Betting on Floatovoltaics:

Floating PV Opportunities in the U.S.

Robert S. Spencer and Teresa M. Barnes
Solar Summit 2019
Scottsdale, Arizona
May 14, 2019

Floating Photovoltaics (FPV)


WATER RETENTION POND

Kunde, USA - 10 kWp


DRINKING WATER POND

QE2, UK - 6.3 MWp


IRRIGATION RESERVOIR

Kawarayama, JP - 1.4 MWp


WATER TREATMENT RESERVOIR

Godley, UK - 2.9 MWp

FLOATING PV APPLICATIONS

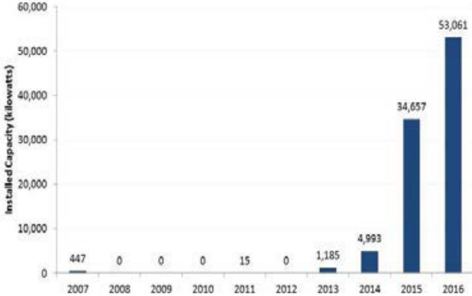
- Industrial water ponds
- Quarry/Mine lakes
- Irrigation reservoirs
- Retention ponds
- Desalinization reservoirs
- Water treatment sites
- Drinking water surfaces
- Aquaculture Farms
- Dams / Canals
- .....


AQUACULTURE POND

Yothathikan, TH - 5 kWp


HYDROELECTRIC DAM

Sobradinho, BR - 4.9 MWp




QUARRY LAKE

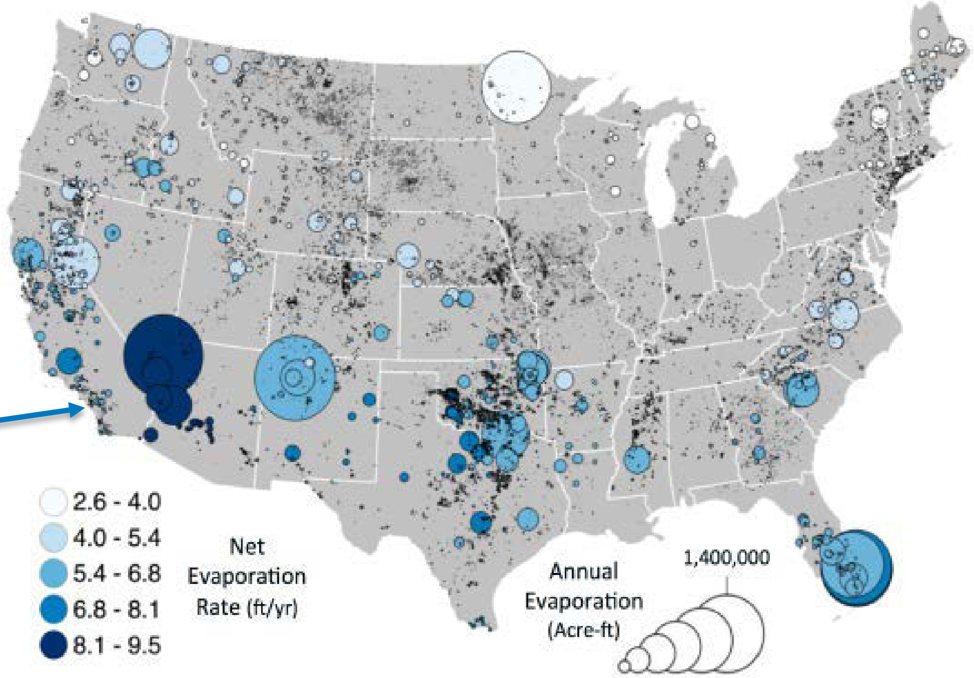
Piolenc, FR - 15 kWp

Source: Adapted from Solarplaza, 2016 and Ciel & Terre, Company Profile, 2017

FPV: Benefits & Tradeoffs

- Land-energy conflicts (e.g. fuel vs. food)
- Unused space that generates revenue
- Panel efficiency
- Water quality
- **Evaporation reductions**
- Land acquisition and site preparation costs

The net evaporation rate (dot color) and annual volumetric evaporation loss (dot size) of each FPV feasible water body in the U.S.



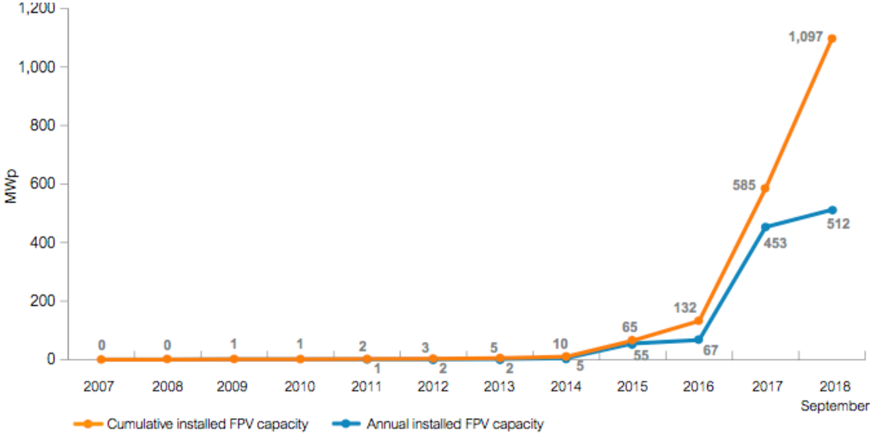
Source: Spencer, R.S.; et. al. “Floating PV: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental U.S.” ***Environ. Sci. Technol. 2019, 53, 1680–1689***

Floating Solar Around the World

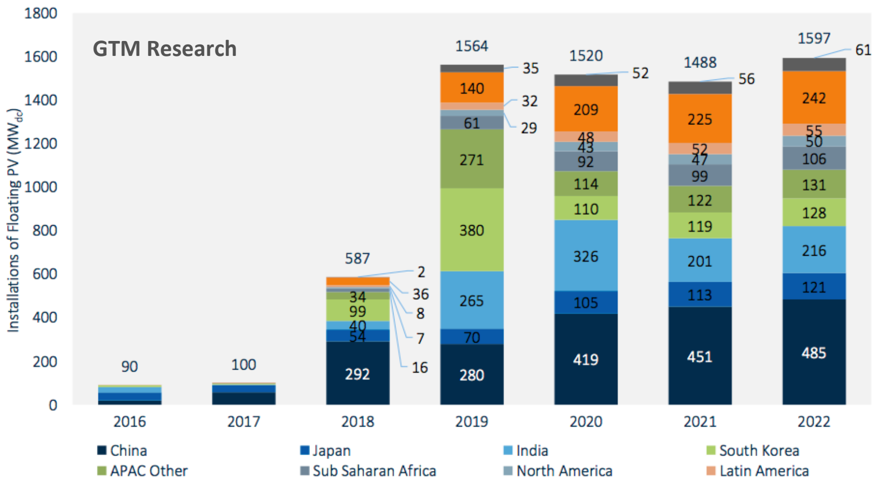
- Rapid Growth in China, SE Asia, and Latin America
- Northern European markets also expanding
- Historically dominated by land-constrained areas
- “Co-Benefits” increasing adoption

FIGURE 3 **Global installed floating PV capacity**

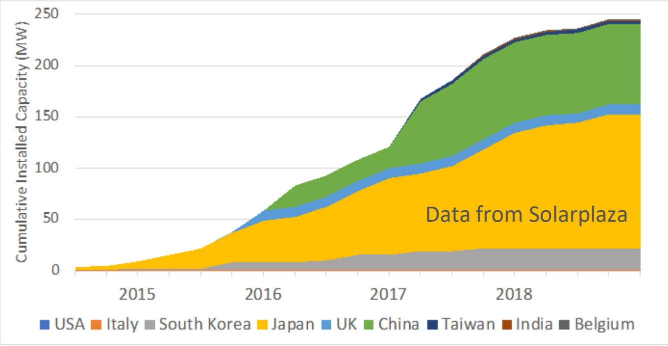
World Bank, 2018



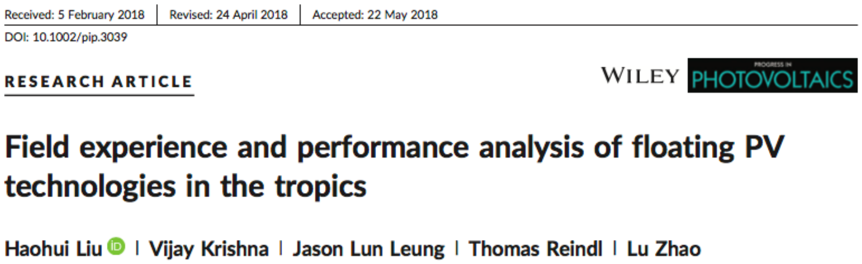
Installations of Floating PV by Country and Region, 2016-2022E (MW_{dc})



Source: GTM Research



SERIS Floating Solar Testbed



Received: 5 February 2018 | Revised: 24 April 2018 | Accepted: 22 May 2018
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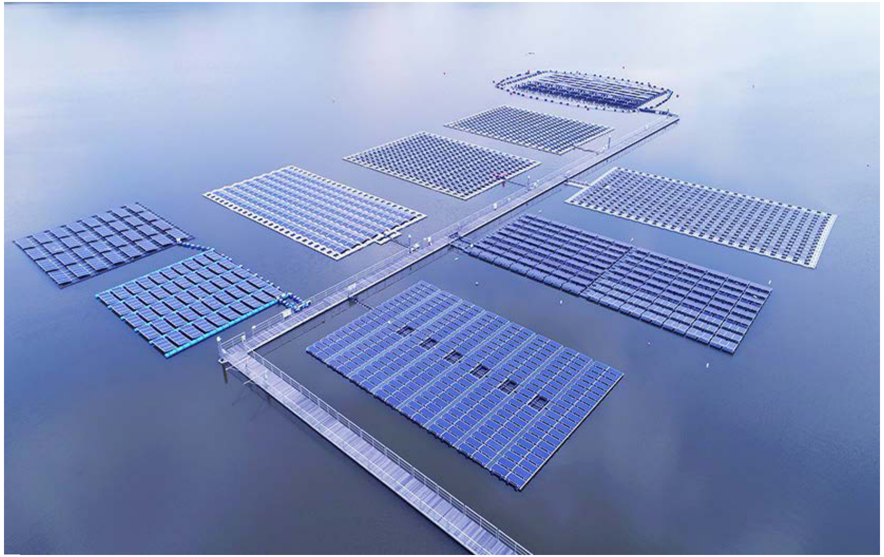
RESEARCH ARTICLE

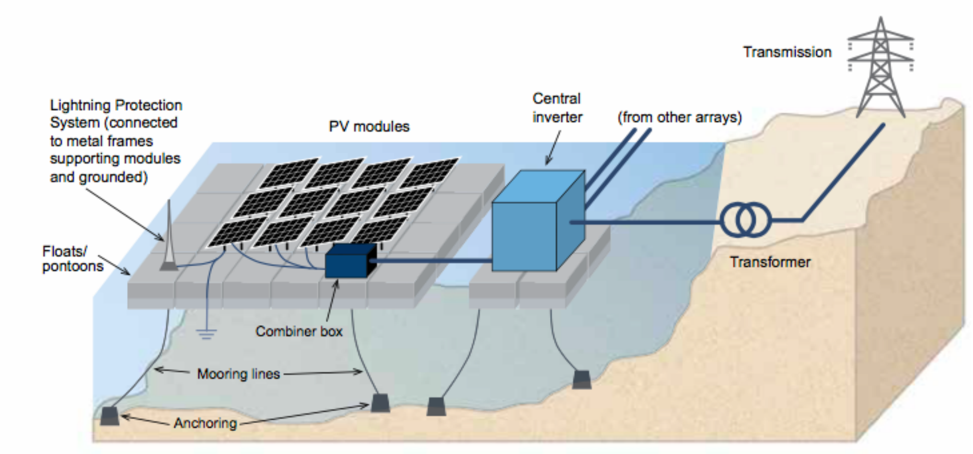
WILEY PROGRESS IN PHOTOVOLTAICS

Field experience and performance analysis of floating PV technologies in the tropics

Haohui Liu | Vijay Krishna | Jason Lun Leung | Thomas Reindl | Lu Zhao



SERIS and World Bank, Where Sun Meets Water 2018



Source: Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS).

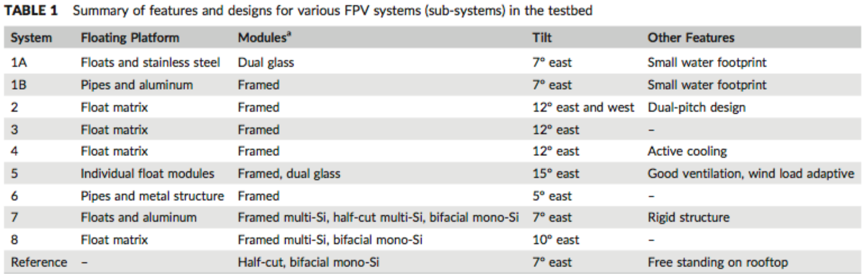


TABLE 1 Summary of features and designs for various FPV systems (sub-systems) in the testbed

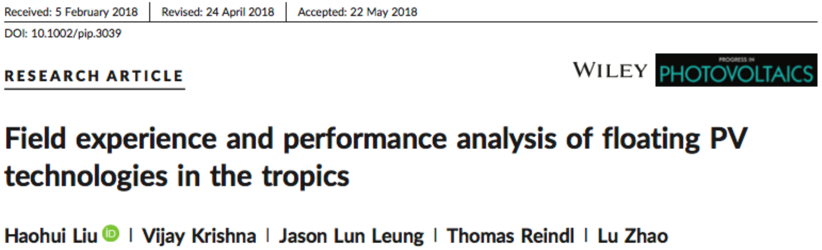
System	Floating Platform	Modules[a]	Tilt	Other Features
1A	Floats and stainless steel	Dual glass	7° east	Small water footprint
1B	Pipes and aluminum	Framed	7° east	Small water footprint
2	Float matrix	Framed	12° east and west	Dual-pitch design
3	Float matrix	Framed	12° east	–
4	Float matrix	Framed	12° east	Active cooling
5	Individual float modules	Framed, dual glass	15° east	Good ventilation, wind load adaptive
6	Pipes and metal structure	Framed	5° east	–
7	Floats and aluminum	Framed multi-Si, half-cut multi-Si, bifacial mono-Si	7° east	Rigid structure
8	Float matrix	Framed multi-Si, bifacial mono-Si	10° east	–
Reference	–	Half-cut, bifacial mono-Si	7° east	Free standing on rooftop

1 MW, Established 2016

Floating Solar Performance

	Roof	Floating Systems
Air Temp	VERY HOT	1 to 3°C lower
Humidity	MISERABLE	OPPRESSIVE
Wind Speed	~ 1m/s	1-2 m/s
Albedo	13%	5-7%
Module Temp	HOT	0 or 5-10°C lower
Energy Yield	It's	Complicated

Reference System is ideal – bifacial, well ventilated, and low mismatch



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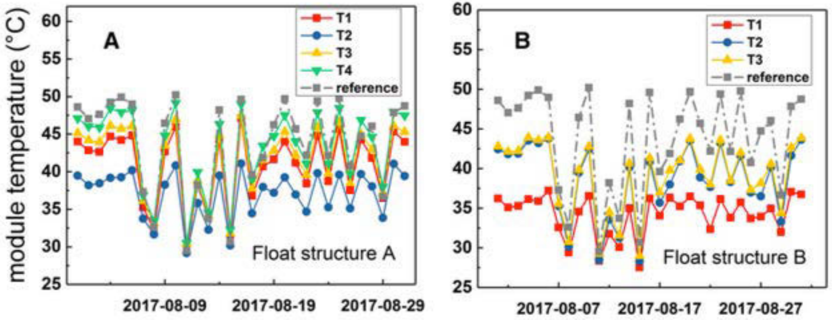
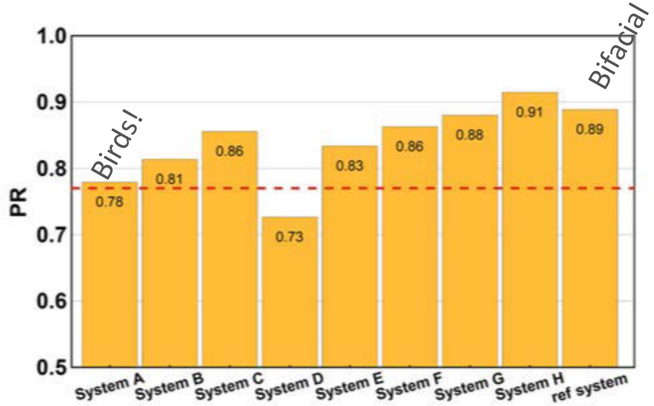
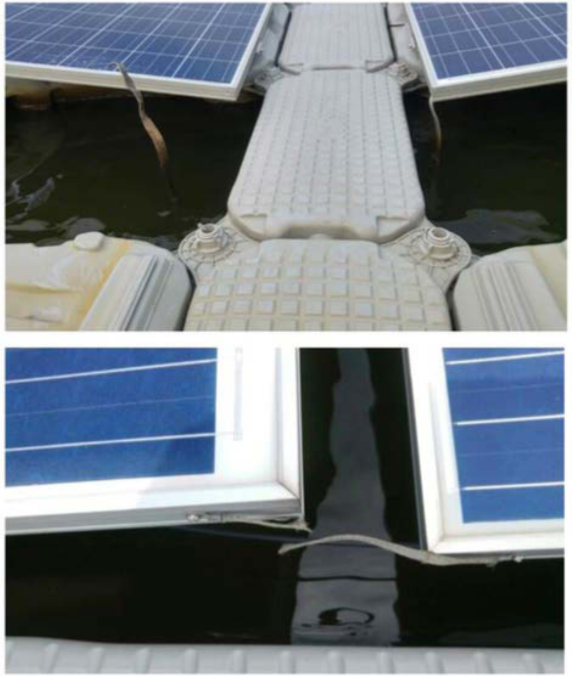




Typical PR in Singapore

Floating Solar Challenges

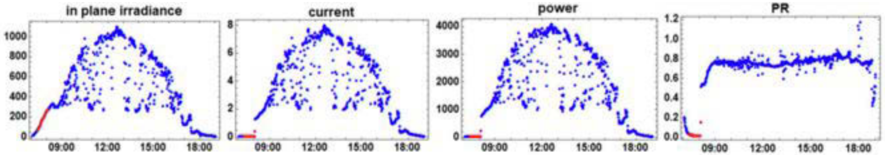


Mechanical Failure due to cyclic loading

All Systems Require O&M

www.thehindu.com, C.V. Subrahmanyam

Soiling

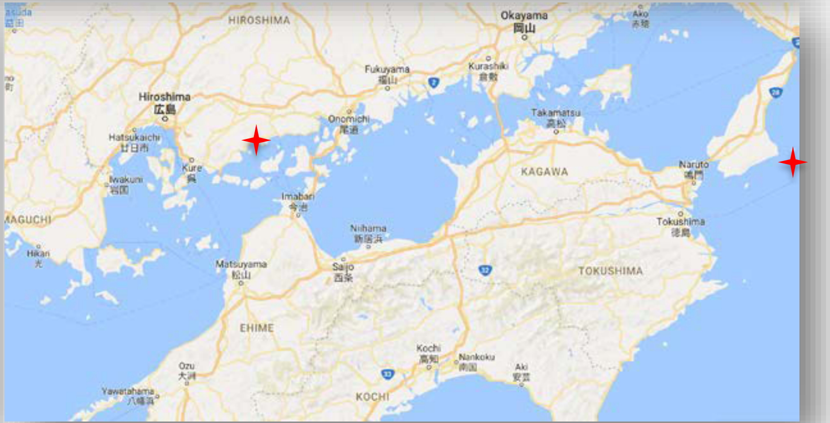


Inverter Late Starts
Insulation test failure

PID is a real problem – buy high quality modules!

Floating Solar in Japan

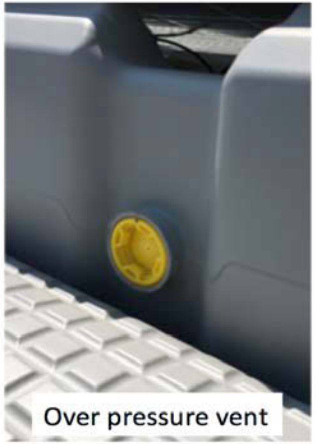
Team toured a four floating solar installations near Tokushima. Two 1.5 MW and one 681 kW system.



Component Details from NREL Visit

System flex points and evidence of system flexibility

System Components



Over pressure vent

Junction Box

Panel Wiring

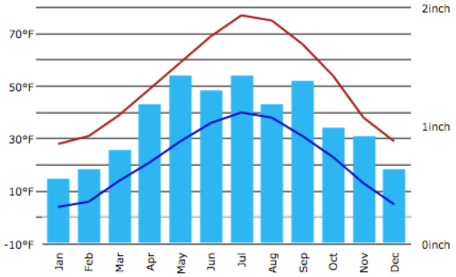
System Design in Japan

Sprinkler system, pump, temperature sensor, and anemometer

Evidence of vegetation and algae impacts

FPV: Case Study – Walden, CO

- 75 kW system powers water treatment facility
- Reduces evaporative losses of drinking water retention pond in arid region
- Minimal site preparation
- Community involvement & volunteer activity (GRID Alternatives)



Usclimatedata.com

Surviving Storms

42 kW damaged in 7550 kW plant in Aug. 2016 in Japan

https://tech.nikkeibp.co.jp/dm/atclen/news_en/15mk/090600817/?ST=msbe

Reliability vs. Resiliency

- 20.5 kW testbed in the Philippines on Laguna Lake
  - 95,000 hectares
  - Averages 20 storms/year
  - https://youtu.be/T2wNc9Ya4fw
- 25 MW in Andijk, NL by Floating Solar BV
  - 15 plants covering half of the reservoir surface
  - Tracking with storm stow for 60 mph winds
- Other interesting cases
  - Ocean – Waves + Salt
  - Mining waste – pH + ?
  - Floodplain PV – (Don't do it)

https://www.pv-tech.org/news/floating-solar-testbed-to-battle-filipino-typhoons

https://www.pv-magazine.com/2019/05/06/a-floating-solar-island-archipelago/
https://www.theguardian.com/world/2019/apr/21/dutch-engineers-build-worlds-biggest-sun-seeking-solar-farm

Hydropower + FPV

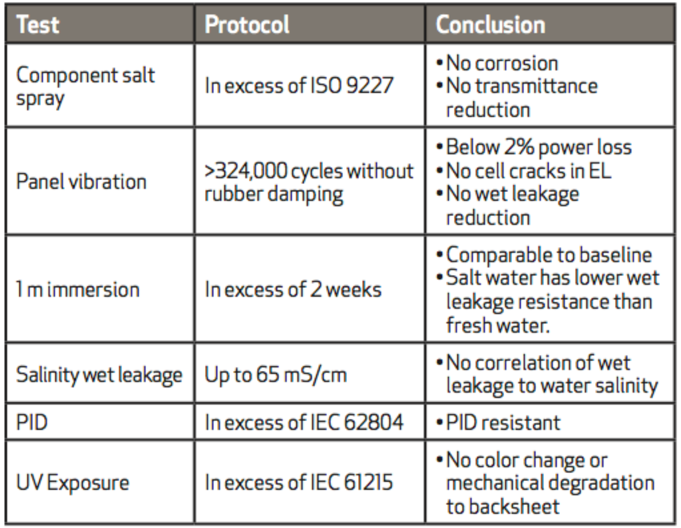
- Leverage existing transmission infrastructure
- Longyangxia in Qinghai is ground mounted 30 km away (World Bank)
  - 330 kV dedicated connection
  - 1,280 MW hydro + 850 MWp PV
  - Higher dispatch setpoint during the day and **ZERO** curtailment. Smooth output
- Floating + Hydropower
  - 218 kWp in Portugal (World Bank)
  - Thailand planning 2.7 GW in 9 reservoirs by 2037
  - $63M for 45 MW in 2020 at Sirindhorn Dam (Bloomberg Renewable Energy World)

https://www.renewableenergyworld.com/articles/2019/03/thailand-planning-massive-floating-solar-power-plants-on-hydropower-dam-reservoirs.html

Design Considerations

- NO IEC, UL, SEMI standard for floating systems or components
- Most of what we know comes from calm, tropical, inland waters
- We are going to learn a lot more by 2022

Table 1: The REC testing regime for floating PV applications



Test	Protocol	Conclusion
Component salt spray	In excess of ISO 9227	• No corrosion • No transmittance reduction
Panel vibration	>324,000 cycles without rubber damping	• Below 2% power loss • No cell cracks in EL • No wet leakage reduction
1 m immersion	In excess of 2 weeks	• Comparable to baseline • Salt water has lower wet leakage resistance than fresh water.
Salinity wet leakage	Up to 65 mS/cm	• No correlation of wet leakage to water salinity
PID	In excess of IEC 62804	• PID resistant
UV Exposure	In excess of IEC 61215	• No color change or mechanical degradation to backsheet

Water or Humidity

- Modules
- Cables
- Connectors
- PID
- Immersion

Environment

- Thermal cycles
- Freeze/thaw
- Soiling

Mechanical

- Wind
- Waves
- Cyclic loading, vibration
- Extreme weather

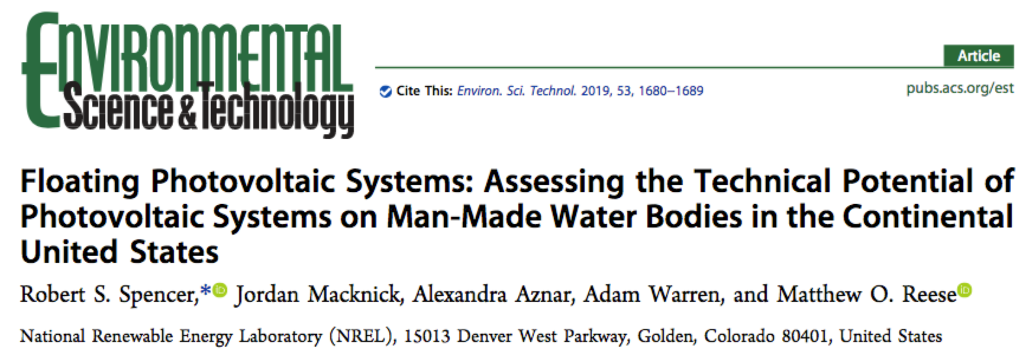
Other

- Water quality
- Wildlife
- User conflict

Cable and connector management is critical!

The Technical Potential of Floating Solar in the U.S.

See more information:
https://vimeo.com/268064164/be9320425d



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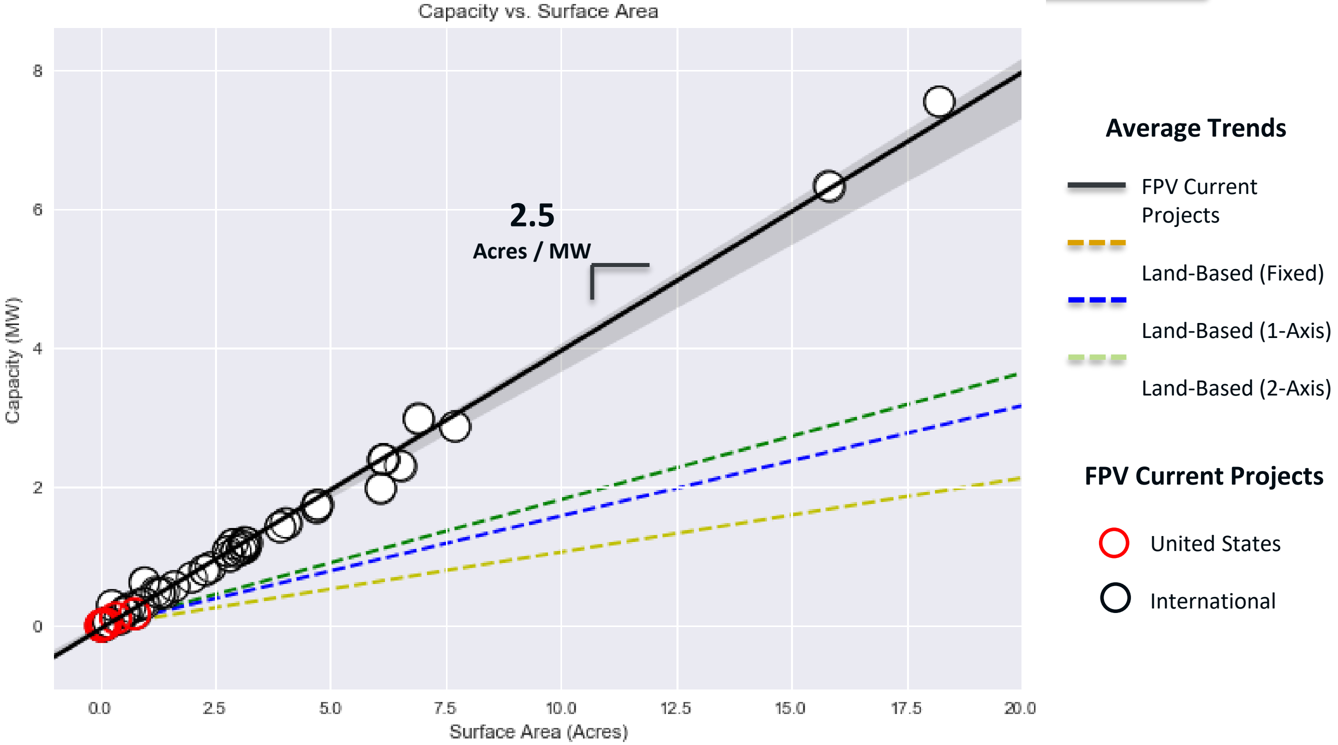
Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States

Robert S. Spencer,* Jordan Macknick, Alexandra Aznar, Adam Warren, and Matthew O. Reese

National Renewable Energy Laboratory (NREL), 15013 Denver West Parkway, Golden, Colorado 80401, United States

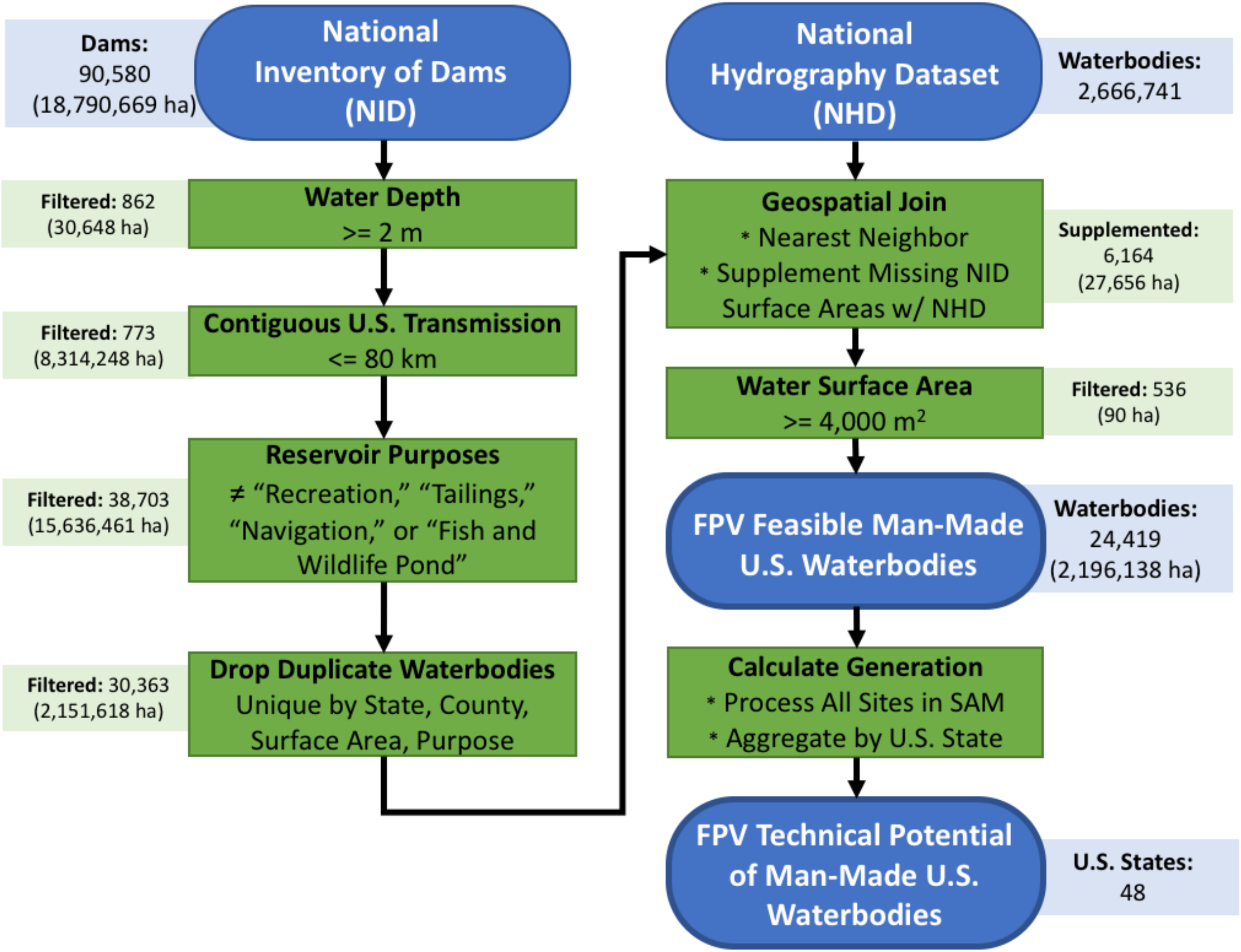
FPV Project Characterization

New Insight: Higher PV panel density per unit area



Panel density as the total generation capacity per system surface area

Data Processing: Datasets (🟦) & Workflow (🟩)



Dams:
90,580
(18,790,669 ha)

National Inventory of Dams (NID)

Filtered: 862
(30,648 ha)

Water Depth
>= 2 m

Filtered: 773
(8,314,248 ha)

Contiguous U.S. Transmission
<= 80 km

Filtered: 38,703
(15,636,461 ha)

Reservoir Purposes
≠ "Recreation," "Tailings," "Navigation," or "Fish and Wildlife Pond"

Filtered: 30,363
(2,151,618 ha)

Drop Duplicate Waterbodies
Unique by State, County, Surface Area, Purpose

National Hydrography Dataset (NHD)

Waterbodies:
2,666,741

Geospatial Join
- Nearest Neighbor
- Supplement Missing NID Surface Areas w/ NHD

Supplemented:
6,164
(27,656 ha)

Water Surface Area
>= 4,000 m^2

Filtered: 536
(90 ha)

FPV Feasible Man-Made U.S. Waterbodies

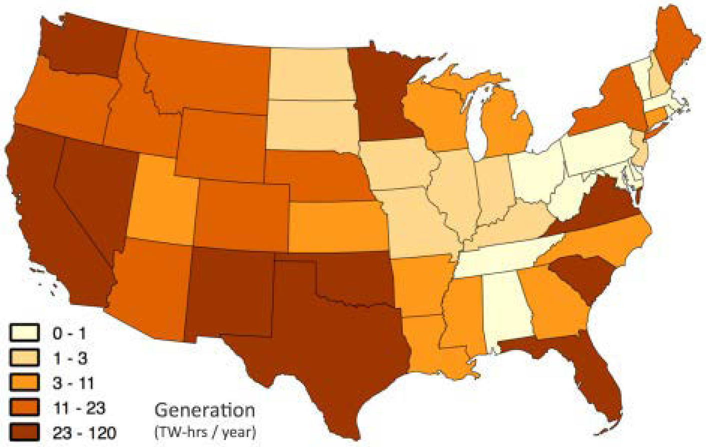
Waterbodies:
24,419
(2,196,138 ha)

Calculate Generation
- Process All Sites in SAM
- Aggregate by U.S. State

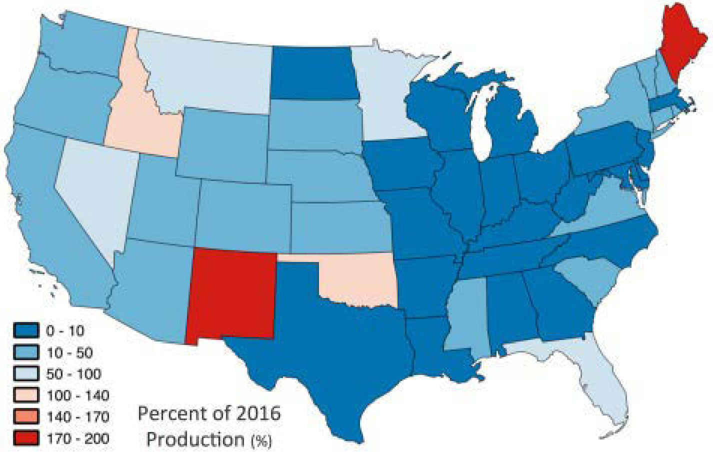
FPV Technical Potential of Man-Made U.S. Waterbodies

U.S. States:
48

FPV Generation Potential



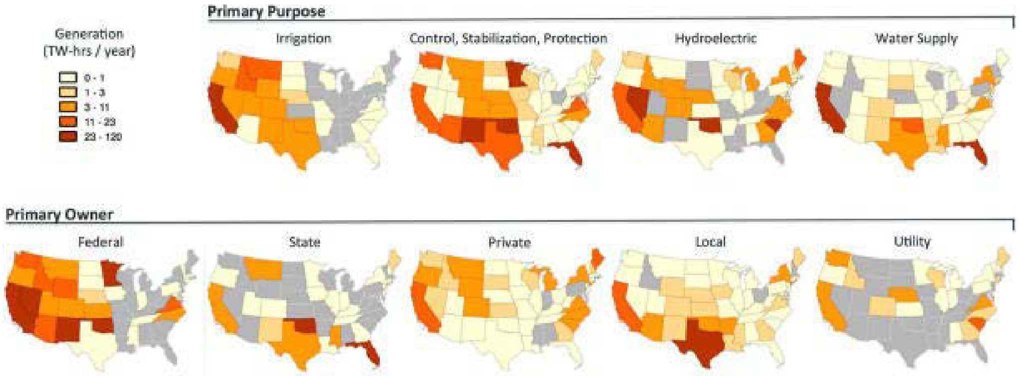
The potential annual generation of FPV

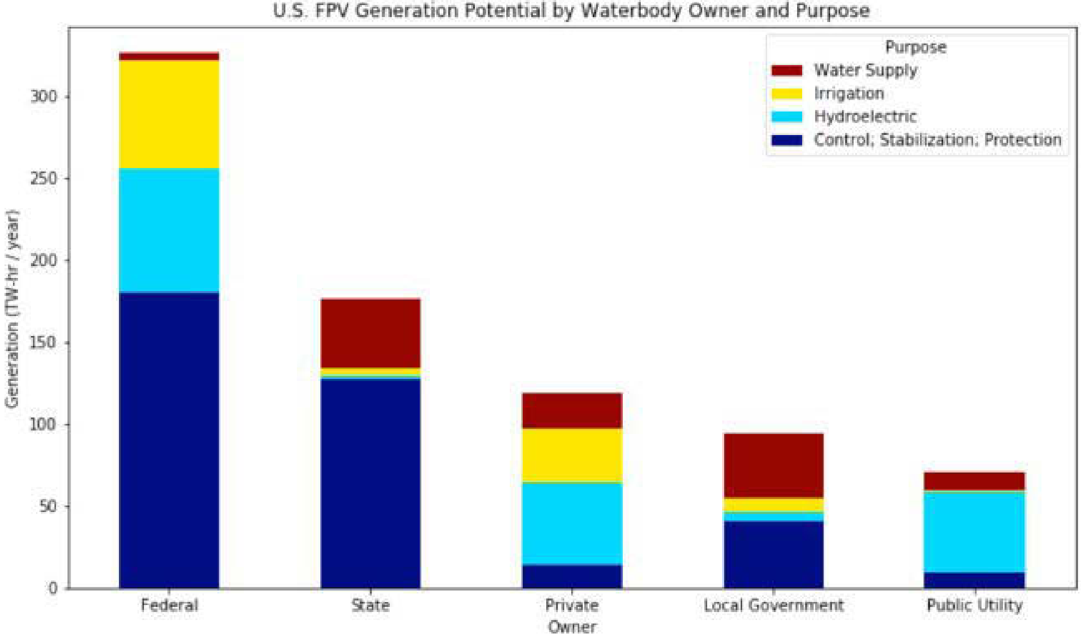


The percent of potential annual generation by FPV to current annual production in 2016

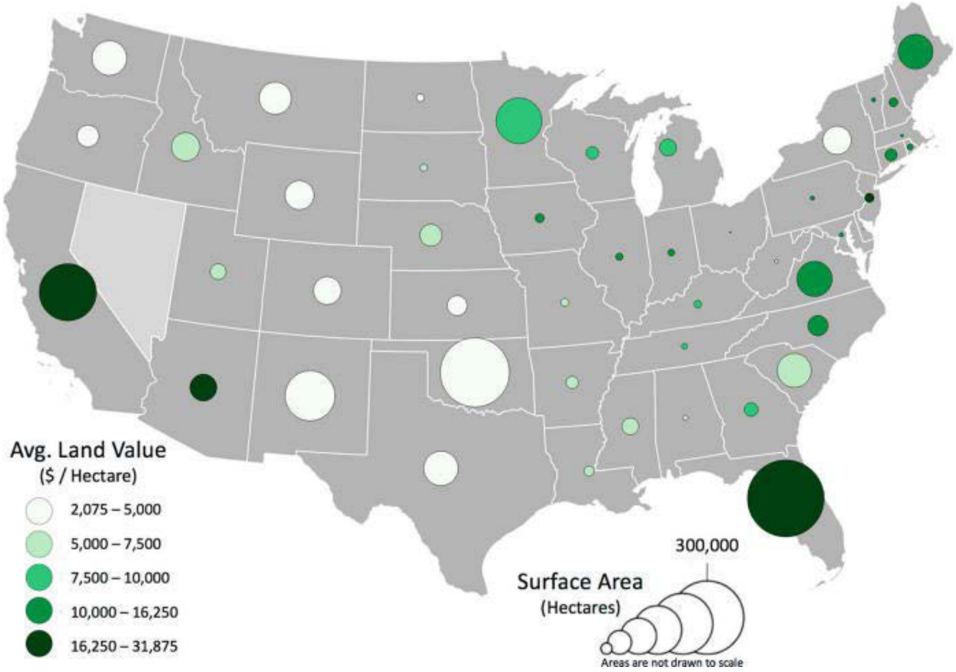
National Production:	**8,157**	**TW-hrs/yr**	(EIA 2017)
National FPV Potential:	**786**	**TW-hrs/yr**	(9.6%)
Highest Potential: Florida	**120**	**TW-hrs/yr**	

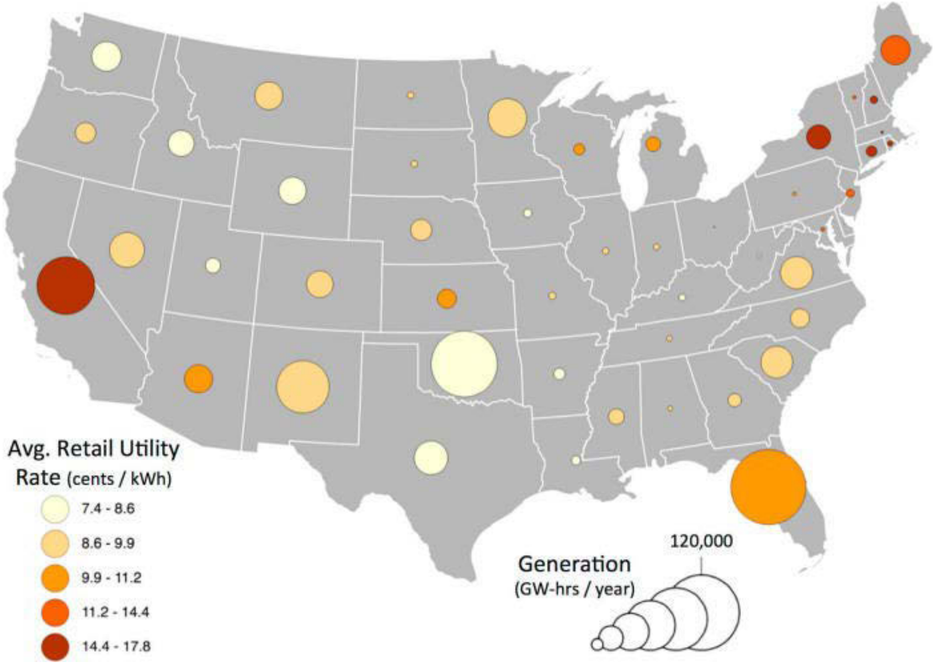
Source: Spencer, R.S.; Macknick, J.; Aznar, A.; Warren, A.; Reese, M.O. Floating PV: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental U.S. *Under Review*



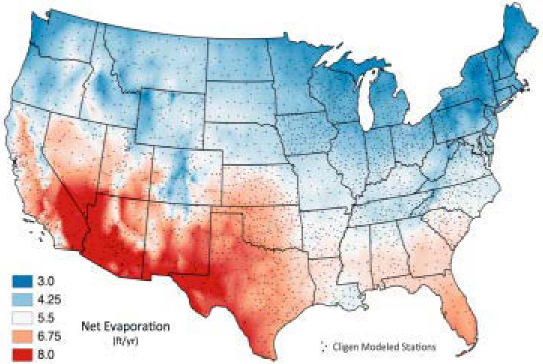

U.S. FPV Generation Potential by Waterbody Owner and Purpose

FPV Potential



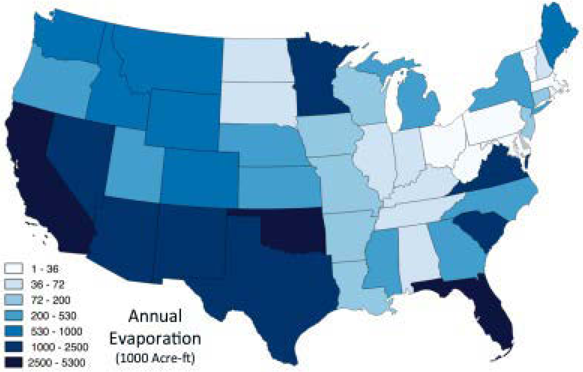


FPV Evaporation Reductions



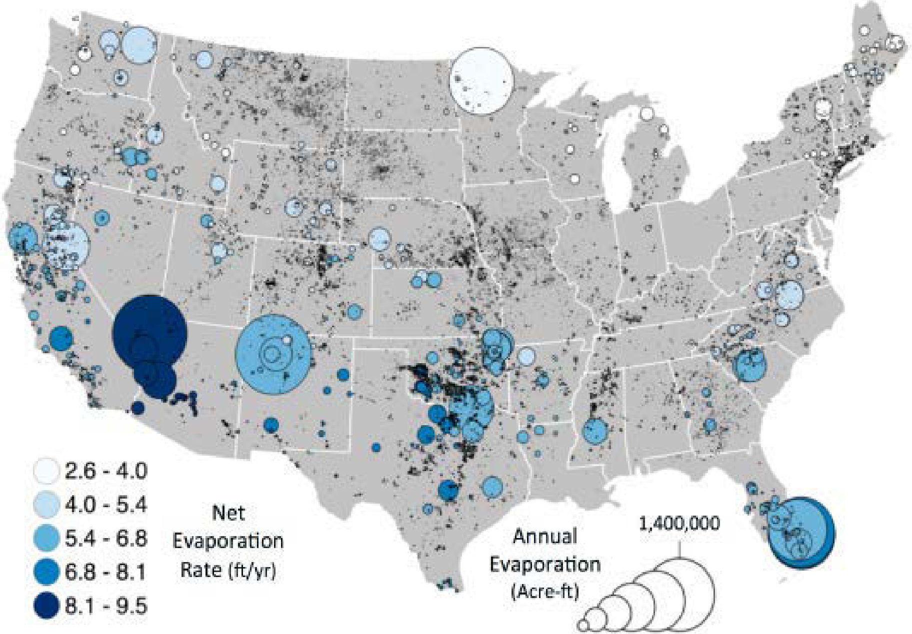
The simulated net evaporation rates of open surface water bodies in the United States.

FPV Evaporation summarized at the state level

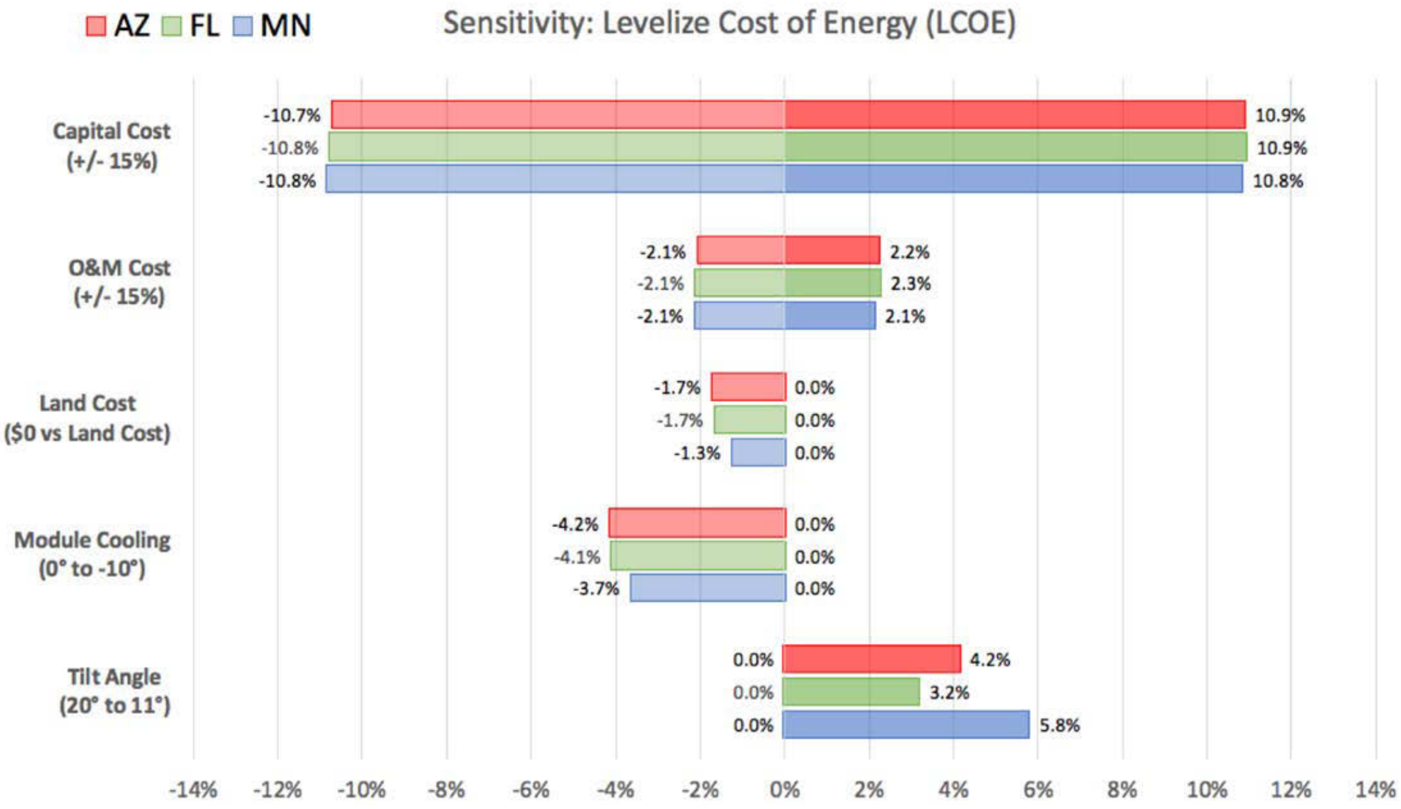


New Insight: Evaporation Benefits

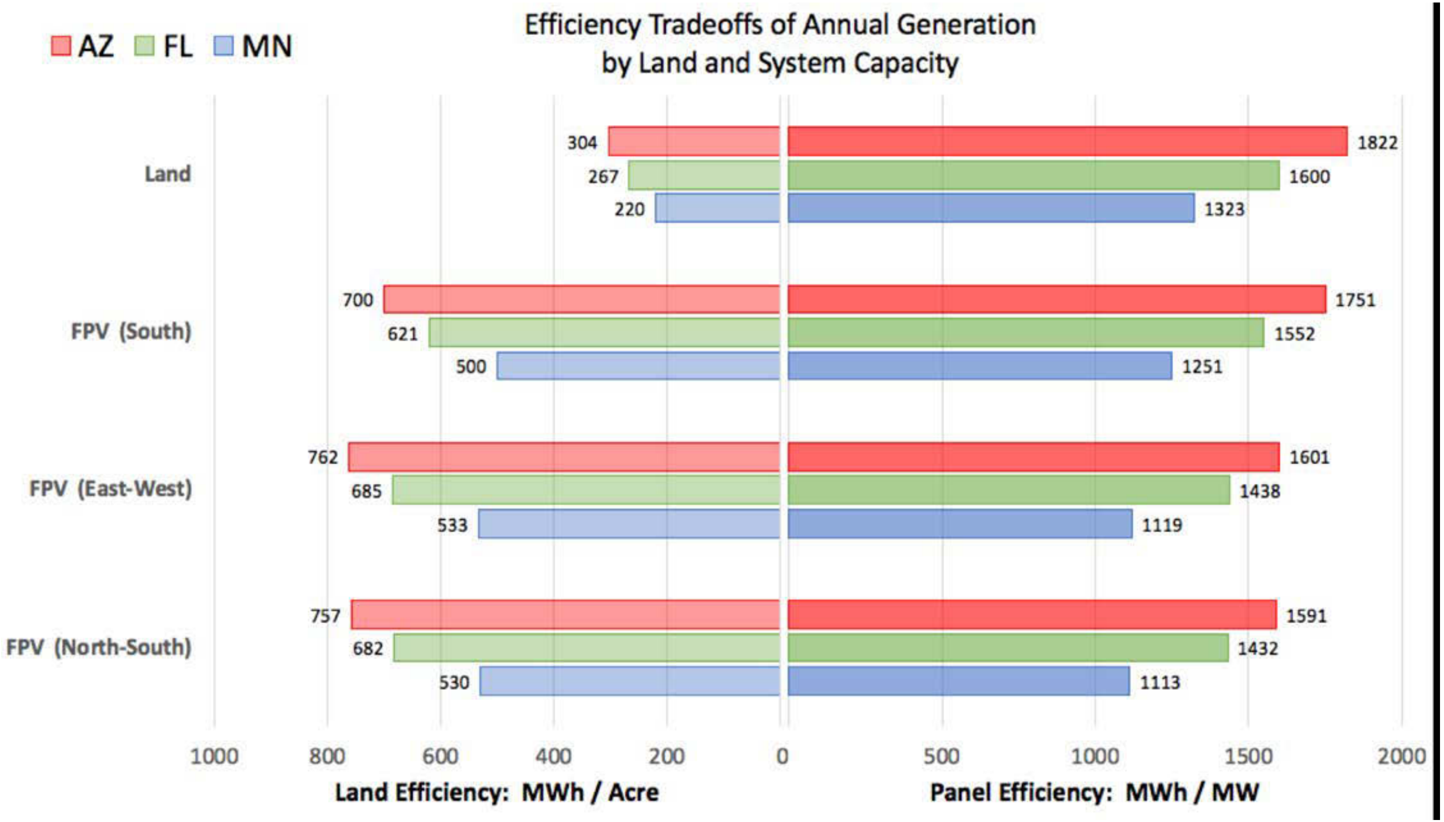
The net evaporation rate (dot color) and annual volumetric evaporation loss (dot size) of each FPV feasible water body in the U.S.



LCOE Sensitivity Analysis



Efficiency Tradeoffs



Questions? Thank you!

www.nrel.gov

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Reliability vs. Resiliency

- “Grid reliability is commonly defined as the ability of the electric power system to deliver electricity in the quantity and with the quality demanded by end-users. Resiliency is the ability for the electric power system to withstand and recover from extreme, damaging conditions, including weather and other natural disasters, as well as cyber and physical attacks. While the two are different, resiliency directly impacts reliability.” (Electric Light and Power)

Reported Benefits

- PV system efficiency gains due to lower ambient temperatures underneath the panels
- Reductions in unwanted algae growth
- Reduced rates of evaporation
- Lower land acquisition and site preparation costs
- Avoidance of land-energy conflicts (e.g., fuel vs. food)
- Conversion of unused space into a space that generates revenue
- Minimal risk to wildlife
- Higher panel density for a given area

Time-lapse of FPV Installation