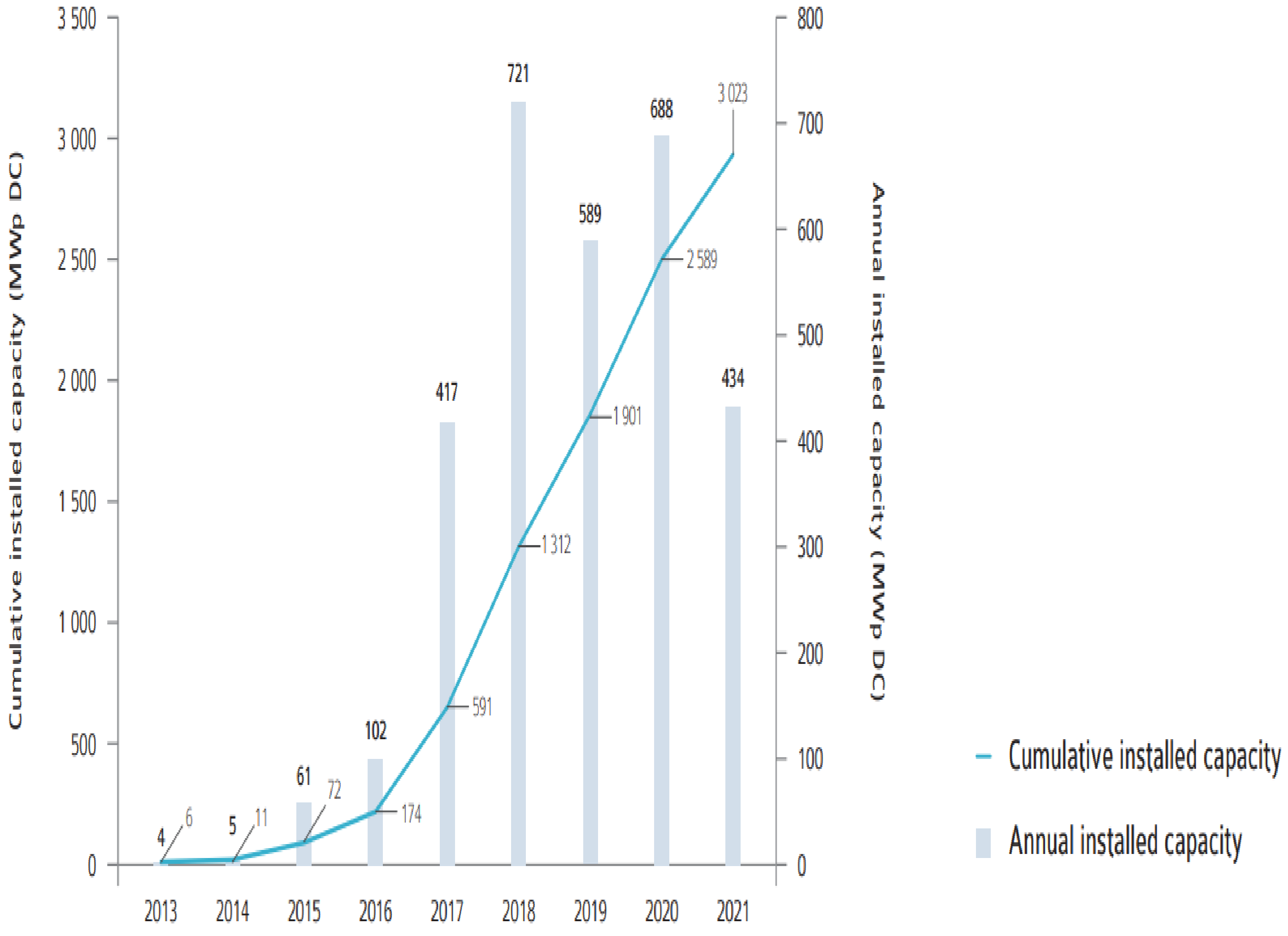
- **No land occupancy**: FPV do not take up any land, thereby providing a way to avoid competing with other land interested parties
- **Installation and decommissioning:** FPV plants do not require land clearing and the systems can in most cases be easily installed and removed, unlike the foundations used for ground-mounted plants
- **Grid connection:** When coupled with hydropower plants, the possibility to utilize the existing infrastructure can reduce the cost of installing a floating PV plant
- **Cooling effect:** Siting on water improves energy yields by reducing solar module temperatures. The effect depends on location and climate patterns. Estimated: 3% within colder climates, and 6% within warmer climates
- **Water saving:** Partial coverage of the waterbody reduces water evaporation. Effect will depend on climate conditions and on the percentage of the surface that is covered
- **Reduced dust particles and vegetation:** FPV plants are less exposed to dust and vegetation issues compared to ground-mounted system, may require less regular

FPV Challenges

- **Higher costs**: FPV requires special equipment and personnel. Costs differ significantly depending on environmental conditions, water depth, reservoir size, soil conditions, and anchoring options
- **Complex anchoring and mooring systems**: Installations are highly site-specific and might require more complex anchoring and mooring system to handle wind and wave pressures. limited ability to standardize
- **Negative wind, wave, and snow effects:** Microcracks can from in the solar cells, or the floating platforms due to the constant movement. Potentially affecting system stability or performance, increasing maintenance and repair costs
- **Coverage limitations**: Normally 1–10% coverage to reduce environmental impact and restrict installations from the littoral zone where aquatic life is most present. Uncertainty about environmental impacts may increase local opposition or complicate environmental review processes
- **Water use conflicts**: The selected waterbody may already be used for leisure or recreational activities, which can pose significant challenges for developers
- **Limited experience and knowledge gaps:** Limited experience of long-term effects that may negatively impact installations later in the life cycle

Evolution of the FPV market

- First FPV system built in Japan in 2007
- Utility-scale systems developed since 2013
- Over 70 countries are developing or operating FPV projects
- More then 1000 projects active or in development
- FPV electricity output estimated at 3 GW



Source: IEA-PVPS 2021

Potential & Growth Trends

- Growth factors: Land scarcity, aggressive renewable energy targets, falling PV costs, and FPV-specific subsidies
- Industry growth will segment within Asian markets, currently accounts for 66% of all new project development. China to remain the dominant market, but other Asian countries will catch up
- Growth outside Asia primarily driven within Europe. Mainly because European countries also face space constraints for ground-mounted solar
- European FPV installations centred within France and the Netherlands. Portugal, Spain and Germany developing large-scale projects
- Very little development outside of these two continents

Global FPV Potential by continent

Continent	Africa	Asia and the Middle East	Europe	North America	Oceania	South America	Total
Total Surface Area (km2)	101,130	115,621	20,424	126,017	4,991	36,271	404,454
No. of waterbodies	724	2,041	1,082	2,248	254	299	6,648

Source: World Bank

Global Market

- Significant development in the last two years – continued trend toward increasing project scale
- Estimated market growth: 5GW-10GW
- First GW projects in South Korea and Indonesia
- Several new countries embracing FPV Development

The 10 largest FPV projects globally

Taiwan	181 MW	Chengua County	Chenya Energy	2020
China	320 MW	Changhe and Zhouxiang reservoirs in Cixi	Hangzhou Fengling Electricity Science Technology	2020
China	550 MW	Wenzhou, Zhejiang Province	Chint Group	2021
Vietnam	500 MW	Laly hydropower reservoir, Dong Nai	Blueleaf Energy Asia	2021
Thailand	45 MW	Sirindhorn Dam, Chanin Saleechan	B.Grimm Power, Energy China	2021
Indonesia	145 MW	Citara, West Java	Masdar Solar Energy	2022
India	600 MW	Omkareshwar Reservoir, Madhya Pradesh	Tender process ongoing	2023-2024
Laos	240 MW	Nam Theun 2 hydropower plant, Khammouane	Electricité De France – EDF	2024
South Korea	2100 MW	Saemangeum floating solar energy project	SK E&S, Ocean Sun, Hanwha Q Cells	2025-2030
Indonesia	2200 MW	Duriangkang reservoir, Batam Island	Sunseap, BP Batam	2024-2025

Market Players

FPV project developers

Solar Renewable Energy LLC, Etihad Energy Services, KYOCERA, acciona, edp renewables, VATTENFALL, SECI SUN FOR EVER, akuoenergy Entrepreneurs par nature, eni.com, lightsource bp Powered by Hassan Allam Utilities, GCL SYSTEM INTEGRATION, 中国长江三峡集团公司 China Three Gorges Corporation, n-s-e new southern energy, D3 energy Clean Energy. Made Daily, Hanwha, SunAsia Energy, Inc, adpo, SCG, GroenLeven zonne-energie, BayWa r.e., KHNP Korea Hydro & Nuclear Power Co. Ltd, SUNGROW, Ciel & Terre, isigenere, Scotra

Floating structure vendors

SUNGROW, Ciel & Terre, isifloating floating solar system by isigenere, Scotra, ZIMMERMANN PV-Stahlbau, Ocean Sun, NRG ISLAND, BOSCH, do My BesT, to be the best! MIBET ENERGY, YELLOW TROPUS, Upsolar FLOATING SYSTEMS, ADTECH SYSTEMS LIMITED, SOLARISFLOAT, SUNLIT SEA, Sunfloat®, PROFLOATING, Oceans of Energy, SMCC Taiwan Co.,Ltd, SUN RISE 旭東環保科技股份有限公司 SUN RISE E&T CORPORATION, Koiné Multimedia, texel4trading, KYORAKU, Swimsol, Floating Solar

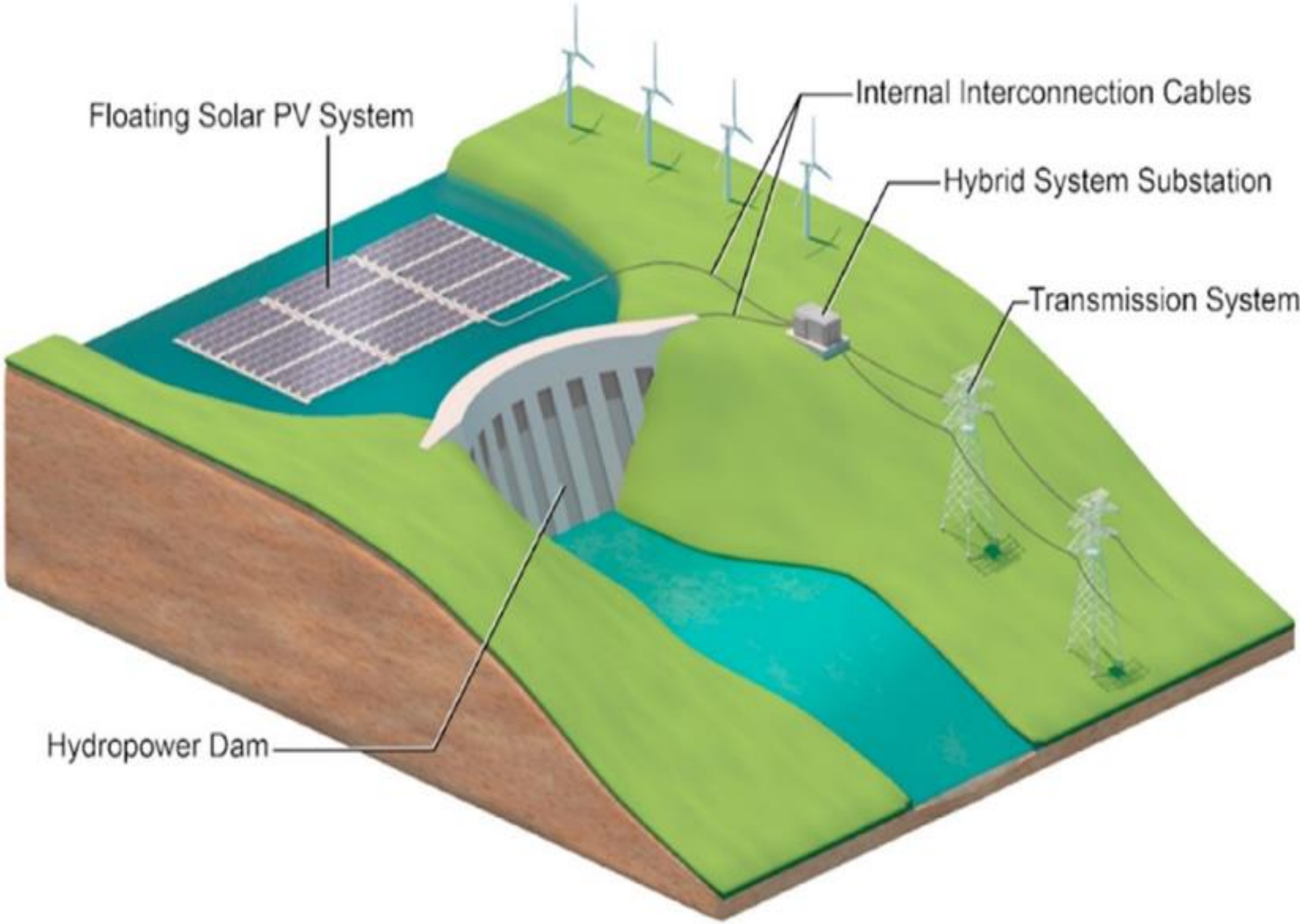
Mooring & anchoring vendors

Hazelett MARINE, Seaflex®

Source: Cox 2021

Hydropower-connected FPV

- Hybridized generation from both hydro and solar allows the systems to benefit of each other, increasing overall capacity, while reducing intermittency
- Hybridization seen as a cost-effective option to increase grid flexibility, while integrating non-dispatchable energy sources
- The hydropower plant functions as a real-time compensator for the variable solar plant allowing the hydroelectric dam to retain water during peak irradiance hours
- Especially beneficial in regions with distinct dry and wet season - Reducing seasonal variations in power production

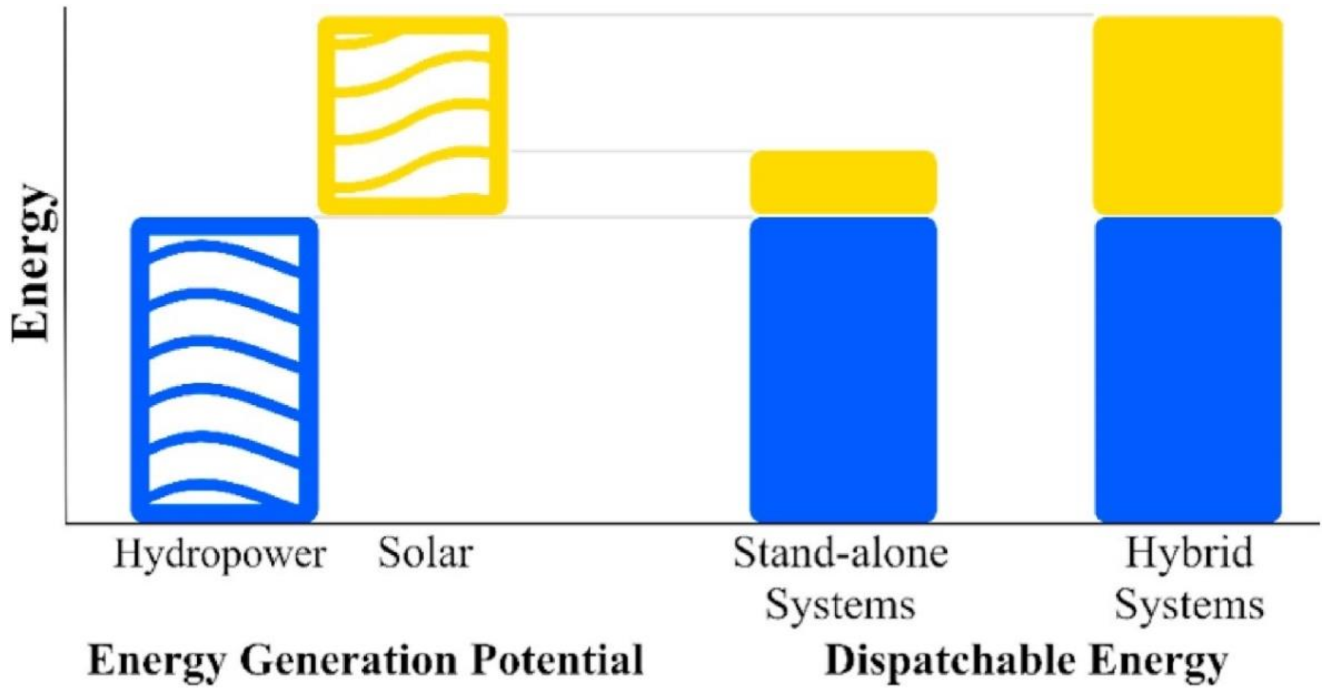


Source: Lee et al. 2021

Hybrid System configurations

- **Co-located hybrid systems**: Rely on the cost optimization of siting assets together to reduce capital costs, but the power systems operate separately without combining generation at any point.

- **Full hybrid systems:** Utilize interconnection to achieve performance improvements through co-optimization of the energy assets with one dispatchable and one variable energy asset.



Hydropower-connected FPV Potential

- EU-funded study analysed Africa's 146 largest hydropower dams. Installing FPV systems, with 1% coverage rate, increased power generation equal to 58% of the overall hydropower output
- NREL assessed 379,068 hydropower water reservoirs and found the energy potential of FPV systems to be between 3 and 7.6 TW per year, from the FPV systems alone
- A 1 MW hydropower plant working alongside an equivalent 1 MW FPV facility found the energy contribution of the FPV system to be 27% on average over a year.

Hydropower Dams and their estimated FPV coverage rate to match generation

Dam/Reservoirs	Reservoir size (km2)	Hydropower Output (GW)	% Of reservoir area required for FPV to match hydropower output
Bakun Dam (Malaysia)	690	2.4	3
Lake Volta (Ghana)	8,500	1.0	<1
Guri Dam (Venezuela)	4,250	10.2	2
Sobradinho "Lake" (Brazil)	4,220	1.0	<1
Aswan Dam (Egypt)	5,000	2.0	<1
Attaturk Dam (Turkey)	820	2.4	3
Narmada Dam (India)	375	1.5	4

Source: World Bank and Global Solar Atlas

Hydropower-connected FPV benefits

- **Enhanced grid stability and flexibility:** FPV hybrid capabilities increases renewable energy generation and enhances flexibility., taking advantage of seasonal climate variation to maximize energy production
- **Making solar dispatchable:** Hydropower's storage capacity reduces the variability of solar energy, making it more dispatchable and facilitating better integration of solar energy onto the grid
- **Modernizing hydropower plants:** Modernization processes are very expensive, while only yielding an increased generation capacity of between 5-10%. FPV systems strengthens the business case for dam operators facing the task of renewing their plants
- **Hybridizing underperforming dams:** Brazil currently has 12 GW of underperforming hydropower capacity because of Increased water evaporation due to higher temperatures and more intense draughts. The partial shading of the reservoir reduces water temperature, conserving water

Hydropower-connected FPV challenges

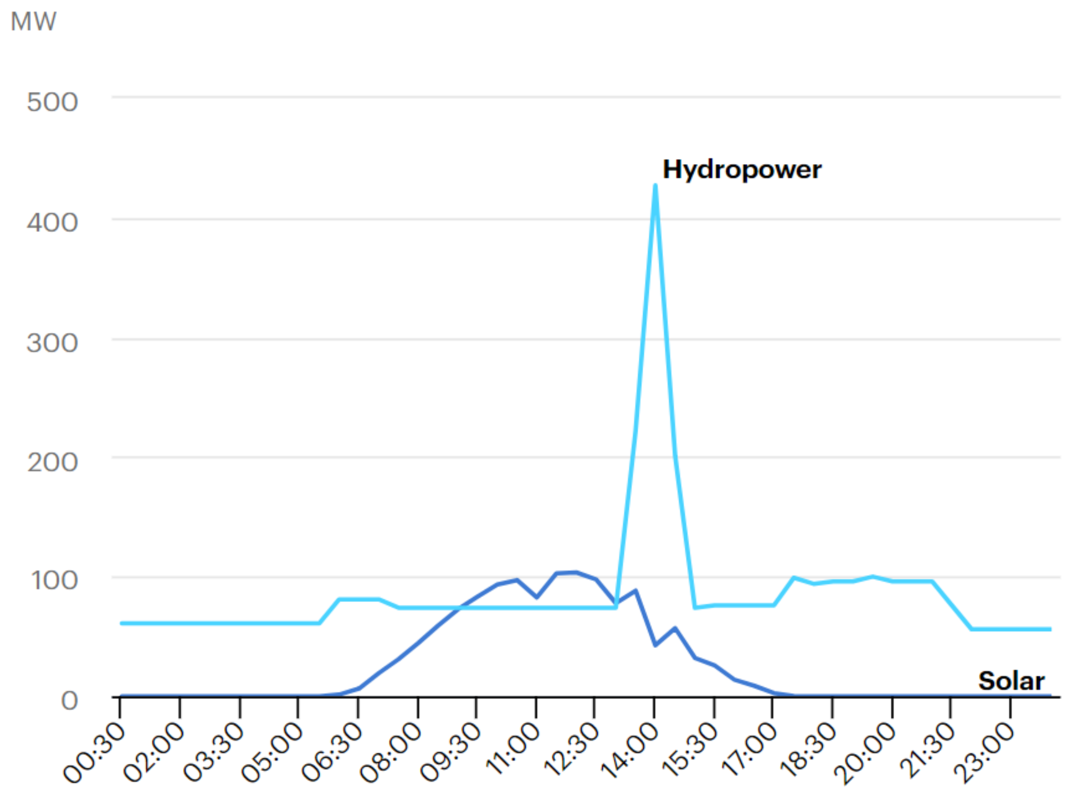
- **Higher costs:** FPV installations used in hydropower-connected systems require more intricate mooring and anchoring systems capable of handling extreme environmental pressures
- **Environmental challenges:** Many reservoirs face water level variance, drifting, and needing to maintain constant cable tension, making the installation more complex
- **Fatigue on structure components due to constant weather exposure:** Connection points between platforms, cables, and anchors are highly susceptible to damage and may need to be strengthened
- **Safety issues:** Developing FPV systems could directly, or indirectly, effect the structural integrity or functionality of the dam, and system damage or failure within hydropower reservoirs carries a significantly higher risk profile
- **Water flow issues:** Installing FPV plants could require changing water flows and/or creating a new water body, which may disrupt access to the dam waterbody
- **Regulatory issues**: The regulatory framework is usually not set up to allow energy assets to be hybridized. Often unclear who has the authority to issue permits or grant regulatory approvals

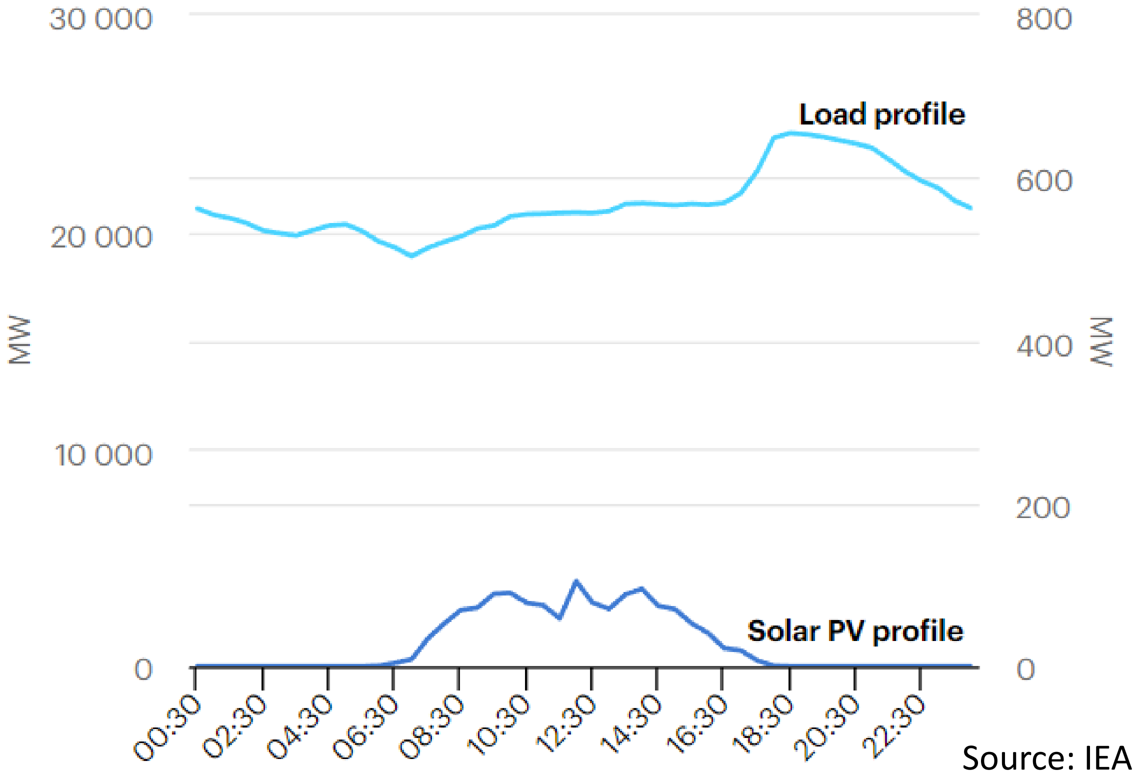
Portugal’s Hydropower-connected FPV Tender

- The auction comprised hydropower-connected FPV projects across seven different dams. Projects as large as 100 MW. The auction allocated 163 MW of FPV capacity.
- Sites were pre-selected, and bidders could choose between a fixed tariff, or a contribution to the system, letting the developer pay an amount in exchange for network access
- EDP: 100 MW project, to be built under a contract for difference regime at a negative price of €-0.04103/kWh over 15 years, meaning EDP will pay the electrical system €4 for each megawatt-hour it generates
- The other fixed tariff project concluded with a price of €0.04103/kWh, meaning the projects were priced in line with the regulators expected price of €0.041025/kWh
- Finerge, Voltalia, and Endesa also won bids for projects agreed through the electricity system compensation scheme
- The auction showcased the potential that exists in hybridizing FPV with hydropower. Remains to be seen if these prices are achievable across locations or are a result of impressive pre-design measures and preferential financing conditions.

Hydropower & Solar generation at Citarta, hydropower-connected FPV plant in Indonesia

- Full-hybrid 145 MW FPV combined with a 1,08 GW hydropower facility
- Scare water availability meant the hydro plant was mainly used to meet afternoon and evening peak demand
- Integration with FPV provides solar output to displace some of the afternoon hydro generation, shifting it to meet the evening peak





Source: IEA 2022

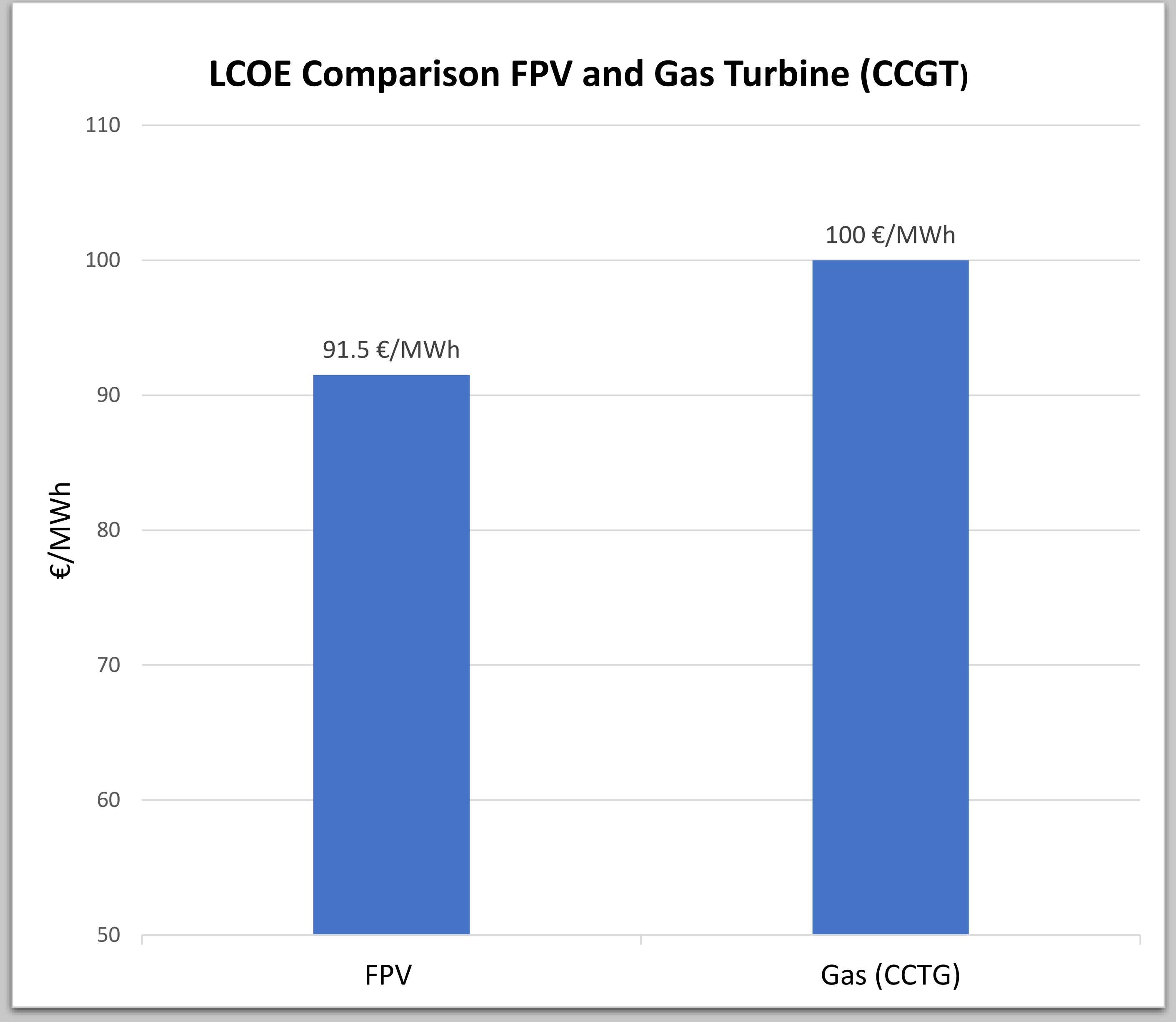
Economic Analysis

- FPV systems are more expensive than ground-mounted systems (10-50%) depending on market maturity
- Higher non-hardware related soft costs, structural costs, and balance of system costs. Up to 35% of project costs for FPV systems, compared to 10% in a ground-mounted systems
- FPV projects tend to be priced more competitively in markets with more experience, such as China, South Korea, and India
- Larger projects benefit from economies of scale effects. For example, float costs are significantly reduced when bought at a higher volume
- 2 MW plant float costs: $0.40/W. 50 MW plant float cost: $0.20/W

LCOE Analysis

- FPV systems encounter a cost-premium of 41.5 €/MWh (46.1%) compared to ground-mounted PV systems within the Dutch market
- Highly competitive compared to (CCGT) gas generation, which is the EU's most likely fossil-fuel substitute
- Gas plants achieve an estimated LCOE of 100 €/MWh
- FPV projects are still financially viable in their own right
- Business case enhanced when the abetment of potential negative externalities and energy savings are considered

Key Financial and Economic Indicators	Unit	Base Case
LCOE	€/MWh	91.5
FIRR	%	3.8%
ERR	%	5.2%
Unit cost	€/kW	986.9
Load Factor	%	11.8%



Unit	Base Case	Generation increased by 15%	CAPEX decreased by 10%	OPEX decreased by 20%
LCOE €/MWh	91.5	79.6	83.4	89.5
IRR %	3.8%	5.6%	5.0%	4.1%
ERR %	5.2%	7.1%	6.5%	5.5%
Unit cost €/kW	986.9	986.9	888.2	986.9
Load factor %	11.8%	13.6%	11.8%	11.8%

Sensitivity Analysis – Potential positive impacts

- FPV technologies still in an early phase of development. Could generate cost reductions through improvements and players entering the market
- The Dutch market has matured considerably over the last couple of years. room for further improvement
- Low technology risk – Significant potential for optimization, new technical solutions, and improvements
- The Netherlands has numerous, shallow waterbodies that can be developed, an ideal scenario for optimization and standardization

Indicator	Base Case	Lower generation by 15%	CAPEX increased by 10%	OPEX increased by 20%	PPA tariff decreased 20%
LCOE EUR/MWh	91.5	107.6	99.6	93.5	91.5
IRR %	3.80%	1.9%	2.8%	3.5%	1.2%
ERR %	5.20%	3.1%	4.1%	4.9%	5.2%
Unit cost EUR/kW	986.9	990.5	1089.6	990.5	990.5
Load factor %	11.8%	10.1%	11.8%	11.8%	11.8%

Sensitivity Analysis – Potential negative impacts

- Microcracks could increase O&M costs, or require complete part replacement, as a project reaches the end of its lifetime
- There is a lack of long-run data to be utilized when it comes to accurately predicting generation patterns
- Generation output could be negatively affected by wind, snow, water level variation, wave strength, reducing overall efficiency and capacity factor

Barriers to Development

FPV Barrier	Specific Challenge, Issue, or Impediment
Economic Barriers	• Phasing out or limiting incentives for emerging and innovative technologies may hinder FPV development • Economic policy uncertainty may stall private sector interest in FPV systems • Workforce shortages, both for highly skilled and medium-to low skilled personnel may raise FPV deployment costs
Cultural Barriers	• Negative visual impacts and competing water use may lead to a lack of public buy-in
Regulatory barriers	• Water use rights and permitting may delay projects and increase costs • Lacking interagency cooperation and coordination may hinder deployment • Expensive, and unclear environmental approval processes for FPV systems is likely to be time-consuming and could make projects less financially appealing

FPV Policy Recommendations

FPV-Specific Financial Incentives	Create FPV-specific financial incentives that cater to industry needs and market maturity – De-risking projects in the short term
Target Artificial Waterbodies	Support FPV deployment on artificial water bodies, rather than natural water bodies to avoid conflicts over regulation and water use
Target land-constrained countries	Focus FPV deployment incentives toward land-constrained countries with underlying reasons to pursue these technologies
Strengthen technological know-how	Strengthen and expand FPV technology knowhow and benefits to all industry stakeholders to help bridge existing knowledge gaps
Create enabling policy frameworks	Creating a robust policy framework for FPV development minimises regulatory uncertainty and reduces administrative hurdles to deployment
Bolster environmental review processes	Institute clear guidelines, criteria, and interagency processes to enhance and provide clarity in environmental review processes
Local community engagement	Local community engagement lowers the risk of conflict for FPV projects and fosters support
Support R&D	Facilitate R&D support, funding pilots, and demonstration projects – especially in countries with limited FPV experience
Industry Collaboration	Bolster industry collaboration, focusing on updating common guidelines, standards, and certifications for the industry

Q&A

Thank you for listening!